Praise for
In Sound Health: A Handbook on Sound, Music and Health

The interrelation between sound, music and health has long been scrutinised. This book, aptly titled *In Sound Health: A Handbook on Sound, Music and Health*, aims to create awareness among healthcare professionals as well as the general public on the impact of sound, noise and music in relation to health.

—Ricky Kej, Multi-Grammy® Award Winner, United Nations Ambassador

Our soundscapes have a huge influence on our physical and mental health and well-being. This handbook on sound, music and health, authored by experts from diverse fields of health, is a timely and good read on the risks of noise to physical and mental health.

—Dr. Pratima Murthy, Director, NIMHANS

In the 21st century where health, tech and sound converge to create the most amazing impact on the human brain, this book would serve as an essential tool to understand the basics of how music and sound impacts us.

—Sneha Iype, Executive Producer / Partner, Nirvana Films

Both music and noise affect human health, but they are antithetical. This book perfectly outlines how music can positively modulate human health and how noise deteriorates well-being. Also, it would help understand how to prevent the ill-effects.

—Prof. M. Pushpavathi, Director, All India Institute of Speech and Hearing, Manasagangothri, Mysuru

The book *In Sound Health: A Handbook on Sound, Music and Health* is perhaps the first of its kind and the authors have done commendable job in integrating all aspects and presenting the subject in a most factual and simple form to benefit society at large.

—Dr. Girdhar Gyani, Director General, AHPI

With advancements in science and technology, noise pollution has increased significantly. The deleterious effects of this on mental and physical health is recognised. On the other hand, much work is also focused on the use of sound to improve health and well-being.

—Dr. J. V. Peter, Director, CMC Vellore

A comprehensive guide to understand the nuances of noise pollution for technical and non-technical persons and a primer to comprehend music and its implications for health and well-being.

—Prof. Dr. George D'Souza, Dean, St. John's Medical College

I am sure this book will enable the common man to understand the science of phonation, hearing and how music can positively affect one's physical and mental health and at the same time help understand the serious health issues of noise pollution.

—Dr. Jayesh M. Lele, Honorary Secretary General, IMA

In Sound Health

A Handbook on
Sound, Music and Health

Edited by
Alexander Thomas, Ramesh A.
and Deepak Alexander

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FOREWORD

Many quotes and phrases in the English language endeavour to capture the magic of music, sound and rhythm. The expression of emotion, the language of the spirit, the vocabulary of nature, the soul of life – in short, the mother tongue of humankind. It is said that "where words fail, music speaks," bringing people together and forging deep connections.

The interrelation between sound, music and health has long been scrutinised. Sounds elicit physiological and psychological reactions, both positive and negative, and are therefore used in a wide variety of situations, from pumping you up at the gym during a workout with a strong beat, reducing anxiety with calm and repetitive soothing sounds, and even being weaponised during modern warfare. This book, aptly titled *In Sound Health: A Handbook on Sound, Music and Health* aims to create awareness among healthcare professionals as well as the general public on the impact of sound, noise and music in relation to health.

The contributors to this book are illustrious minds in the fields of sound, music and health, a fascinating balance of academic thought and entrepreneurial experience. My first connection with Dr. Alex, the chief editor, took place in 2019. He had organised a national conclave on a topic close to both our hearts: climate change and health. My team and I were closely involved with this unique event through which we were able to sensitise the healthcare community on the important topic. Since then, we have collaborated on more projects together. His passion and drive to empower the healthcare community has shone through in every project. Through him, I also met Deepak, a music director of films, and have come to know of Prof. Ramesh, an ENT surgeon with a special interest in the area of sound and deafness.

I have been intrigued by the editors' proficiency and prowess in the different talents they bring to the table. Their diverse, yet harmonious, experiences are evident in the way this book has been structured. The volume explores the spectrum of sound and health, beginning with the evolution of auditions and soundscapes. The next section on understanding sound and health delves into the physics of sound, the physiology of hearing and how to measure the impact of noise on health. The next two sections examine the deleterious effects of noise on human health, and how these can be prevented in various settings. The industrial, medical and music-based applications of sound are considered before the segue into the final section on challenges and future directions, with a framework on how to research the impact of noise and music on health.

It is my pleasure to write this foreword for their labour of love, and I hope that this publication achieves the noble aim of educating the health sector, as well as the larger society, on the topic of sound, music and health.

Ricky Kej
Multi-Grammy® Award Winner
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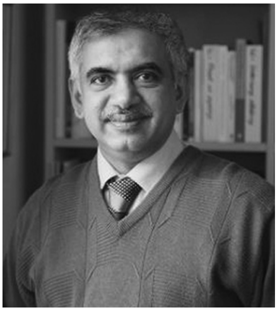

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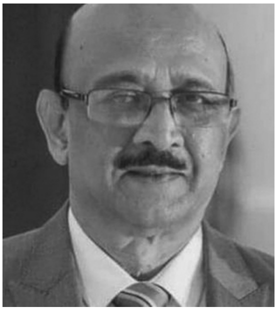

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PREFACE

Sound has played a significant role in the evolution of all living creatures on this planet. As a result, human hearing is a mega power acquired over 370 million years of evolution. Different species have varying hearing and sound processing abilities, configured as per need and purpose. In addition, the balance mechanism is also regulated by the hearing system. Though sound has always been an integral part of our day-to-day life, its influence on our health has remarkably changed as a result of industrialization and urbanization. Furthermore, the changes in life pattern to which the current generation is being subjected, places them at a higher risk of developing various health-related problems as result of the ill effects of noise. As by definition, sound which is pleasant could be termed as music, and that which is unpleasant or hurts the ear could be termed as noise. As a consequence, music has a positive influence on all life on earth.

The book is designed to be easy to read and understand, with clear objectives and takeaways for each chapter. The contributors of this book are renowned national and international subject experts and scientists from institutions of excellence with vast experience in the fields of audiology, musicology and medicine.

As the chief editor, it is my privilege and honour to thank each one of them for contributing their knowledge and time to this important project in spite of their busy schedules. I am deeply indebted to **Mr Ricky Kej**, multi-Grammy Award winner, for his valuable contribution towards this book.

This publication has been made available on an Open Access platform, meaning that it is free to download and be read anywhere in the world and I am grateful to AHPI for enabling this.

I would also like to express my sincere gratitude to the editorial advisors **Dr Shantala Hegde** and **Dr V. C. Shanmuganandan**.

Finally, I would like to thank my co-editors **Dr Ramesh A.** and **Deepak Alexander** for the roles they played in developing this book in addition to contributing chapters in their areas of specialization.

I also thank all others involved in this project including the book reviewers. My grateful thanks to **Mr Shadrach Thangaraj** for having shouldered the responsibility of the entire secretarial work, and also to my colleagues in AHPI for their valuable support. As always it has been a pleasure to work with the publishers. **Mr Gowrishankar Natesan** and **his team** at **Newgen KnowledgeWorks** have provided excellent support and advice.

My hope is that this book will serve the purpose it was meant for – sensitizing the community on music, sound and health.

Dr Alexander Thomas
Chief Editor

INTRODUCTION

Ramesh A.

Music promotes health. It invigorates our mind by generating a myriad of emotions ranging from melancholy to inspiration and joy. Noise, on the other hand, harms our health. It annoys us. Both are sound waves, but vary in rhythm and intensity. Music can enhance our productivity, whereas noise can mar it. Certain types of sounds such as traffic noise annoy most of us. Other categories of sound like rock music are enjoyed by some but may annoy others. Since ages, humanity is aware of the beneficial effects of music. The harmful effects of noise on mental well-being are obvious, but damage to the hearing apparatus became apparent after advances in science and technology allowed us to visualize the inner ear through imaging and electron microscopy.

There are a multitude of monographs and treatises on noise, music and health. Most of this literature is understood by scientists familiar with the field of acoustics and health. For a wider reach of these concepts there is a need for literature that can explain the complex concepts of music, noise and health in a simple language to people in general. This will enable a large number of people to adopt music for its therapeutic effects and recognize the harmful effects of noise. Such recognition will lead to behavioural changes in general that will reduce noise levels in the community and workplace. Noise-induced hearing loss is an important public health issue and noise control requires the co-operation of the entire society. This book targets lay public, musicians, medical and allied sciences professionals, managers of organized sector industries, contractors employing people in the unorganized sector, voice therapy professionals and scientists working in acoustic sciences. As target readers vary in their understanding of this complex domain, the book is written in easily comprehensible language without oversimplifying the scientific tenets of acoustics and health parameters.

Part I of the book, 'Hearing, Music and Health', familiarizes the reader with important concepts to understand this complex area. Chapter 1, 'Music and Health', gives a broad overview of the impact music has on various affective domains in humans like concentration, cognition, performance, memory, emotional regulation, socio-cultural bonding, relaxation, stress relief, motivation, pain management, sleep, mood, endurance, creativity and empathy. The neuro-physiological basis for each of these influences is described in a simple language. The authors also begin a train of thoughts on music as a therapeutic tool, which is elaborated in a later chapter on music therapy. Chapter 2, 'Evolution of Audition, Soundscape and Health', pivots around the term 'Hearing, not hearing' which is a continuum of the book title. It succinctly indicates not just the literary meaning but also metaphorically suggests that the society needs to hear the unheard voices of the hearing-impaired community. Social audiology, soundscape, sound culture and concepts regarding inclusion of the hearing impaired are introduced using real-life anecdotes. The history and evolution of audition is described in detail.

Part II, 'Understanding Sound and Health', deals with various scientific and technical aspects of music, noise, hearing and health. In Chapter 3, 'Physics of Sound, Hearing and Speech', a technically intense topic is explained in an understandable manner for non-domain expert readers. The decibel scale, sound frequency, pure tones, pitch, overtones, voice, phonation and language are defined in layman's language. A passing remark on permissible noise levels in industrial, commercial, residential and silent zones is included. These regulations in various settings are described in another section on the deleterious effects of noise. In Chapter 4, 'Music', the reader gets a glimpse into the history and science of music recording. The role of technology and internet in transforming music distribution is elaborated. Music as a digital therapeutic and concept of neurological music therapy is introduced. All these are explained in an easily comprehensible language. Chapter 5, 'Physiology of Hearing and Speech' explains the anatomical and functional basis of hearing, speech and language. The transformation of sound, a mechanical energy, to electric impulses is described with the aid of illustrations. The reader is introduced to various types of hearing loss (conductive and neural types). Chapter 6, 'Measuring Sound', gives a comprehensive description of the tools and techniques to measure sound. The author lists various types of sounds in the universe and the different techniques of measurement. A chronology of the evolution of the microphone and a table of noise levels of various commonplace sounds are included in the chapter. Chapter 7, 'Principles of Quantifying the Impact of Noise on Health', explains the complex yet essential process of quantifying the impact of noise on health using the tenets of dependent and independent variables. Operationalizing variables and limiting bias during measurement are explained for researchers in the domain of noise, music and health. The chapter also describes the steps to develop a psychometrically validated measurement tool and provides a glimpse into the application of artificial intelligence and machine learning in this domain.

Part III, 'Deleterious Effects of Noise on Health', describes the impact of high noise levels on all the relevant biological systems of the human body. In Chapter 8, 'Auditory Effects', noise-induced hearing loss, the most important harmful effect of noise, is described in detail. The chapter explains the important concepts of early pre-clinical damage and clinically obvious effects as also the important concept of individual susceptibility to noise. Chapter 9, 'Cardiovascular Effects', explains issues close to the heart and noise at the macro, micro and molecular level. The biochemical basis of noise-induced effects on the cardiovascular system is the highpoint of this chapter. It also specifically elaborates the association between noise and hypertension, atherosclerosis, heart rate, stress and insomnia, all of which have deleterious effects on the cardiovascular system. Chapter 10, 'Neuropsychological Effects', paints a complete picture of noise and its impact on the nervous system including cognition. It begins with elaborating on the processing of sound by the nervous system and goes on to describe its effect on cognition across a range of ages (neonate to elderly). There is special emphasis on the impact of noise on communication and school performance. Chapter 11, Immune and Endocrine Effects', deals with all the components of the endocrine system, from the hypothalamus-pituitary axis to adrenals in the context of noise impact. The authors also briefly highlight the benefits of music in this domain. Chapter 12, 'Impact of Infrasound', is an eye-opener even for the experts among readers. A complex topic has been simplified using tables and diagrams. The discussion of the concept of vibro-acoustic disease due to infrasound and low frequency noise is another highlight of this chapter. Animal studies are described to provide evidence for the impact of infrasound on biological parameters.

Part IV, 'Preventing the Deleterious Effects of Noise', is the crux of the discussion on noise and health. Chapter 13, 'Overview of Noise Pollution and Noise Control Measures', elaborates various sources of high noise. The economic impact of high noise is highlighted in a precise manner. The fundamental principles of noise control are listed. The chapter concludes with a short review of the legal regulations relevant to high noise and a set of frequently asked questions about noise regulations and recent advances in noise control technology. Chapter 14, 'Industrial Setting – Organized Sector', begins with a description of sources of noise in the organized sector of industries. This is followed by an explanation of how to conduct a noise survey and implement a hearing conservation education program. Various types of ear protection devices are illustrated. Chapter 15, 'Industrial Settings – Unorganized Sector', describes how to approach the challenging area of measuring and regulating noise in the unorganized industrial sector(. The author describes in detail specific activities that generate very high and harmful noise levels in this sector and explains how hearing conservation can be established in these settings. Healthcare settings which have emerged as an important source of high noise levels is comprehensively described in Chapter 16, 'Healthcare Setting'. All the sources are listed with strategies to limit noise at the origin, transit and recipient levels. The impact of high noise levels on healthcare personnel are also elaborated.

In Chapter 17, 'Community and Social Settings', an often neglected area of high noise levels, is extensively explored. All sources of community noise in urban and rural settings have been described with practical strategies to limit their levels. The maximum permissible noise level in each setting is stated.

Humans have used sound and music productively in various domains. Part V, 'Applications of Sound', gives the reader a comprehensive view of different applications of sound and music. Chapter 18, 'Industrial Applications', describe the use of sound in pharmaceuticals, dairy, food processing, underwater, architecture, microelectronic manufacturing, animal echolocation, remote turbulence detection and emulsion industry.

In Chapter 19, 'Medical Applications,' the diagnostic and therapeutic applications of infrasound, audible sound and ultrasound have been described. Chapter 20, 'Music-Based Interventions', introduces the concept of neuromusicology – how the brain processes music. The reader is taken through the journey of how music therapy started as a socio-cultural phenomenon and has now evolved into a neuroscientific domain.

'A lot of noise, very little substance' captures the essence of Chapter 21, 'Regulations and Implementation', in Part VI, 'Noise Control Regulations and Implementation'. The reader gets to understand the Noise Pollution (Regulations & Control) Rules, 2000, under the Environment (Protection) Act, 1986. With a constructive perspective, the authors suggest how policy can be used to effectively implement these regulations. It empowers the readers to act as agents of noise control.

The answer to any challenge is new knowledge. Research is the process to create new knowledge. Chapter 22, 'Framework for Conducting Research on Impact of Noise and Music on Health', in 'Part VII, 'Framework for Conducting Research on Impact of Noise', takes the reader thorough the seven essential steps of creating new knowledge, namely, identifying challenging healthcare situations and framing research questions, developing a conceptual framework of variables and defining them, review of literature to examine if the question has already been answered, choosing the study design, sampling strategy and sample size estimation, data collection and summarizing results and applying statistical tests of significance.

The mission of this book is to educate, empower and involve the civil society to promote the beneficial effects of music and limit the harmful effects of noise. Chapter 23, 'Challenges and Future Directions', in Part VIII, 'Challenges and Future Directions', inspires readers to own this mission. Beginning with recognizing the historical importance of sound, the chapter weaves the story of human culture, sound and music against the background of other competing stimuli. The challenges are listed as opportunities for future work in this domain.

Part I

HEARING, MUSIC AND HEALTH

1

MUSIC AND HEALTH

Music and Its Effect on Physical Health and Positive Mental Health

Sujas Bhardwaj and Shantala Hegde

1.1 Introduction

Health is a state of complete physical, mental, spiritual, and social well-being, not just the absence of disease or weakness.[1] The way one appears, feels, acts, and performs is influenced by one's well-being. It also impacts our mindset and capacity to handle interpersonal relationships. Mental health refers to our emotional, psychological, and social well-being. According to the World Health Organization (WHO), mental health is a condition of well-being in which a person recognises his or her abilities, can manage typical life challenges, work creatively and fruitfully, and contribute to community.[2] How one deals with stress, communicates with others, and makes prudent decisions are all influenced by our mental health. Spiritual health is the connection with a superior existence, oneself, society, and nature, and it includes those aspects of health or human existence that cannot be explained by physical, mental, or social factors, such as a purposeful life, transcendence, and actualisation of various dimensions and capacities of human beings. Positive mental health is defined as the presence of happy feelings and normal functioning (in both individual and social environments). Personal factors such as lifestyle and self-esteem, as well as the physical environment, such as one's environment or the quality of one's surroundings; the quality of one's interpersonal relationships with family, friends, and the community; and the social environment all have a significant impact on mental health. As the popular saying goes, there can be no health without mental health. One's psychological health has a significant impact on our physical health. Similar to improving the immune system of physical health, practices that promote positive mental health are considered crucial in maintaining good psychological health.

To enhance positive mental health, one should have healthy, meaningful relationships with friends and family; be physically active and maintain a balanced diet; engage in meaningful activities; have a sense of gratitude, empathy, and contentment; have emotions in control and have a right balance of physical activities; and, most importantly, indulge in activities that can enhance resilience. This may range from good psychological health to physical and spiritual health. Music, as not just a cultural phenomenon but as a biological phenomenon, has the power to impact all these realms of health.

Music as a socio-cultural phenomenon binds people to society and culture. It stands as an identity of a given culture. Humans indulge in music, produce music, and are influenced by music in tremendous ways. Music can help improve cognitive functions, emotion regulation, task endurance, and mood; reduce anxiety and depression; stave off fatigue; and improve pain response. Passive music listening often plays an integral part in other daily activities such as physical workout, walking, driving, or other routine day-to-day activities and, most importantly, to kill boredom. For age immemorial, musical activities, musical engagements have been interwoven with several socio-cultural and religious activities across cultures.

This chapter provides an insight into how music permeates several aspects of our functioning and how music positively impacts one's physical and mental health.

Learning Objectives

- Music's role in the promotion of mental health
- Music and its association with mental health and brain physiology
- Neuroscience underpinning the music-related brain plasticity
- Neurochemical participation in music production and listening.

1.2 Music as Promoter for Positive Mental Health

Music is not only enjoyable but also beneficial to overall health. Indulging in music, either actively, by singing or playing an instrument, or passively, by listening to music, is known to impact the socio-emotional development across one's lifespan. This impact includes mood regulation, development of cognitive-emotional skills, socialization ability, personal and cultural identity and overall development of personality. Music has a wide-ranging and profound psychological impact. Music, among other things, can aid in the development of positive mental health by reducing anxiety and stress, facilitating emotion regulation, and improving neurocognitive functions, such as attention, memory,[3] mood, and motivation. Music-based interventions have been demonstrated to benefit patients with a range of clinical conditions such as stroke, headaches and migraines, pain management, Parkinson's disease, and dementia, among other neurological illnesses.[4] Music helps in the management of pain and often acts as a powerful method of distraction; recent scientific research has provided evidence as to how music helps in the release of natural pain killers – the endorphins – in the body. There are several examples of how music plays a very important role in our daily lives. Music often evokes feelings that help us connect as social beings, uplifts our thoughts, encourages us and leads us to greater mental health, reflecting in our improved physical and mental performance. There is a strong body of scientific literature demonstrating the association between music engagement and quality of life, well-being, prosocial behavior, social connectedness, and emotional competence.

1.3 Music and Mental Health

It is widely acknowledged that both listening to and creating music can have a favourable impact on one's mood and mental health. Music is both intellectually and physically stimulating, and it boosts psychological well-being. The brain engages a host of higher neurocognitive functions in order to process and comprehend music. Music can help with health and well-being by stabilising or optimising emotions. Various forms of music therapy have shown beneficial effects in various clinical conditions. Music can help people process emotions, trauma, and grief, as well as relax and regulate anxiety and dysregulation. Incorporating music into one's daily routine can help improve mood and motivation, relax, and improve the brain's processing efficiency. There are several ways to use music for mental health in day-to-day life.

1.3.1 Concentration and Cognitive Performance

Classical music is an excellent aid to concentration. Music at a pace of 60 bpm (beats per minute) improves the brain's ability to process information. Background music, or music played while the listener is primarily focused on another activity, has been shown to increase learning and memory in older adults, according to research. Listening to more upbeat music improves processing speed, while listening to both upbeat and downbeat music improves memory.[5] Instrumental recordings in the background, rather than intricate lyrics, which can be distracting at times, can be quite good for concentration and cognitive performance.

1.3.2 Memory

Scholars prefer to listen to their favourite music as a pleasant distraction while concentrating on their work. Music-naïve or musically untrained persons benefit from it more than trained professionals in terms of memory enhancement. Trained professionals are more concerned with grasping the music, but the naïve person appreciates the music's positivity and finds that it does not interfere with the production of new memories. In comparison to rhythmic speaking of sentences, singing new words out loud aids in the learning of new languages.[6]

1.3.3 Emotion Regulation

Emotion regulation is an intrinsic process that allows a person to maintain a relaxed level of arousal by adjusting one or more characteristics of emotion. Emotion regulation issues can have a long-term impact on a person's mental health and well-being.[7] Many experts believe that appropriate emotion regulation is a sign of mental health since it allows a person to respond and react to events and periods of discomfort in a variety of ways. Music can help people express themselves more effectively. Producing music can help express and process emotions. Few options for producing music are writing lyrics or playing music on an instrument. Music is not about how it sounds but about how it makes one feel. The effect of music also varies according to one's level of involvement in understanding it. Music, therefore, may be defined as a form of auditory communication between the producer and the receiver. There are other forms of auditory communication, such as speech, but the difference is that music is more universal and evokes emotion. It is also relative and subjective. Listeners perceive the music depending on the surroundings, state of mind, mood, and understanding of its content and not only lyrics. An active listener indulges in music and tries to appreciate the musical choices and the lyrics. Sometimes, a passive listener may also use music as a background activity while focussing on some other activity or task at hand.

1.3.4 Socio-cultural Bonding

Music has the power to alleviate feelings of loneliness and isolation. Whether it is sharing playlists with friends or meeting new individuals, music pulls people with similar cultural and social tastes together and aids in forming bonds. Research suggests that music-based mental health treatments may help health by providing benefits historically linked with exposure to and engagement in arts, such as increased social connectivity.[8]

1.3.5 Relaxation and Stress Relief

Music can help one unwind and cope with stress. The right music helps one relax by resonating with the brain's alpha frequencies. Hypertension, headaches, and migraines can all benefit from meditation music that focuses on relaxing brain frequencies. Low-frequency music has a unique influence on the autonomic nervous system, which aids in stress reduction.[9]

1.3.6 Motivation

Optimism and positive feelings are strongly linked to good mental health. Uplifting and joyful music played loudly can help one get through a terrible day. The upbeat musical tones and lyrics lifts spirits and prepares one for upcoming challenges. Upbeat, fast-paced music gets the mind and body moving, energising and motivating one to embrace what is ahead.[10] According to studies, classical and ambient music have the best mood-boosting properties, whereas metal and hard electronic music have the opposite impact.

1.3.7 Pain Management

Music can be quite beneficial in the treatment of pain. One research of fibromyalgia patients revealed that listening to music for one hour a day reduced pain significantly compared to a control group.[11] As a result of these findings, music therapy may be a useful aid in the treatment of chronic pain. The researchers also discovered that listening to music before surgery improved outcomes. Additionally, music listeners use less medication to control their pain. When patients were permitted to choose their own music, there was a slight, but not statistically significant, improvement in pain management results.

1.3.8 Quality of Sleep

Music has the potential to be a non-pharmacological treatment for sleep problems. For those suffering from sleeplessness, listening to relaxing classical ragas can be a safe, effective, and economical solution.[12] Music influences the stress hormone cortisol, which improves the quality of sleep. For non-pharmacological treatments, the subject's positive expectations and belief in the treatment method are always key requirements.

1.3.9 Positive Impact on Mood

Music makes people happier, increases arousal, and boosts self-awareness. The secret to improving one's mood is to listen to positive, upbeat music.[13]

Music therapy can be a safe and effective treatment for depression and anxiety in patients suffering from neurological conditions such as stroke, dementia, Parkinson's disease, and so forth. The type of music one listens to plays a big role in this. Classical and meditative music have the most positive effects on mood, whereas heavy metal and techno music are ineffectual and even detrimental.

1.3.10 Endurance and Performance

Music has the power to improve performance. People can be inspired by the addition of a powerful, rhythmic beat, such as a fast-paced musical track.[14] Athletes who listen to music are more motivated and have more endurance. A tempo of between 125 and 140 beats per minute is great for working out. Music can assist in shifting attention away from the intensity induced by physical activity, allowing the person to continue working hard in the gym without feeling tired, muscle soreness, sweating, or increased breathing.

1.3.11 Creativity

When one listens to or composes music, it stimulates their brain's creative thinking. Experimenting with various forms of music can help one find a way to flourish at a creative endeavour while also improving their mood. Music from the past does not challenge the brain in the same way as novel music. The unfamiliarity causes the brain to work hard to absorb the new sound, even if it may not seem pleasant at first.

1.3.12 Empathy

Engaging with music passively or actively requires components of cognitive and affective processing. Music is considered a form of language and is a powerful medium of communication. The core of any human interaction is empathy. It requires both cognitive and affective aspects which enable individuals to recognise the emotional and mental states of others and respond appropriately to the given situation. Empathy is important as it allows perception of the other person's thoughts and feelings and helps predict how the other person is likely to behave. Music is a powerful elicitor of emotion. Engaging with music requires perception of the emotional and psychological content in music, interpretation of thoughts and feelings, understanding of the complex auditory cues, and experiencing the emotion. Studies have shown that children and adults alike can predict the direction of a melodic phrase or narrative. Empathy is, therefore, strongly connected with perception, interpretation, and our reaction to music. Studies have shown that music enhances prosocial behaviour. Long-term group musical interaction has shown to increase emotional empathy. Several research studies are still being carried out to understand the myriad ways in which music enhances empathy, especially in certain clinical conditions where socio-cognitive deficits play a central role.

1.4 Music and Brain

1.4.1 Music – a Higher Neurocognitive Process

Music engages a wide range of neural networks; diverse parts of musical experience are generated by networks formed by several areas of the brain. Music perception involves acoustic analysis, auditory memory, auditory scene analysis, processing of interval relations of musical syntax and semantics, and activation of premotor representations of actions. Music perception alone involves a host of cognitive processes including encoding, storage, and decoding of information and events relating to musical experiences; musical performance extends these processes to reading, motor planning, decision making, and so on. Perceiving the basic acoustic features of music demands awareness of frequency, duration, and loudness. In order to perceive higher-order musical features, an understanding of harmony, intervals, and rhythm is needed. If one focuses and tries to keep track of music in time, both attention and working memory play important roles. Recognizing music and recalling associated memories requires aid from episodic memory. Playing, singing, and moving to the beat of the music involves motor functioning of the brain. Music also influences emotions and the experience of pleasure and reward. Now if we combine the effect of music on various cognitive abilities, it becomes evident that the role of music is crucial in order to understand and modulate cognition in humans.

1.4.2 Music Engages a Host of Neural Networks

Music is a combination of multiple processes where producing, listening, and understanding are major areas experts focus upon. Tools such as magnetic resonance imaging[15] and brain stimulation techniques are being used to test causal roles of specific targeted brain areas and their inter-dependence. Musical experience, be it producing or listening to it, influences multiple neural networks in the brain which enable specific aspects of music. All brain functions are controlled by networks of brain areas, from primary senses like audition and vision to motor functions, association networks like multisensory integration and spatial navigation, and higher-level cognitive functions like attention, working memory, and learning, all of which are required for proper musical performance. The whole process of understanding and enjoying the music involves not only the auditory cortex and auditory pathways but also the perisylvian network,[16] areas of motor network,[17] and produces multisensory perception in the brain. This multicentric feeling which makes the brain lit like a bulb on the fMRI shows the complexity of the musical stimulus. The reason behind this multicentric activation is the distributed activation of the grey matter throughout the brain. Beyond the primary auditory cortex, other functional networks such as language and generalized auditory processing, motor pathways, reward pathways, emotions, and visualizations all get activated when the listener experiences the music from its very core. Auditory-motor mapping is an important phenomenon in the understanding of music. The arcuate fasciculus plays a crucial role in mapping sounds to motor motions because it is positioned as a connective conduit between auditory regions in the temporal lobe and motor regions in the frontal lobe.[16] Music learning is also one of the complex tasks which involves perceptual, motor, affective, and autobiographical memory integration. It becomes challenging to separately study these behaviours while music is presented as a stimulus. The temporal lobe and superior parietal regions play a crucial role in the interaction of these behaviours and in turn learn the melody, recognizing it, memorising it, and so forth.[18] Table 1.1 provides the summary of various brain areas involved in music perception, cognition, and production across studies that have used the functional neuroimaging method. Figure 1.1 provides an overview of different areas of the brain known to be engaged or activated during music-based activities.

1.4.3 Music Facilitates Neural Plasticity

Neural plasticity is the restructuring or adaptation of the brain caused by the formation of new neural pathways during learning processes. Cognitive neuroscientists working on the concept of music-based therapies, music therapy in collaboration with neurosciences, are particularly interested in a deeper understanding of how music facilitates and enhances neural plasticity. Hebbian learning is the hypothesis that states that synapses that are used repeatedly become stronger over time as a result of repeated exposure to similar sensory experiences.[19] In this context, repeated practice and performance of musical activities may provide an appropriate stimulus, altering the shape of brain regions and strengthening their connecting fibres.[20] Music therapy for motor rehabilitation is the best illustration of this. Scientists are looking into how music-based therapy might help with speech,[21] cognitive,[22] and mood

Table 1.1 Functional magnetic resonance imaging (fMRI) studies have provided the evidence that music activates several different parts of the brain

Brain Area	**Function**	**Role of Music**
Frontal Lobe	Thinking, decision making, planning	The most crucial part of being a human is the frontal lobe. In comparison to other animals, we have a large frontal lobe. We can improve its functionality by listening to music.
Parietal Lobe	Sensory integration, memory retrieval, and mental rotation	Memory performance, learning, mental transformations.
Temporal Lobe	Processes what we hear	Although language and words are evaluated in the left hemisphere, music and sounds are interpreted in the right hemisphere, we use the language centre to appreciate music, which spans both sides of the brain.
Occipital Lobe	Processes visual information	When professional musicians listen to music, they use the visual cortex, whereas lay people use the temporal lobe to process it.
Broca's Area	Speech production	To express music. Playing an instrument can help one communicate more effectively.
Wernicke's Area	Comprehends written and spoken language	To analyse and enjoy music.
Cerebellum	Movement coordination and physical/muscle memory storage	An Alzheimer's patient who played the piano as a child can still play it since it has become muscle memory. The memories that are stored in the cerebellum never fade away.
Nucleus Accumbens	It seeks pleasure and reward and releases the neurotransmitter dopamine, which plays a key role in addiction	Music has the potential to be a drug – one that is highly addictive since it acts on the same area of the brain as illegal narcotics. Music, like cocaine, boosts dopamine levels in the nucleus accumbens.

(*continued*)

Table 1.1 (*continued*)

Brain Area	**Function**	**Role of Music**
Amygdala	Processes and triggers emotions	Music can calm one down, prepare one to fight, and improve one's pleasure. The amygdala is triggered when one gets shivers down their spine.
Hippocampus	Memory retrieval and production. Emotional response regulation. Central processing unit of brain.	Music may increase neurogenesis in the hippocampus, allowing the production of new neurons and improving memory.
Hypothalamus	Maintains the body's equilibrium, connects the endocrine and neurological systems, and generates and releases important hormones and chemicals that control thirst, hunger, sleep, mood, heart rate, body temperature, metabolism, growth, and sex desire, to mention a few.	Heart rate and blood pressure variation with music.
Corpus Callosum	Enables communication between the left and right brain hemispheres. Coordinated body movement. Complex thinking involves both logic (left hemisphere) and intuition (right hemisphere)	Coordination between the left and right hemispheres helps the musicians to better understand the music and is important in order to analyse music.
Putamen	Processes rhythm and regulates body movement and coordination.	Music can increase dopamine in this area, and music increases our response to the rhythm, which may help in temporarily improving the symptoms of Parkinson's disease. Rhythmic music, for example, has been used to help Parkinson's patients to get up and down and their gait. Parkinson's patients require aid in moving, and music can act as a cane for them. Unfortunately, the pathology returns when the music ends.

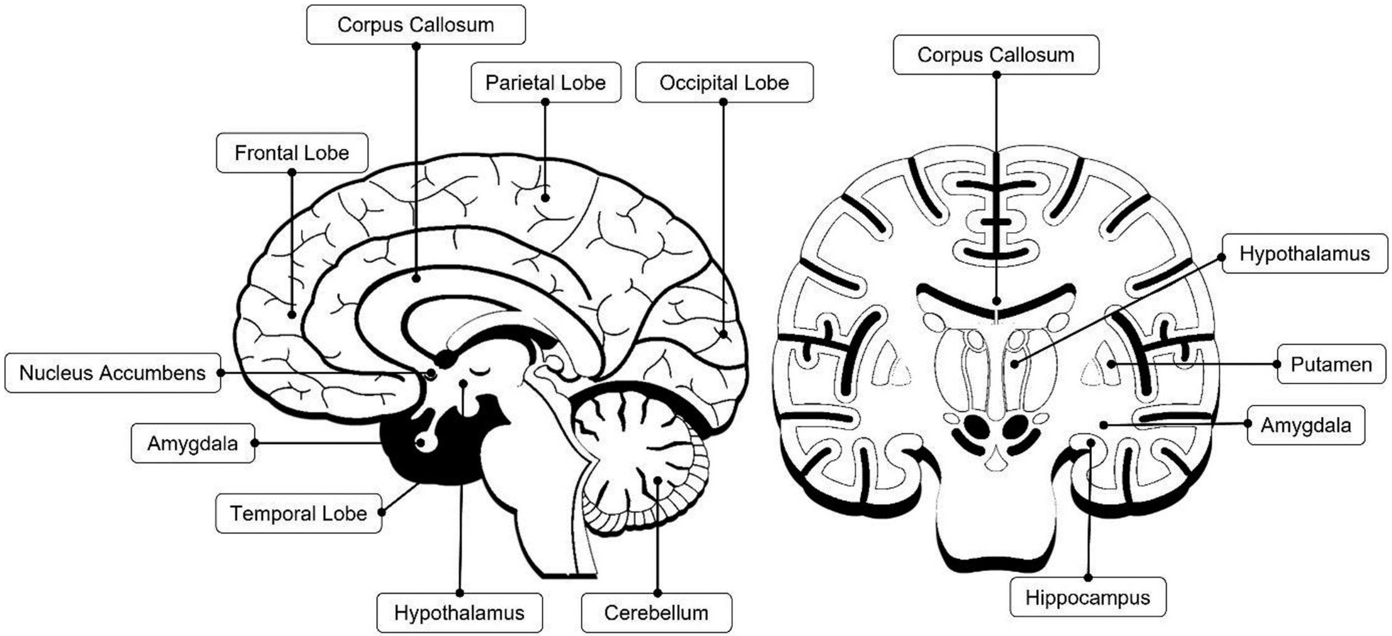

Figure 1.1 Diagrammatic representation of key brain structures relevant to music-related activations.

problems[23] and consciousness disorders.[24] In fact, this veritable nature of the human brain is the fundamental principle of music-based interventions.[25]

1.4.4 Musicians Are a Role Model to Understand Neural Plasticity

To understand the modulations induced by the external stimulus, the first investigations in the field of neuroplastic alterations used animal models. These animal researches revealed some fundamental cortical plasticity rules and demonstrated how cortical neurons use somatosensory modalities (expansion of the receptive field) and spatial tactile discrimination (localization of the receptive field) to make fine-grained temporal judgments. These animal models can be used to investigate the cellular and molecular mechanisms of plasticity in depth. However, the range of stimuli employed, the behavioural manipulation, and the training length, however, limit the investigations. Because cognitive processes involve various molecular and cellular networks, studying them with animal models is difficult due to the large-scale involvement of neural networks. As a result, it became critical to examine human brains in order to resolve these challenges. One of the most challenging endeavours is professional music performance. Music is a multifaceted stimulus with a complex and organised structure. As a result, the richness and complexity of data being analysed by the brain are immense when compared to other external inputs. The integration of sensory and motor information, as well as precise performance monitoring, are required for music composition. The study of musicians may aid in separating the effects of musical training and experience from those of genetic predisposition. Musicians have excellent sensorimotor abilities. Musicians receive continual multisensory feedback as they learn and practise the connection of motor activities with precise sound and musical notation. A musician's brain could be an appropriate model for investigating neuroplasticity in the auditory and motor domains, as well as the impacts of abnormal plasticity.

1.4.5 Near Transfer and Far Transfer Effect of Musical Instrumental Training

Long-term music education has been shown to improve cognitive capacities such as inhibition and planning, according to cognitive neuroscientists. However, 'far transfer' does occur in therapy-based treatments, and more research is needed for systematically recording these changes and impact due to the intervention. Musical instrumental training is influenced by several factors, including the learner's motivation, rhythmic entrainment and social synchrony, musical predispositions, personality, and parental and teacher participation, as well as music-induced rewarding feelings. The practitioner acquires near and far transfer abilities after considering these variables and their effects on cognition. Improved listening abilities, fine motor skills, temporal processing, and attention orienting in time are all examples of near transfer skills. Long-term musical instrumental training, on the other hand, results in improved social skills, increased general IQ, improved executive functioning, improved listening and reading skills, as well as improved verbal memory and vocabulary.[26] These modulations or plastic alterations in brain connections are dependent on the practice effect as well as one's level of expertise.

1.5 Music and Its Impact on Neurochemical Functioning of the Brain

Music appears to activate pleasure-seeking parts of the brain that are engaged by food, sex, and drugs. Music has four basic structures: iterative, reverting, strophic, and progressive.[27] These structures have the capacity to alter the listener's health and well-being. The activity of several neurotransmitter systems, including dopaminergic, serotonergic, and endorphinic, is influenced by music and its structure. Other chemicals, such as cortisol (the stress hormone) and oxytocin (which promotes social bonding), are also influenced by music and its structure.

The cognitive background of musical appreciation, stress relief, and emotion identification has been largely examined with the heart rate variability (HRV) and hypertension, which seek to explain the cognitive basis of musical appreciation, stress relief, and emotion identification. The signals are carried by messengers in the body that range in size from small to large molecules that are essential for physiological wellness. In other words, music has been demonstrated to have an influence on neurotransmitters and the neuroendocrine system in previous research.[28] In comparison to the baseline, music decreases epinephrine (related to fear or anger), norepinephrine (controls heart rate and skeletal muscle contraction), beta-endorphins (blocks pain sensation) and increases opiate receptors (nociception, stress, temperature, respiration, memory, mood, motivation, and so on) and dopamine (enhanced motivation, concentration, and so on). Both stimulating and calming music, on the other hand, have distinct functions to play in determining the levels of these neurotransmitters. Music can alter the immunological response of the body in form of modulating Leukocytes,[29] cytokines (Interlukin-6),[30] and immunoglobulins (salivary immunoglobulin A-SIgA).[31] Music has also been shown to help combat cerebrovascular illness by activating the parasympathetic nervous system and reducing IL-6, tumour necrosis factor (TNF), adrenaline, and noradrenaline concentrations. Before and after gastroscopy, the levels of adrenocorticotropic hormone, cortisol, adrenaline, and noradrenaline were all tested. The generation of biochemical messengers has been demonstrated to be important in giving a soothing effect in older Alzheimer's patients. Music has been shown to boost immune system activity. Similarly, music influences the amount of hormones in the body of the listener. Hormones such as cortisol (stress hormone, increases glucose in blood stream), growth hormones (maintains body structure, metabolism, etc.), adrenocorticotropic hormone (related to cortisol hormone, and Cushing's disease), corticotrophin-releasing hormone (hypothalamic hormone), prolactin (milk production, mammary gland development), oxytocin (love hormone, social bonding, attraction etc.), testosterone (growth, reproduction etc.) and others are also modulated by music exposure, resulting in an emotional or physical burst.

The level of brain-derived neurotrophic factor (BDNF) in dorsal hippocampus sub-regions is increased by music exposure, which improves spatial cognition.[32] BDNF is a protein that aids in the treatment of depression and improves mood. By assisting in the growth, maturation, and maintenance of neurons, BDNF also aids in the survival of nerve cells. Music can therapeutically alter emotions and autonomic nervous system activity, and it is a potentially low-cost and safe intervention adjuvant. Music stimulates brain areas, causing neurotransmitters to be released. These chemicals rush to our brain, resulting in an emotional response. We react emotionally to what we hear or experience because of these hormones. We may be filled with joy, grief, nostalgia, or enthusiasm. Music helps team members communicate more effectively, reduces anxiety, and increases efficiency. Therefore, surgeons and surgical personnel occasionally listen to music while performing procedures; it reduces the surgical team's tension as well as the patient's anxiety prior to surgery.

There is a need to determine the precise activities of cytokines, neurotransmitters, hormones, peptides, and other messengers. While music can reveal such functions by revealing trends in messenger production, it is by no means causative. The potency of another messenger can offset or amplify a trend in the output of one messenger. As a result, comprehending the links between the mind and the body requires an understanding of messenger production pathways. Music may help to balance messenger levels by boosting or reducing steroids in people who have low or excessive hormone levels.

1.6 Music and Its Role in Management of Neurological Disorders

Music instigates human health and well-being while also laying the groundwork for non-pharmaceutical treatments for neurological disorders. Engaging, emotional, physical, personal, social, persuasive, and synchronization are seven aspects of music that aid in the management of neurological disorders, according to the Therapeutic Music Capacities Model (TMCM).[32] Therapeutic contexts, active components, brain mechanisms, and effects are all encompassed by music-based therapies. Some of the brain mechanisms behind the benefits acquired by music therapy in neurological disorders include autobiographical memory, language, activation of the mirror neuron system (MNS), auditory motor coupling, stimulation of motivation and reward, and neuroplasticity.

Music, as a structured, complex language of time, provides temporal structures that enhance perception processes, namely in the areas of cognition, language, and motor learning, thanks to its unique capacity to reach affective/motivational systems in the brain. Individual or group music-based therapies can be provided in either passive (listening) or active (e.g., singing, drumming, clapping, dancing) forms, depending on the therapeutic environment. Music-based therapies have been shown to induce brain processes that lead to demonstrable improvements in behavioural, cognitive, motor, and psychosocial domains. Pain, anxiety, agitation, and depression can all be relieved by music. Music can elicit vivid personal memories and associated emotions, reinforcing a sense of identity in people with Alzheimer's dementia (AD); music-based treatments can improve gait and speech functions in people with Parkinson's disease (PD); and it can improve attention and understanding of emotions in children and adolescents with autistic spectrum disorder (ASD). Researchers use several music-based strategies to help patients with neurological disorders achieve positive mental transformations, which aids in better medication control.

1.7 Concluding Remarks

As we gather experience with how to use music most effectively, its role in fostering positive mental health will continue to rise. Music has the potential to lead society towards a higher level of health – also known as positive health.

- Music promotes brain activity, enhances people's moods, and encourages social interactions.
- It has the potential to significantly improve brain health and well-being for people of all ages and health levels.
- Music strengthens the cognitive reserve in the brain, promoting resilience. Such abilities can enhance a person's ability to learn throughout their lives, opening the door to rewarding new experiences.

There is definitely a need to carry out further systematic research on music's impact on psychological and overall physical health.

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2

EVOLUTION OF AUDITION, SOUNDSCAPE AND HEALTH

R. Rangasayee

2.1 Introduction

More than 100 years ago, German Nobel laureate Robert Koch predicted that 'a day will come when mankind will have to fight noise as fiercely as human plague or cholera!'. That day is not far away. We live in a world of sound. The sense of hearing is active 24x7 from the fifth month of foetal (intrauterine) life and lasts lifelong. The living zone is ever immersed in both meaningful sounds, such as speech, music, sound alerts (doorbell, traffic alerts, etc.), that are critical to childhood to acquire spoken (verbal) language skills and education, avoid dangers and so forth, and unwanted sounds, often referred to as noise.

In other words, from birth to death, life is bombarded with sounds of various types such as music, speech, laughter, rain, transport, traffic, sports, and so forth. The level of such sounds and noise has been steadily increasing in the past decades owing to mechanization, automation and the more recent, Fourth Industrial Revolution (4IR).

It is said that not only industrial noise but all high-volume sounds such as loud music are harmful to hearing and health. Well-established data is available on all aspects of sound pollution and its harmful effects on human hearing and on other body functions leading to stress, loss of sleep (sleep deprivation), accidents, communication breakdown, blood pressure, cardiovascular disorders, abdominal pain, tinnitus (ringing sound in the ear), giddiness, and so forth.[1] Hence, it is time that reasonable action is initiated to reduce the burden on human hearing and health. It is said, 'you may forgive noise but your body never will'.

In fact, hearing the sounds in our living or working environment and not hearing them for any number of reasons including hard-of-hearing have a significant impact on human sustenance and survival. Therefore, balancing the activities such as hearing the sounds in the living and working environment, be it speech, music, sound alerts, or noise, and not hearing them is critical in the emerging world.

This chapter discusses the evolution of human hearing and its usefulness; how soundscape is a factor influencing exposure to sound (music/noise/sound alerts/speech); the effects of noise/sound on hearing/health and what may happen if we fail to hear them and address ways to contain the problems of sound pollution; a proposed launch of a branch of study – 'social audiology' – to address social issues of hearing and not hearing speech, music, sound alerts, or noise and its management.

Learning Objectives

- Evolution of human hearing, its functions and the possible role of artificial intelligence (AI) in shaping the future of evolution of hearing
- Soundscape, sound culture (acoustemology), effect of hearing and not hearing sounds in the immediate environment
- Impact of noise on hearing and safe listening practices
- Impact of hearing loss on a person's life in creating an inclusive world
- Social audiology and its relevance.

2.2 Brief on Evolution of Hearing

Human Hearing is a mega power acquired over 370 million years of evolution; all began with a fish named Eusthenopteron. A kinked, small bone in the gill opening of a fish called Eusthenopteron developed a larger version of that bone, known as a spiracle. Spiracles, which allowed fish to breathe air while underwater, were believed by scientists to be the missing link between fish gills and land-animal's ability to hear. Many other evolutionary steps have occurred since, which have developed human's ability to hear, but it all started with a fish!

In evolution, different species have acquired varying ear, hearing, and sound-processing abilities shaped by need and purpose, including the balance mechanism regulated by the hearing system.

Despite not having an outer ear or middle ear, the early amphibius vertebrates such as salamander and lungfish were able to hear almost 250 to 350 million years ago. In 2015, researchers in Aarhus University[2] substantiated that during the transition phase from amphibious vertebrates to terrestrial vertebrates, approximately 100 million years ago, the vertebrates could have been deaf or hard of hearing on land, to an extent of the absence of the outer and middle ear. By design or default, cynodonts (100 to 250 million years ago), mammal-like reptiles, which were nocturnal, escaped extinction from the jaws of dinosaurs, which did not turn nocturnal and evolved a good sense of hearing as it was more useful than a good vision for hunting in the dark.

Anna Ginther says[3] that while reptiles like crocodiles and lizards have only one bone in their middle ear, the mammalian middle ear has three bones, namely, malleus, incus and stapes. The three middle ear bones have facilitated hearing high-frequency sounds in mammals though the chimpanzees and humans are in the lower end and dolphins and bats are at the higher end. It is worth recalling that Von Bekesy (1960), Nobel Laureate (1963) in Medicine for his work on hearing, said[4] that the ossicular chain acts as a simple lever providing a mechanical advantage that matches the impedance of the air with the impedance of the cochlear fluids. In the context of the auditory system, the single-most-important environmental demand that dictated the evolution of vertebrate hearing is the ability to listen and interpret the soundscape. Those who listened to the sound effectively in inter- and intra-species activities, perhaps, survived longer. For example, according to David Mann of the University of South Florida and his colloborators[5], the stranded bottle nosed dolphins and rough-teethed dolphins, among other marines, were found to be having hearing loss. Efforts to include them back in the ocean were not possible as they are found to locate their prey just 2 to 3 yards away as against their hearing peers who could detect preys 100 yards away.

Each species has a hearing that is best suited for its survival in a given environment; not to be labelled as better or worse than the other species. Mammals have a wide range of unique hearing abilities. While humans use sonic range 20–20,000 Hz, the elephants use infrasonic sounds and dogs and bats use ultrasonic sounds to detect and locate. Interestingly, the barn owls with two ears placed at different levels (asymmetrically) on either side of the head have a far superior ability in locating their prey even in darkness than owls with symmetrically placed ears.

The sense of hearing facilitated the ability of a species to locate the source of sound, its distance, and direction in addition to what it could gauge by the senses of sight, smell, taste, and touch. The primary functions are to catch the prey and flee from predators. Modern-day predators are, for example, motor vehicles plying on the urban roads or the verbal intimidation in the living space, to name a few. Human hearing is well adapted to living in a world of airborne sounds despite going through a wide range of civilization shaped by advances in science, technology, and culture.

Hearing, as a function, has come to play a key role in Homo erectus, a social animal. Homo erectus is bestowed with the audio-vestibular system to cope with the needs to survive on land, in water, and in air. The Homo erectus survived through a competitive, threatening evolutionary process with a highly evolved brain to handle complex symbols.

In the civilized world, hearing the sounds is vital to learning verbal language skills for effective communication apart from schooling, employment, interpersonal relationship, recreation, and so forth, all based on the effectiveness of hearing as a sensory system.

Dwelling upon how hearing may evolve to the next level in evolution, less is said about how in the upcoming days/evolutionary process may alter the human ear and hearing, However, the developments in digital technology in conjunction with AI will make the ear as the modern wrist. Digital technology and AI together will not only replace mobile phones but also translate as many as 27 languages, thus making hearing aid as a common man's wearable. This predicted trend in usage of hearables is a good reason too for the perusal of the ongoing pages.

Also, it is of great interest to note that divers can detect sounds of up to 100 KHz under water as against the upper limit of 20 KHz on land.[6] The researcher attributes it to bone conduction clues for the enhanced hearing underwater. Any effort in creating underwater human inhabitants should also take care of the evolution of hearing, soundscape, possible effects of hearing, not hearing, and ways to tackle.

However, as a corollary to the application of AI in hearables, mankind will witness soon a system destined to isolate speech signal among a plethora of other voices and background sounds, no matter what the environment.[7]

2.3 Soundscape

According to International Standards Organization (ISO),[8] soundscape is 'an acoustic environment as perceived or experienced and/or understood by a person or people in context'. The field of soundscape studies and disciplines have evolved differently around the world. It is a perceptual construct of sound scene related to a physical phenomenon (acoustic environment), and, further, the ISO clarifies that the soundscape exists through human perception of the acoustic environment. The sound sources may be sounds generated by nature or human activity and the acoustic environment is the sound received by the receiver from all sources, as modified by the environment. The acoustic environment can be actual or simulated, outdoor or indoor, as experienced or in memory.

It is not out of place to say that the soundscapes are not only unique to a location but also to the person exposed to it. Accordingly, the hazards of harmful noise no longer exist if one does not hear them. In other words, those with difficulty in hearing may find working easier in a noisy soundscape. All those who voice against this on the grounds of non-auditory effects of noise as observed by Kryten[9] and Mathias,[10] have no evidence to show that non-auditory effects of noise are caused by non-auditory means, leave alone effects of vibration on human hearing and health as documented by the World Health Organization (WHO).[11]

2.3.1 Brief on Sound Culture

Interestingly, how mankind had been using sound clues in life and living is scantily documented. In other words, the 'sound' culture of mankind is not documented adequately as much as evidence of our ancestors' lifestyle is being obtained through visual-based observation; for example, the Harappa and Mohenjo-Daro culture is reflected through visual study or inspection of such remains. Realizing the gap in culture studies, a new branch called 'acoustemology' is launched to study, understand, and document the sound culture of a society. Steven Feld,[12] an American anthropologist coined the term to refer to the 'sonic way of knowing and being in the world'. The branch of acoustemology can support with the factual role of sound in the daily life of people around the world so that the relevance of hearing and not hearing can be used for realism-based practice.

In addition, many acousticians have studied the acoustic scene analysis and have attempted to classify the environmental sounds. Such studies are conducted for designing of AI-based operations for regulating the functioning of hearing aids, mobile phones, movement of wheelchairs, and so forth.

2.3.2 Anecdotes for Not Hearing or Missing the Sound-based Situational Awareness

(i) It is a common sight to see trolley boys in airports gathering and pushing trolleys to their slots. In one such situation, a man wearing two high-end hearing aids walking ahead was hit by the trolley as he failed to hear the sound alerts. Perhaps the hearing aid programming was to capture speech sounds filtering out other sounds in the environment.

(ii) Studies[13,14] have been done on road traffic accidents among persons with difficulty in hearing with or without hearing loss/hearing aid/cochlear implant or hearables. In a high percentage of road safety incidents involving deaf people, the inability to hear the external audible information was found to be a contributory factor. This is particularly apparent in deaf cyclists, where the evidence indicates an increased risk.[15]

(iii) Another situation involves the inability to hear the sound of the car engine and to be aware of potential problems through changes in this sound or unexpected noises in the vehicle.

(iv) The use of Active Noise Cancellation (ANC) technology-based ear phones by cyclists or pedestrians and the quietness of hybrid and electric cars claim their toll too.
(v) There is a widely reported case of a lady listening to music at a high volume who failed to hear the sound alerts and was fatally hit by a train at a level crossing.

2.4 Impact of Noise and Hearing Health

Prolonged exposure to loud noise as in a generator room or music, say in a club or a one-time exposure to intense sudden bursts as in crackers burst during festivities or bomb blasts, can damage the ear and hearing or cause permanent hearing loss of varying degrees. Noise levels causing damage to hearing and health can be found in places of work, recreational centres such as clubs, stadium, restaurants, marriage halls in India, and in the inclusive classroom or even in the personal audio devices. However, differing susceptibility to the damaging effects of noise has been documented in human populations .Sound is measured in decibels (dB). An ordinary conversation is about 65 dB; an office room is around 50 to 60 dB; hospital wards are less than 50 dB; an autorickshaw is about 80 to 85 dB; music concerts are between 85 and 110 dB; engine testing is 120 dB; a bulldozer or tractor is 110 to 120 dB; crackers are 110 to 125 dB. Sounds at 130 dB induce pain in the ear.

Accordingly, various agencies have recommended cutoff safe hearing levels, that is, permissible dose of sound, be it noise or music or speech.

Human ear's ability to discriminate pitch and localize sound sources has evolved as secondary derivations as the ear was preadapted to the inevitable presence of noise.[16]

Toughening of the ear as an example is worth considering here. It has been substantiated with evidences that pre-exposure to continuous low-level noise reduces hearing loss caused by subsequent high-level noise exposure, a phenomenon described as toughening, priming, or conditioning.[17] Also, the subclinical exposure to noise may lead to synaptopathy (disorder in the neuronal junction in the transmission of electric nerve impulses), resulting in functional deficits in suprathreshold (above the level of hearing thresholds) levels in primates and non-primates; the toughening effect mitigates both outer hair cell (in the inner ear) damage as well as synaptic loss.

The European Commission[18] emphasizes the need to actively manage not only industrial noise but also the sound outside workplaces to enhance citizens' well-being.

According to WHO, more than one billion people are at risk of hearing damage due to unsafe recreational listening practices. To combat these risks, WHO created the 'Make Listening Safe' initiative in 2015.

'Make Listening Safe' aims to realize a world where people of all ages can enjoy recreational listening without risk to their hearing.

The approach of this initiative is to change listening practices and behaviours. WHO aims to achieve this through

- raised awareness about the need for and means of safe listening, and
- implementation of evidence-based standards that can facilitate behaviour change in target population groups.

The 'Make Listening Safe' mission is developed and carried out in collaboration with all stakeholders in the field.

2.4.1 Creation of Evidence-Based Standards

The WHO creates standards that outline safe listening features for a variety of situations where unsafe practices are common. These include:

- The WHO-ITU Global standard for safe listening devices and systems
- The Global standard for safe listening venues and events.

The above two standards, available freely online, were released on 3rd March 2022 on World Hearing Day celebrated with the theme of 'To Hear for Life, Listen with Care'. Cafeterias with loud music, for example, are advised to have a silent room for those with hearing fatigue to seclude and give rest to the ear, have an internal noise-level monitor, keep the sound level below 100 dB(A) LAeq, 15min with weekly exposure not exceeding 80 dB(A) for 40 hours.

Noise-induced hearing loss, accounting for 16% of disabling hearing loss in adults ranging from 7 to 21% in various subregions worldwide, denies access to education, employment, health, independent living, justice, recreation, information, and disaster survival. Therefore, as under the provisions of UN Convention on Rights of Persons with Disabilities (UNCRPD, 2006) and Rights of Persons with Disabilities Act 2016 (an Indian Act complying with UNCRPD, 2006), any program dealing with habilitation or rehabilitation of persons with difficulty in hearing needs to resolve issues in realizing their rights.

2.4.2 Impact of Hearing Loss or Not Hearing

Hearing loss or not hearing may lead to activity limitation and participation restrictions as outlined in the International Classification of Functioning, Disability and Health of WHO (2001).[19] They are Learning and Applying Knowledge (e.g. listening copying, reading), General Tasks and Demands (e.g. preparing, initiating, and arranging the time and space for a simple or complex task; handling responsibilities), Communication (e.g. conversation, communicating using signs), Mobility (e.g. walking, driving, using transportation), Self-care (e.g. toileting, dressing, eating, drinking), Domestic Life (e.g. preparing meals, caring for household objects, assisting others), Interpersonal Interactions and Relationships (e.g. maintaining family relationship, relating with strangers), Major Life Areas (e.g. education, employment, economic life), and Community, Social and Civic Life (e.g. recreation, religious activity, political life).

2.4.3 Moving Towards an Inclusive World

Needless to say, in order to ensure an inclusive world for persons who do not hear (with or without hearing aid/ear implants), the people in the world of sound need to play a proactive role to ensure equality and equalization of opportunities. Hearing is evaluated in a way as is measured or measurable for clinical purposes; in other words, what is measured is considered as the hearing ability of a person. It is right but not complete. Evolution has supported hearing as a sense for its ability to infer from the sound in its ecosystem to save the species from threats, to get food, and to procreate.

The current-day hearing devices including advanced speech processors do not necessarily take these life-saving social functions of hearing into consideration, thus leaving the users vulnerable to threats of survival and interpersonal relationship crucial for life and living, depending on age. Limited abilities to localize sound sources and other reduced spatial hearing capabilities remain a largely unsolved issue in hearing devices such as hearing aids .[20] A study by Dorman et al.[21] in 2016 showed that modern cochlear implants do not restore a normal level of sound source localization for listeners fitted with Cochlear Implants with access to sound information from two ears.

The situation is no better among certain categories of deaf people who do not wear hearing devices and thus fail to use clues of sound for life and living. In other words, this is a group of persons devoid of the advantage of hearing sound where hearing is defined 'as a psychoacoustic experience of sensation and perception of sound that occupies space and time, in the soundscape'. This definition gives scope to incorporate the operational problems of the deaf and need to facilitate getting sound clues either through hearing or through tactile or visual clues (to those who do not use or benefit from hearing aid) in this world of sound. This approach will rectify the impact of not hearing essential sound clues in the living environment, especially of persons wearing hearing aids, cochlear implants, or the deaf persons who do not use amplification devices or those having difficulty in processing auditory signals (Auditory Processing Disorder).

It is not uncommon to read news in media such as, 'A deaf woman hit by a vehicle in Hollywood'; 'A deaf man dies struck by a car – 2015'; 'A hard-of-hearing woman dies in RTA '; 'A hard-of-hearing man wearing high-end hearing aids hit by a moving trolley in the airport' (personal experience of the author); 'Deaf/hard-of-hearing persons being unaware of bodily sounds such as belching or passing gas'.

2.5 Way Forward

(i) Acoustemology needs to be pursued with reference to audiological needs with a focus on studying, accessing, and sharing sonic experience in life and living.

(ii) Technology applications have to be channelized to create an inclusive world to those with difficulty in hearing in a world of sound.

(iii) Definition/scope of audiology has to focus more on the International Classification of Functioning, Disability and Health (ICF)[19] framework and assign accountability for such negative conditions arising as a result of hearing or not hearing while wearing an aid, or being a deaf person not using an amplification device.

(iv) Study of soundscape and sonic way of knowing and being in the world have to be emphasized. Soundscape describes the sounds around us in lines with the analogous term landscape to describe the view of all the land around us.

(v) Promoting cues/indicators to provide timely information of crucial changes of the human system and its environment.

Thus, it is hereby recommended to focus on social audiology, operationally defined as, 'the study of sound scene, making sound clues accessible for activities and participation of persons who have difficulty in hearing, processing auditory information, or deaf (not using amplification devices/dependent on signing) persons, individually and collectively, thus resolving cost-effectively all issues relating to hearing sound with or without amplification devices, in shared family and community living environment'. Social audiology is an open-ended concept which is generative rather than prescriptive and follows realism-based practice (new concept proposed here) where realism is thinking and acting based on facts and what is possible, unlike evidence-based practice, which may sometimes be non-implementable. This branch needs to promote the emergence of a rights-based world as under the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) (2006) and Rights of Person with Disabilities Act (RPD Act 2016), an Indian Act . The conclusions below reflect the scope of social audiology.

2.6 Conclusions

After carefully considering the points raised in this chapter, the following are the conclusions:

(i) Study of sound scene that are part of the lived-in experience of the people (includes heterogenous diverse population) so that technologists and others work out remedial measures. The study may include noise/alerting sound, its audibility, and response of people thus exposed (say in a bus stand), or roadside vendors. The risks of noise for professionals such as a dental doctor, a plastic surgeon or an orthopedic surgeon using noisy drilling machines needs to be studied.
(ii) Preventive and promotive strategies such as (a) public education in universal design, (b) hearing screening activities, (c) public policies, for example, noisy products to be sold along with ear muff and a warning label 'Noise is injurious to hearing/health', (d) ensuring accessible and affordable solutions, and (e) standards with essential boundaries than a single boundary need to be prioritized.
(iii) Promotion of environmental facilitators and reduction of the barriers to optimize activities and participation in the ICF framework, for example, (a) changing the attitude, (b) issues in accessing public services, (c) involving in sports and recreation, (d) disaster survival strategies, and so forth.
(iv) Damage control measures to reduce the impact of hearing loss on a person's life including (a) limitations in the use of hearing technology at bedtime, (b) bullying control, (c) interpersonal issues arising out of not hearing, and so forth.
(v) Guiding and development of appropriate technologies to the heterogenous group of people such as hard-of-hearing/deaf, typical hearing (e.g., public announcements, public convenience, noisy inclusive classroom, communicating in workplace) denied of sound clues, through

need and gap analysis. The individual susceptibility for noise-induced hearing loss needs to be studied and understood, so that the cost of universal care and ban on sound pollution may be reviewed.

(vi) Use of standard outcome measures, economic guidelines, and related data management systems need to be augmented.

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Part II

UNDERSTANDING SOUND AND HEALTH

3

PHYSICS OF SOUND, HEARING AND SPEECH

Bhujanga Rao Vepakomma and Spandana Pardikar

3.1 Introduction

Sound is the main form of communication for both humans and animals. Humans communicate verbally through speech and body language. The ear is a wonderful sensory organ in our human body to perceive the sensation of sound when exposed to pressure fluctuations about the mean atmospheric pressure. These pressure fluctuations in the air medium around are due to the disturbance created by any vibrating structure or source. The vibration energy can come from a tuning fork, a guitar string, the vocal cords of a speaker, or anything that vibrates in a frequency range 16 to 20000 Hz that is audible to the listener[1]. The ear can easily pick up sound with pressure fluctuations as low as 10^{-5} Pa to as high as 10^{3} Pa. Communication experts call this 'dynamic range' which is of the order of 10^{8} which the ear can easily accommodate as part of hearing.

Complex sound waves are produced by the speaker as part of the mechanism of speech involving lungs, vocal folds, mouth and nose, and it becomes the primary source of raw material for the listener to recover the speaker's message by way of hearing. The total process is very complex.

The purpose of this chapter is to review some basic principles underlying the physics of sound, hearing and speech. Complex sound waves which we produce as part of speech communication include sounds consisting of various combinations of buzzes, hisses, and pops, and so forth. These sounds get modified through a filtering action by making a number of fine adjustments to the movement of tongue, lips, jaw, soft palate and other articulates before we recognise them as intelligible language.

It is very interesting to understand the various complex steps at the receiving end that occur in the ear such as splitting this complex sound into various frequency components in much the same way that a prism breaks white light into different optical frequencies or like a spectrum analyser in the laboratory. Putting it in a different way, a sound that is picked up by the pinna goes through external auditory canal (EAC), then to the middle ear, inner ear, auditory pathway and finally to the auditory cortex area no. 41 in the brain to get the sensation of sound.

Hearing, with the ear being the most important among the five senses, plays an important role in the development of speech, communication, cognition, emotional and social development of a human being. Being a hearing-impaired puts a step backward in the overall development of an individual. It is very essential to identify any hearing impairment in the early stages and treat it effectively. Some pleasant sounds like birds chirping, gushing water and soft music will reduce stress, lower blood pressure and give a feeling of tranquility. On the other hand, noisy sounds can make humans suffer stress and cause high blood pressure and other ailments.

In any perspective, it is very important to have a good knowledge of how sound is generated, communicated and heard by the human body; this is the core focus of this chapter.

Learning Objectives

- Fundamentals of sound and relevant terminologies
- Characteristics of sound and its units of measurement
- Physiology of speech along with speech processing and production
- Various aspects of sound interaction with the human body.

3.2 Physics of Sound

Sound energy is a form of mechanical energy that produces the sensation of hearing in our ears. Sound is a travelling disturbance like a ripple produced on the surface of disturbed water in a pond. Any vibrating object produces sound. It reaches us through the vibrations of particles of the medium. A sound wave propagates in the form of a longitudinal wave consisting of compressions and rarefactions of the molecules of the medium, be it air, liquid or solid, in which it travels.

A sound wave which travels in the air is a pressure fluctuation about the mean atmospheric pressure that results from any source of vibration. The vibration can come from a tuning fork, a guitar string, the vocal cords of a speaker or virtually anything that vibrates in a frequency range that is audible to a listener (roughly 16 to 20,000 Hz)[1]. A sound wave must not only be within the hearing range, but it has to be loud enough to be perceived. Mass, elasticity and density of the air medium are necessary characteristics for a sound wave to travel from the source to the receiver. The ear, as the receiver, perceives such pressure fluctuations in the medium and converts them into electrical pulses or neurons and transmits the neurons to the brain which interprets the disturbance as sound. The ear has got some response time to receive and process the signal. Human beings respond to mean square pressure averaged over 35 msec interval.

Although the human ear can hear from 16 Hz to 20 kHz, the human speech frequency range covers only 125 Hz to 8 kHz. Among the genders, speech in males lies between the frequencies of 125 to 4000 Hz while females can go one octave higher, that is, between 125 to 8000 Hz. The audible frequency range is divided into octave bands such that the ratio of two frequencies is two. About 1000 Hz is recognised internationally as the standard reference frequency, and mid-frequencies of all octave bands have been fixed around this frequency. The human ear responds differently to different frequencies.

As stated earlier, human ears are sensitive to only a limited range of frequencies from 16 Hz to 20 kHz, which is known as the range of audibility. But this audibility range reduces with age as the hearing sensitivity of ears falls for both low and high frequencies, leading to gradual hearing loss.

The sound frequencies below 20 Hz are known as infrasonic sound while frequencies more than 20,000 Hz are known as ultrasonic sound. Both the infrasonic and ultrasonic frequencies are inaudible to human ears. But some animal species such as elephants, bats, whales and so forth can hear both infrasonic and ultrasonic sounds.

3.2.1 Reflection of Sound Waves

When sound waves strike a hard surface, they return back in the same medium obeying the laws of refelction, that is,

a. The angle of reflection is equal to the angle of incidence
b. The incident ray, reflected ray and normal at the point of incidence all lie in one plane.

Unlike light waves, sound waves do not require a smooth and shining surface for reflection. They can get reflected from a surface that is either smooth or hard. The only criteria for the sound to be reflected is that the size of the reflecting surface must be bigger than the wavelength of the sound waves. This phenomenon is utilized in megaphones, soundboards, ear trumpets and so forth.

The sound that is heard after reflection from a distant object or obstacle like a cliff, wall of building and so forth after the original sound has ceased is called an echo. This concept is used in medical applications to do ultrasound scans of different parts of the body (ultrasonography) like echocardiography to get a graphic outline of the heart's movement, pumping action of the heart and so forth. Ultrasound energy is also used to break kidney stones.

Animals have different range of audible frequency. The upper audible frequency range of bats, dolphins and dogs are much higher than that of human beings. Bats can produce and detect the sound of very high frequency up to about 100 kHz. Bats can locate the obstacle with the use of echoes so that they can fly safely without colliding with it. This process of detecting the obstacle is known as sound navigation and ranging. Ultrasonic waves are used by dolphins, whales and so forth in underwater for navigation, communication and hunting for prey as part of their existence in the oceanic environment. There are innumerable applications of ultrasound, besides medical applications, such as ultrasonic cleaning, welding, stitching, cutting, repelling birds/animals like dogs, rats, bats, birds and so forth.

3.2.2 Characterisation of Sound

Audible sound can be characterised in two ways. One is through objective characterisation using measurable qualities such as sound pressure level (SPL), frequency, sound intensity and so forth. The second way is through subjective characterisation using non-measurable human perceptions such as loudness, pitch, timbre (quality). In musical acoustics, we often use terms like pitch, loudness and timbre to describe the musical quality on the basis of our perception in a subjective manner. This may differ from person to person. But in medical acoustics when one wants to use ultrasound to break kidney stones, we use measurable quantities such as sound intensity, frequency and SPL to characterise the sound in an objective manner. This setting up of the values of these quantities remains the same irrespective of the operator who is working with the equipment in a given situation.

3.2.3 The dB Scale

The human ear accommodates a very high range of fluctuation or disturbance of sound pressure levels of the order of 108 (also called dynamic range). This forces us to use a logarithmic unit called decibel for the measurement of sound levels. Linear units cannot be used to accommodate such large fluctuations of sound! The letter B in dB is always a capital letter which is introduced to commemorate the inventor of the telephone, Graham Bell.

We can use the dB scale to represent sound power, sound intensity and sound pressure as given below:

i) Sound Power Level, L_W= 10 log10 [W/W_{ref}] dB W_{ref} = 10^{-12} Watts
ii) Sound Intensity Level, L_I = 10 log10 [I/I_{ref}] dB I_{ref} = 10^{-12} W/m^2
iii) Sound Pressure Level,L_P = 10 log10 [P^2/P^2_{ref}] dB P_{ref} = 20. 10^{-6} N/m^2
Or P_{ref} = 20 μPa.

P_{ref} = 20 10^{-5} N/m^2 is used because it corresponds to the threshold of human hearing.

Similarly, I_{ref} = 10^{-12} W/m^2 is used to represent the threshold of hearing (plane wave approximation).

Sound power gives an idea about the power capacity of the sound source which causes the disturbance. The propagation of such disturbance in the medium can be measured in terms of sound intensity. The term 'sound pressure' is used to explain the loading pressure of such disturbance in the ear as an effect. Sound power and sound pressure are scalar quantities whereas sound intensity is a vector quantity.

As mentioned earlier, the human ear responds differently to sounds of different frequencies. Extensive audiological surveys have resulted in the introduction of weighting factors called A, B, and C for sound levels below 55 dB, below 85 dB, and above 85 dB respectively. For example, if somebody is exposed to machinery noise of sound pressure level of 70 dB ref to 20 μPa measured using A weighing factor network, then we write it as 70 dB(A) or 70 dBA.

For practical reasons, measurement of sound pressure is far more common than measurement of sound intensity. Hence, a decibel formula that makes use of pressure ratios rather than intensity ratios was derived. This derivation was based on the fact that intensity is proportional to pressure squared. The standard reference for the dB SPL scale is 20 μPa. However, any level can be used as a reference as long as it is specified.

The dBHL scale, used widely in audiological assessment, was developed specifically for measuring sensitivity to pure tones of different frequencies. The reference that is used for the dBHL scale is the threshold of audibility at a particular signal frequency for the average, normal-hearing listener. In particular, the ear is more sensitive to mid-frequencies sound between 1000 and 4000 Hz than it is at lower and higher frequencies. The complex shape of this curve provides the underlying motivation for the dBHL scale.

3.2.4 Noise – Unwanted Sound

Noise is defined as 'unpleasant sound', 'disagreeable' or 'undesired sound'. Sometimes it may happen that sound to one person can very well be noise

Table 3.1 Permissible Exposure in Cases of Continuous Noise or Short-Term Exposures (*Source:* Government Of India, Ministry of Labour, Model Rules Under Factories Act 1948)

Noise level (dBA)	Permitted daily exposure (h)
87	16
90	8
93	4
96	2
99	1
102	0.5
105	0.25

5dB rule of time intensity states that 'any rise of 5dB noise level will reduce the permitted noise exposure time to half'.

to somebody else. The intense noise as a serious health hazard is now well-recognised with increased human civilisation in modern times. Heavy industry, high-speed machinery, increased vehicular traffic, urbanization and so forth have created a multitude of noise sources which have accelerated noise-induced hearing loss problems among the exposed population.

India has adopted the international standard limit of 90 dBA during an 8-hour shift for workers. Limits for durations other than 8 hours are provided in Table 3.1.

Sound pressure level is the strength of the sound in Pascals measured in dB scale at a distance of 1m with reference to 20 μPa. Listed below are some examples of SPLs of common occurrence:

- Whisper – 30 dBA
- Normal conversation – 60 dBA
- Shout – 90 dBA
- Discomfort of the ear – 120 dBA
- Pain in the ear – 130 dBA

A constant hearing of sound at a level above 100 dB can cause headaches and permanent hearing damage. The safe limit of the level of sound for hearing is from 0 to 80 dB.

3.2.5 Noise Limits in India[2]

The Ministry of Environment and Forests (MOEF) of the Government of India, on the advice of the National Committee for Noise Pollution Control,

Table 3.2 Permissible Limits of Noise as per the Noise Pollution (Regulation and Control) Rules 2000, Ministry of Environment and Forest, Government of India

Zone/Area	**Day (6 am to 10 pm) Limits in dB(A) Leq**	**Night (10pm to 6am) Limits in dB(A) Leq**
Industrial	75	70
Commercial	65	55
Residential	55	45
Silence	50	40

Note: 1. Day time shall mean from 6.00 a.m. to 10.00 p.m.; 2. Night time shall mean from 10.00 p.m. to 6.00 a.m.; 3. Leq = Energy mean of noise level over a specified period.

has been issuing Gazette notifications prescribing noise limits as well as rules for regulation and control of noise pollution in urban environment. These are summarised below:

The noise pollution (regulation and control) rules, 2000:[2]

These rules make use of limits as indicated in Table 3.2 for the ambient noise that is allowable.

i. A peripheral noise speaker or a public address system shall not be used except after obtaining written permission from the authority.
ii. A loudspeaker or a public address system or any sound-producing instrument or a musical instrument or a sound amplifier shall not be used at nighttime except in closed premises for communication within, like auditoria, conference rooms, community halls, banquet halls or during a public emergency.
iii. The noise level at the boundary of the public place, where a loudspeaker or public address system or any other noise source is being used, shall not exceed 10 dB(A) above the ambient noise standards for the area (see Table 3.2) or 75 dB(A). whichever is lower.
iv. The peripheral noise level of a privately owned sound system or a sound-producing instrument shall not, at the boundary of the private place, exceed by more than 5 dB(A) the ambient noise standards specified for the area in which it is used.
v. No horn shall be used in silence zones or during nighttime in residential areas except during a public emergency.
vi. Sound-emitting firecrackers shall not be burst in silence zone or during nighttime.
vii. Sound-emitting construction equipments shall not be used or operated during nighttime in residential areas and silence zones.

3.2.6 Perception of Sound Waves

The terms ‘intensity’ and ‘pressure’ denote objective measurements that relate to our subjective experience of the loudness of sound. Intensity, as it relates to sound, is defined as the power carried by a sound wave per unit of area, expressed in watts per square meter (W/m^2). Power is defined as energy per unit time, measured in watts (W). Power can also be defined as the rate at which work is performed or energy converted. Pressure is defined as force divided by the area over which it is distributed, measured in newtons per square meter (N/m^2) or, more simply, Pascals (Pa).

In relation to sound, we specifically look at air pressure amplitude which is measured in Pascals. Air pressure amplitude caused by sound waves is measured as a displacement above or below equilibrium atmospheric pressure.

The greater the intensity or pressure created by the sound waves, the louder is the sound. However, loudness is only a subjective experience – that is, it is assessed by an individual saying how loud the sound seems to him or her. The relationship between loudness and air pressure is not linear. One cannot assume that if the pressure is doubled, the sound seems twice as loud. In fact, it takes about 10 times the change in the air pressure for a sound to seem twice as loud. It is like saying that 10 mixers in the kitchen can produce a sound level twice as loud as one mixer unit.

Another subjective perception of sound is pitch. The pitch of a note is how ‘high’ or ‘low’ the note seems to an individual. The related objective measure of pitch is frequency. In general, the higher the frequency, the higher is the perceived pitch. But once again, the relationship between pitch and frequency is not linear. Also, our sensitivity to frequency differences varies across the spectrum, and our perception of the pitch depends partly on how loud the sound is. A high pitch can seem to get higher when its loudness is increased, whereas a low pitch can seem to get lower. Context matters as well in that the pitch of a frequency may seem to shift when it is combined with other frequencies in a complex tone.

Each sound has a specific tonal quality which is called timbre. It makes the sound produced by any instrument different from others, even if they play the same note. For example, a guitar and piano can play the same note simultaneously but still sound different because of their unique tones. The uniqueness comes because of several harmonics and overtones which are produced simultaneously along with the fundamental.

The sound perceived by the listener is directly related to the physical characteristics of the sound wave. For a given frequency, the greater the pressure amplitude of a sound wave, the greater is the perceived loudness.

One of the important factors is that the ear is not equally sensitive to all frequencies in the audible range. A sound at one frequency may seem louder than one of equal pressure amplitude at a different frequency.

3.3 Physics of Speech

Speech is a special ability possessed by human beings and acquired along the path of evolution. Cognition-enabled speech with multi-linguistic abilities helps in communication. Speech is the product of sound produced by involving the central brain, peripheral nervous system and the aerodigestive tract.

3.3.1 Speech Centres in the Brain

When people talk to each other, a great deal of activity happens in their brains, which are storehouses of all information about the language they are using for speech communication.

The speech centres of the brain carry information about the phonology of the language, intonation, rhythmic pattern, the grammatical and syntactic procedures which govern speech and the very extensive vocabulary to string into a communicative language which is carried out by neuromuscular instructions to different muscles involved to produce the desired speech.

3.3.2 How Intelligible Sound Is Generated in the Human Body

This is generally explained using the well-accepted source-filter model in which the voice is considered to involve two processes: the *source* of sound produced from air ejected by lungs and converting this into intelligible speech by vocal tract *filter*. To explain further, the larynx produces a sound whose spectrum contains many different frequencies. Then, using the articulators, the tongue, teeth, lips, velum and so forth (Figure 3.1), the raw sound spectrum gets modulated to include language, phonology and tonal quality to make it a sensible voice information to the listener to understand.

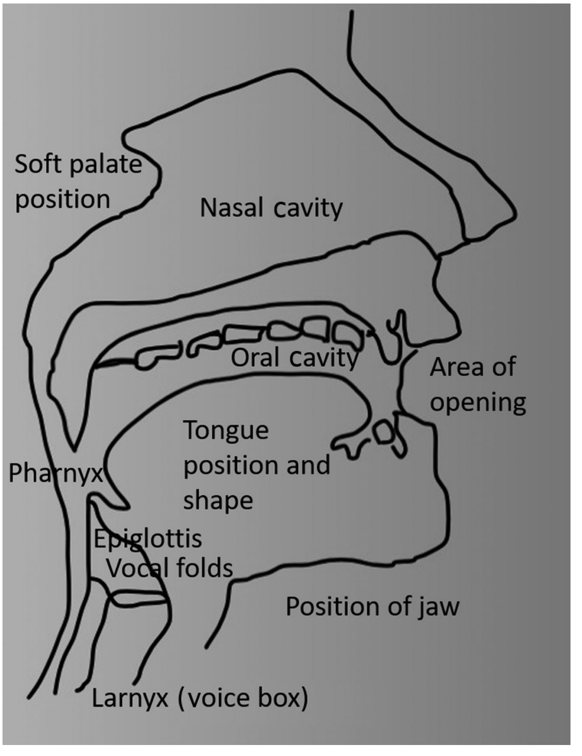

Figure 3.1 Sagittal image showing larynx, pharynx and articulators of speech.

3.4 The Source[3]

The air expelled from the lungs carry sufficient sound energy. At the larynx, this airflow passes between the vocal folds and through the vocal tract with constrictions. A set of perfect vocal folds has the following characteristics:

- Being open about half the time and closed about half the time in a vibratory cycle
- Letting air out in between the vocal folds in measured puffs
- No air leakage during the closed phase
- Vibrating symmetrically.

Loudness and pitch of the voice are dependent on lung capacity as well as on the anatomy of vocal folds such as thickness, mucosal wave pattern, tension, mass of vocal folds and its movement during the phonation.

In a voiced speech, the vocal folds vibrate while allowing puffs of air to pass, producing modulated sound. The modulated sounds produced in voiced speech usually contain a set of different frequencies called harmonics. Harmonics are basically multiples of fundamental frequency which is the frequency of vibration of vocal folds.

In whispering sound, the folds do not vibrate but are held close together with a small gap. When air moves through a small gap, the airflow becomes a turbulent flow with air vortices. Otherwise, the flow would have been a laminar flow. This is explained by the Reynolds number. A turbulent flow produces characteristic sound comprising a mixture of very many frequencies. The sound consisting of many frequencies is called broadband sound which is characteristic of whispering.

This analysis tells us that speech sounds are of two classes: *voiced sounds*, produced by the vibration of the vocal folds, and *unvoiced sounds* which are produced by other effects, such as whispering. Unvoiced sounds are also present in normal speech. This being an introductory chapter on this complex subject, the authors do not want to go into more details. Interested readers can refer to advanced works on this subject.

3.5 Glossary of Frequently Used Terms in Audiology and Acoustics

Frequency – It is the number of cycles per second. The unit of frequency is Hertz (Hz), named after the German scientist Heinrich Rudolf Hertz. A sound of 1000 Hz means 1000 cycles per second.

Decibel (dB) – It is 1/10th of a Bel and is named after Alexander Graham Bell, the inventor of the telephone. It is not an absolute figure but represents a logarithmic ratio between two sounds, namely the sound being described and the reference sound.

Pure Tone – A single frequency sound is called pure tone.

Complex Sound – Sound with more than one frequency is called complex sound.

Pitch – It is a subjective sensation produced by the frequency of sound. The higher the frequency, the greater is the pitch.

Overtones – A complex sound has a fundamental frequency, that is the lowest frequency at which a source vibrates. All the frequencies above that tone are called the overtones. It determines the quality or timbre of the sound.

Voice – Voice, sometimes called ‘vocalization’, usually refers to sounds that are produced at the laryngeal vocal folds, mostly through the air from the lungs. In humans, vocalizations comprise the fundamental components of speech, but not all vocal sounds are part of the speech spectrum. Indeed, we utter many involuntary sounds from cough to an infant babble that are generated at the vocal folds but are not morphed into articulated sounds of speech.

Phonation – Is the term that describes the production of the voice via vocal fold modifications. The essence of voice depends on vocal fold anatomy, physiology and neuromuscular control.

Speech – It is the verbal vocal communication.

Language – It is the global expression of human communication – spoken, written or gestural, consisting of words in a structured, ordered and conventional manner.

Most definitions have been internationally standardised and are listed in standards publications such as IEC 60050-801 (1994).

3.6 Conclusion

- Sound energy is a form of mechanical energy produced by a vibrating object which creates a disturbance in the particles of a medium in which it travels.
- Sound energy travels through a medium in the form of longitudinal waves consisting of compression and rarefactions.
- Human ears are sensitive to the 16 Hz to 20,000 Hz frequency range, which is known as audible frequency.
- Human speech frequency ranges between 125 Hz and 8 kHz.
- Sound frequencies below 20 Hz are known as infrasonic sound. Frequency above 20,000 Hz is known as ultrasonic sound. Both are inaudible to human ears.
- Sound is described objectively using measurable quantities such as sound pressure level (SPL), frequency and intensity.
- Subjective description of sound is non-measurable and it depends on human perception. It is described in terms of loudness, pitch and timbre.
- Speech is the product of sound initiated in the brain, coordinated by the peripheral nervous system and produced by the aerodigestive tract. It is further modified in the oral cavity by articulators to convert into sensible voice information which can be understood by the listener.

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4

MUSIC

Kalyan Sivasailam and Deepak Alexander

4.1 Introduction

The benefits of music on our mental health are much better understood today than they were even a decade ago. For centuries, music has been touted as beneficial in stressful situations, but it is only recently that the study of music as a therapeutic has taken a structured and scientific approach. Thanks to the latest imaging and diagnostic techniques, how sound, and in particular music, impacts stressors has become clearer.

In the 21st century, and even more so over the last few decades, the relevance of the effect of music on our well-being has risen greatly, and it has never been more important than it is now. This can be attributed to the fact that access to music today is as ubiquitous as access to the internet. For example, the channel with the largest subscriber base on YouTube, the world's largest video streaming platform with over a billion daily users, is T-Series, an Indian music label that boasts the world's biggest collection of Indian film songs.[1]

The internet has played a key role in introducing audiences to a global pool of music. A simple Google search with keywords such as 'calming music' or 'soothing music' will give a plethora of options including playlists of Buddhist chants, Chinese flutes and even the sounds of rainfall and the rustle of leaves in the wind. Leading music streaming providers now have dedicated playlists that are regularly curated by experts and focus on putting the listener in a better frame of mind. Even mental health applications such as Calm and Headspace use soothing background sounds and music during their online sessions. The relevance of music as a digital therapeutic can be directly tied back to the growth in audio recording and distribution industry. To understand the scope of music as a digital therapeutic in the age of music streaming and on-demand availability, it will be helpful to first understand the history of music recording and distribution.

This chapter aims to give the reader an insight into the ubiquity of music and its effects on finding new use cases for music – namely, as a digital therapeutic. Music has been known as a mood-changer for centuries, but the scientific method is now helping us channel music's power to help tackle some of our biggest challenges.

Learning Objectives

- The history and science of music recording
- The role of internet in transforming music distribution
- The introduction of music as a part of the experience by new-age internet businesses
- How music has become a digital therapeutic
- How music as a digital therapeutic is helping to solve difficult problems

4.2 Sound and Music Recording

4.2.1 The Early Days of Sound Recording

Prior to music recording, live performances were the only way for audiences to experience music. Such performances were generally community events, with the music performance being either the main attraction or a part of the ambience such as during a wedding. In the 17th and 18th centuries, live bands became increasingly common as background music became a standard feature of social gatherings. The invention of sound recording has been attributed to Thomas Alva Edison, who invented the phonograph in 1877.[2] However, the first audio recording device was actually invented by the lesser-known French scientist Édouard-Léon Scott de Martinville.[3] Scott's device was patented in 1857, a good two decades before Bell's telephone and Edison's phonograph. Scott's idea behind the phonautograph was to build a device that would set sound to paper, just like the camera set an image to paper. A phonautograph is almost like a seismograph for general audio. Scott built his new device to mimic the workings of the human ear – a vibrating membrane was connected to a stylus, which would trace the movement of the membrane on a piece of paper. With an incoming sound, the membrane would vibrate and the stylus would capture this wave on a piece of paper. With training, a person could theoretically 'read' the sound wave and make sense of it. This was, however, much easier said than done. Over many iterations, Scott improved the accuracy of his traces. Incredibly, it did not occur to him to play this sound back into the air! Enter Edison and his phonograph in 1877. It would be fair to say that Edison was the first to both record and reproduce sound. He applied for a patent for his invention in December 1877,[4] and in typical Edison style, his invention caused a significant buzz in the scientific world. While the theory of how to record and reproduce sound was sound (pun intended), the phonograph needed significant improvements to become mainstream and commercially viable.

4.2.2 Technological Advancements in Music Recording

With Edison focusing his attention on other projects, the Volta Laboratory in Washington DC, headed by another prolific inventor Alexander Graham Bell, pushed the boundaries of this new technology and invented what would eventually become the dictaphone and the gramophone. Edison, who was focusing his energies and efforts in building New York City's light and power system, had sold his patent to a company owned by Gardiner Green Hubbard. Hubbard was no stranger to Bell – Bell was his son-in-law, and Hubbard succeeded in enticing the inventor of the telephone to take up the challenge of improving Edison's invention which was not ready for mass adoption. In the next 10 years, Bell and his associates at the Volta Laboratory successfully solved many of the technical challenges that halted the adoption of the Edison phonogram. The inventor group also went on to file patents and incorporate companies to license their technology, and in essence created the market for sound recording and sound playback instruments. The 'acoustic era' of sound recording, which lasted for close to 50 years from the invention of the phonograph, was characterised by the mechanical nature of recording and playback of sound. A paradigm shift occurred in 1925, when Western Electric introduced electronic microphones, amplifiers and signal recorders, and this marked the end of the acoustic era and the beginning of the 'electronic era' of sound recording. The electronic era of sound recording is significant because it allowed for the post-processing and editing of sounds for the first time. Sound amplitude could now be adjusted appropriately. This meant that noise could also be reduced in recordings – a major problem that the original dictaphones could not solve. With the frontier of accurate voice recording being passed, the electronic era of recording opened up the space of music recording and created a market for music distribution.

Like almost all early technologies, sound and music recording had its initial problems – there were almost no standards, discs were fragile and reproduction quality degraded precipitously. Recordings were also grainy and unclear, which significantly reduced adoption. Finally, even with mass manufacturing, the cost of a buying a record player and discs was not small, which kept this marvelous innovation available to only the more affluent sections of society.

This changed with the emergence of the magnetic tape, which ushered in the 'magnetic era' of sound recording. The electronic era had already solved for sound quality, and the magnetic era now solved for the robustness and the cost of the distributed material. Magnetic tapes were significantly cheaper to procure and use as storage, and also lasted longer than their predecessors. With great sound quality and an accessible storage media, the music recording business exploded. For the first time in history, recorded music royalties outstripped earnings from live shows. Improving quality and decreasing storage and distribution cost is a time-tested method to build any market and industry. In this case, technology created a recording and distribution industry, which led to the creation or forced the evolution of many other industries. For example, man's ability to record and distribute sound and make it accessible to millions led to a complete overhaul of our understanding of copyright and intellectual property.

4.2.3 The Internet Changes the Music Industry

If there is one rule of business, it is that no industry, however efficient, is safe from disruption through technology. In 1989, Tim Burners-Lee developed a file sharing protocol and standard that eventually became the World Wide Web. And with the creation of the audio standard mp3, the magnetic era was also officially over. Like pretty much everything else in our lives today, audio and music became a digital good. For over two decades, however, they were consumed physically – usually in the form of CDs. As core internet infrastructure became better and as people got faster access to the web, the digital aspect of music started taking over. Mp3 allowed audio files to be downloaded freely off any server, and music distribution, once again, played a significant part in redefining our understanding of intellectual property. While the famous (or rather infamous) *Napster v Metallica*[5] case did put a brake on digital music distribution, on-demand access to music was an idea whose time had come.

A decade ago, one had to buy physical copies of an album, buy it off iTunes or risk one's system by illegally downloading music (Bollywood music fans would be all too familiar with sites such as songs.pk). Today, for an affordable sum, or in exchange for listening to some creative audio advertisements, people have access to the whole world's music literally at the tips of their fingers. The music streaming industry has seen double digit year-on-year growth for the past four years, and services such as Spotify, Apple Music, YouTube music and Gaana are household names. Hidden in these numbers, however, is an interesting observation. The fastest growing sub-segment in terms of revenue in music streaming is not direct-to-consumer, but in-service streaming. In-service streaming is when a piece of music is streamed as a part of a larger experience being delivered to an end consumer. For example, fitness service Peloton streams music as a part of an online workout. The popular meditation and mental wellness app Calm streams music to their users as a part of their guided mindfulness and therapy sessions. For these services, and for their millions of users around the world, music is an integral part of an experience that helps them feel better. While we never needed empirical proof of music's ability to put us in the right frame of mind, these examples give us proof in a metric that is possibly even more valid than the results of a double-blind study: money.

4.3 Music as a Digital Therapeutic

Digital therapeutics is one of the hottest fields in medicine today. Mobile apps and video games, hitherto thought of as play activities, have recently gained traction in helping people cope and recover from severe ailments.[6] With software and new technologies touching every part of our lives, and with sensors embedded into pretty much everything we touch, even delivering care is going digital. The use of VR to treat patients suffering from PTSD is a perfect example of a new-age digital therapeutic. While digital therapeutics is an umbrella term for any software intervention in the care process, we will particularly focus on the use of music as a digital therapeutic to show its true potential.

4.3.1 Scientific Studies around Music as a Digital Therapeutic

By using functional neuro-imaging (f-MRI), it has been shown that music affects the brain by triggering signal activities in parts of the brain.[7] This clearly supports the case for music being used as a therapeutic and not just an auxiliary in the course of treatment. Streaming technology has allowed us to insert our choice of music into specific contexts, and this has enabled us to dynamically measure the impact of different types of music in different situations. One of the most studied situations in this regard is the use of music in treating depression. Estimates say that over 300 million suffer from clinical depression, and music therapy could potentially offer an alternative to strong chemical interventions. Studies [8,9,10] have already proven music's role in our mental wellness to be statistically significant, but how far are we from experiencing the benefits ourselves? Imagine a situation where, depending on your mood, your music streaming provider picks out a playlist that has been clinically validated using functional imaging studies and proven to improve your state of mind and wellness. Sounds incredible, right? It is. And it is not far from reality – music streaming giant Spotify is already investing heavily into music and sound therapy that will automatically pick a curated playlist based on your mood.

A recent study published in the *Frontiers in Psychology*[11] underscored the power of music to positively affect our well-being by citing a multi-country study done during the first wave of the COVID-19 pandemic. The study focused on the effect of music on possibly the most stressed demographic in the world at the time – healthcare workers. The findings showed that music promoted emotional well-being for hospital clinical staff in Italy by reducing their feelings of fear, sadness and worry. In Australia, a positive association was found between music listening and life satisfaction. Other research done during the pandemic, combining stats from both music listening and music playing, showed that music was considered the most helpful coping activity in the United States, Italy and Spain.[12]

The effect of our better understanding of music as a drug and its near-universal availability means that it is now the drug of choice for many. Mental health app sessions have grown 66% year on year and the expected valuation of global mental health apps went up 27% since 2019. The use of music for coping with anxiety and depression, both on and off these platforms, has also grown proportionately. In addition to being the drug of choice for many, music is quickly becoming a key differentiator, with the ability to increase both engagement and efficacy for digital wellness and mental health platforms. As mentioned earlier, leading meditation app Calm is quickly becoming an established music label, leveraging direct artist relationships and competing head-to-head with major record companies in the music and wellness arena.

4.3.2 Use Cases of Music as a Digital Therapeutic

An area of cutting-edge research where music therapy is showing huge promise is in Stroke Rehabilitation. Sometimes you just can't help but move to the beat of a song, right? It turns out that Brian Harris, a certified music therapist based in Boston, is using exactly this phenomenon to help patients recover their limb movements after a stroke. Harris specialises in Neurological Music Therapy (NMT). NMT involves using music and feedback to train the brain during physical therapy. According to Harris, many of his patients have shown significantly improved mobility post NMT. NMT works because of an underlying phenomenon called Audatory-Motor Entrainment. In essence, the subconscious mind has a mapping between the audatory system and the motor system. When we hear music, the two systems work in sync, just like two wheels connected by an axle, and we start walking to the rhythm of the music. A team at Stony Brook University found in 2019 that listening to music, combined with feedback based on their gait, helped people with Parkinson's disease walk better. Scientists in the field are excited because they believe we are just scratching the surface. A start-up called MedRhythms is already making waves, having raised USD 25 million; they have also tied up with Universal Records, the world's largest music studio, and are gearing up to have their music-based therapeutics submitted to the FDA for approval. If all goes according to their plan, they could be the first ever prescription music!

4.3.3 Potential Downsides

While music's potential for positive impact in our lives is clear, it would also be prudent to mention the potential downsides. There is a body of research which shows that certain types of sounds and music can lead people to be more aggressive and encourage crime. A study in the UK explored 'drill music; – music that has threatening lyrics – and its correlation to attention-seeking crime. In India, the late Sidhu Moose Wala, a popular gun-toting hip-hop and pop artist, often linked his power and influence to his armaments. His music was recently banned for enticing youth to pick up arms, and sadly he became a victim of gun violence himself. While these incidents are quite common, there is a case to be made that such music, be it Drill Music or Moose Wala's songs on the supremacy of gun-wielding Punjabis, is the consequence of a rise in crime, poverty, deprivation, inequality and lack of access to resources, and not the cause. It would be wise to listen to Eminem, the world's best-selling hip-hop artist, when in his hit song 'Sing for the Moment' he asks rhetorically, 'They say music can alter moods and talk to you / But can it blow a gun up and cock it too?'

Music as a drug will soon be a scientific reality. While it would need that stamp of approval to fit into our definition of a scientific object, music has been a getaway drug for billions throughout centuries. One could go as far as to say that music is one of the essential ingredients of life. For if there was none in my life, I'm not sure it'd be worth going on.

So I say
Thank you for the music, the songs I'm singing
Thanks for all the joy they're bringing
Who can live without it? I ask in all honesty
What would life be?
Without a song or a dance, what are we?
So I say thank you for the music
For giving it to me[1]

4.4 Conclusion

The tremendous ubiquity of music can be attributed to the incredible advances in technology for recording, storage and distribution. It is this same characteristic of music today, its ubiquity, that allows us to find new use cases for music. While music has been used as a mood-changer for centuries, it is only recently that we have been able to scientifically understand its impact on our minds and our moods. Music as a digital therapeutic has shown many early successes and has the potential to become a part of standard medical prescriptions.

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PHYSIOLOGY OF HEARING AND SPEECH

C. John Panicker

5.1 Introduction

Hearing and speech are perhaps one of the most valuable gifts of nature to mankind. Though the perception of sound is important to every animal, its importance for man is unique in the sense that language and communication to which the whole development of the human race is indebted solely depends on the capacity to hear sounds and communication by speech.[1] Though in early life the perceptive frequency range of man is 20 Hz (cycles per second) to 20,000 Hz, as age advances this range narrows down to a great extent. By the age of 50, the vast majority do not appreciate sounds above 8000 Hz. This decline is marked and happens much early in those persons with a history of chronic noise exposure and co-existing lifestyle diseases such as diabetes mellitus.[2]

The intensity range of human hearing is so huge that it is expressed in terms of a logarithmic ratio. If we consider the minimum threshold of hearing of a healthy person as 1 (in logarithmic value it is zero) the maximum capacity to hear without pain that one can perceive is 14 raised to 10 (140 dB or 1000 trillion times of minimum threshold of 0 dB).

Learning Objectives

- Understanding anatomy of the ear (external, middle and inner)
- Nerve connections of the inner ear to the brain
- How the external and middle ear compensate for the loss of sound energy when the sound travels from the air medium to the fluid medium of the inner ear
- Mechanism of converting sound energy into electrical impulses by the hair cells inside the inner ear (cochlea)
- Final understanding of speech by the cerebral cortex

- Initiation of speech by the brain cortex
- Sound production (phonation) by the larynx
- Modulation of the sound from the larynx by throat and mouth (resonance and articulation) to produce legible speech.

5.2 Mechanism of Hearing – How We Hear?

When sound waves, which are indeed pressure waves, reach the tympanic membrane (TM), they cause vibrations of TM's moving part or what is commonly called the "ear drum". These vibrations from the TM are transmitted to the oval window (OW) which is situated in the medial (inside) wall of the air-filled middle ear (ME) where the smallest bone in the body, stapes, is attached. Vibrations from the TM are transmitted through the three small bones, namely malleus, incus, and stapes. (Figure 5.1)[3]

The stapes bone, one of the ossicles connecting the TM to the inner ear, works like a piston that moves in and out of the inner ear (cochlea). The cochlea is filled with a fluid namely perilymph. The amplitude of these vibrations depends on the loudness of the sound, and the frequency depends on the pitch of the sound.

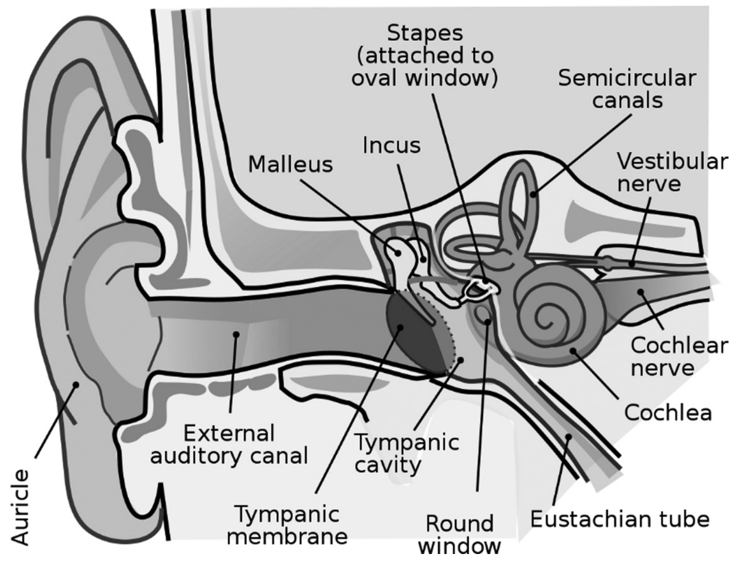

Figure 5.1 Schematic of the auditory system with its primary components (adapted from Chittka, L. & Brockmann, A. (2005). Perception space, the final frontier. PLoS Biology, 3: 564–68).

Inside the cochlea, lying in the perilymph is a tubular structure, the membranous cochlea, which is filled with another special fluid, the endolymph. This endolymph is the only extracellular fluid (fluid outside the cells) that has more potassium ions than sodium, whereas all other extracellular fluids have the reverse.

The specialized organ which converts sound energy into electrical impulses (*action potential*) is inside this membranous cochlea of the inner ear and is known as the "organ of corti", which has specialized sensory cells called "hair cells" (HC). Hair cells have long hair-like structures called "kinocilium" (long) and "stereocilium" (short) (Figure 5.2)[4]

Normally, when sound vibrations travel from air to fluids, most of the energy reflects back and only 1/30th of the energy travels into the fluid media. This resistance to sound vibrations travelling to a fluid media is called "Impedance". The same resistance happens to sound waves entering the inner ear fluid. To overcome this disadvantage and to pass maximum sound energy into the inner ear fluid, we have the special structure of the middle ear which includes the TM and its ossicular chain (OC), which helps in compensating and preventing this loss of energy to a great extent. This mechanism of overcoming the resistance is otherwise called "impedance matching" (compensating the impedance). [6]

5.3 Middle Ear Mechanics and Impedance Matching

It is to be noted that the total vibrating area of TM is 54^2 mm which is 17 times more than the surface area of the OW (3 mm), through which the sound vibrations enter the inner ear fluids. Thus, the energy or force reaching 54^2 mm of TM is focused on 3^2 mm of OW, or, in other words, the pressure reaching OW per sq mm is 17 times more when compared to that reaching TM. Also, the ossicles have a lever effect of 1.3 times because of the higher length of the malleus handle (1.3 times that of the incus), which is connected to the TM, compared to the length of the incus which is connected to the stapes. Though this lever effect reduces the amplitude of the movement of the stapes, the force increases by 1.3 times. The product of TM, OW ratio (17) and lever ratio (1.3) comes to 22, which is the total force amplification at the OW. Even though this amplification does not fully compensate for the loss of energy as the sound vibration travels from air to the inner ear fluid, the perilymph, which as mentioned earlier is 30 times, this middle ear mechanism helps to compensate to a great degree of the loss (impedance).[6]

If there is any disruption in the middle ear, ossicular chain or large perforation in the TM, this middle ear mechanism does not work and the force advantage is lost by only a small part of the sound energy reaching the

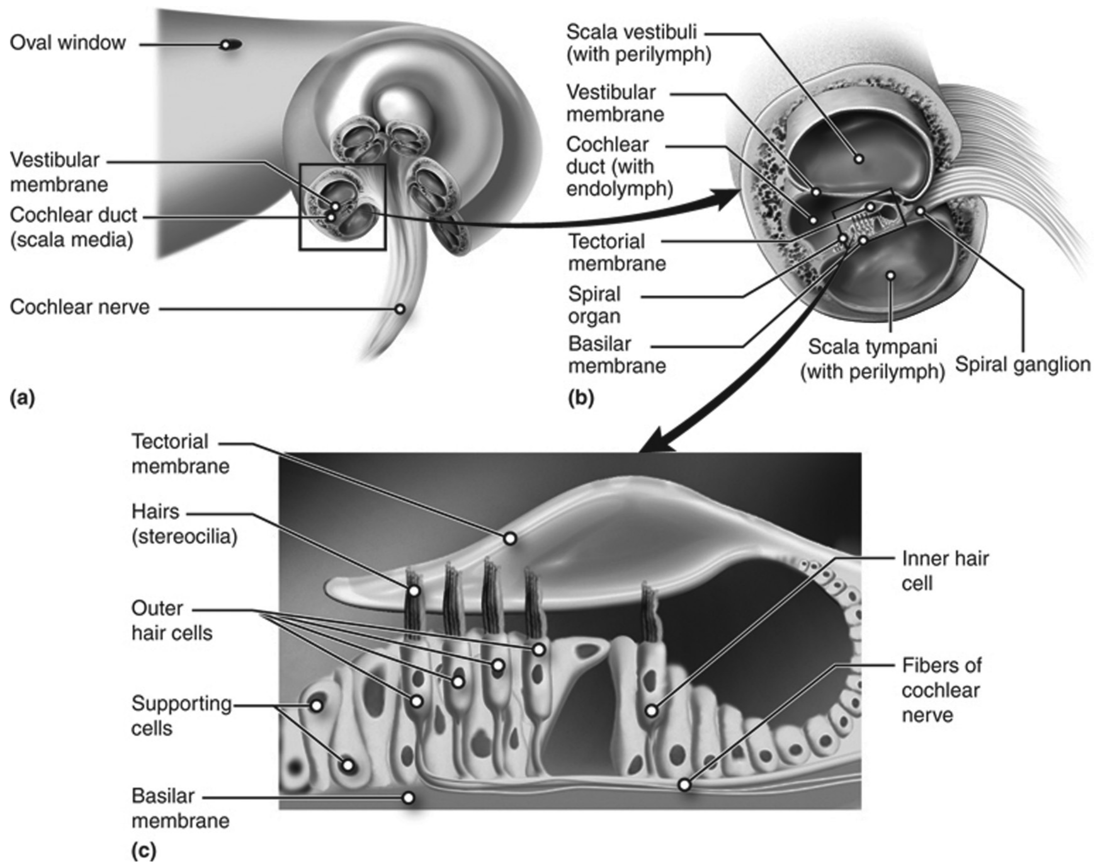

Figure 5.2 (a, b, c): Structure of hair cells.

inner ear. Thus, the person develops hearing loss and it is called “conductive deafness” because the problem is in the conduction of sound waves to the inner ear.

5.4 How the Cochlea Works – Travelling Wave Theory

The cochlea is a coiled bony structure having 2 and 3/4 turns and situated medial to the ME. The part near the ME corresponds to the basal turn. The tip of the coil is directed to the front and the inside, towards the brain. At the centre of the cochlear coil, modiolus (at the brain facing side), emerges the cochlear nerve (CN), which carries impulses to the brain. When the sound pressure reaches the inner ear (cochlea), through the piston-like movement of the OW, it produces a positive pressure in the adjoining perilymph of the scala vestibule compartment, and this pressure is transmitted to the corresponding membranous cochlea, scala media (SM). The pressure inside the SM produces deflection of the basilar membrane (BM) downwards to the scala tympani (ST), which is the second compartment filled with perilymph. The scala tympani has a window towards the middle ear covered by a membranous structure, and this is called the “round window” (RW) (Figure 5.3).[5]

When the positive pressure due to the deflection of BM reaches the ST, the RW bulges into the ME from inside, thereby releasing the pressure wave.

There are sensory nerve cells on the BM called “hair cells” (HC). These hair cells are specialised nerve cells that can generate electrical impulses by the movement of the hairs, stereocilium (short) and kinocilium (long).[6]

The BM acts as a string attached to two ends of the cochlea. The deflection of the BM downwards at the base of the cochlea as a result of the sound pressure entering through the OW travels in a wave from one end of the cochlea to the other end. Depending on the frequency of sound, the location of maximum deflection of the BM varies. Thus, high-frequency sounds produce maximum deflection at the basal turn and low-frequency sounds produce deflection at the tip. Mid-frequencies have a maximum deflection at the middle part of the BM.

The deflection of BM induces a bending of the cilia of the hair cells, which are fixed over the BM; this movement induces an action potential (AP) inside the hair cells. This AP travels through the first-order auditory neurons which are situated in the modiolus (axis) of the cochlea.[3]

These first-order nerve cells in the modiolus are called “spiral ganglion” (SG). Impulses from the SG travel to the brain stem, cochlear nucleus (CN), of both sides. From there, it travels as a nerve bundle (lateral lemniscus) to the inferior colliculus of the mid-brain and to the medial geniculate body of the thalamus and from there to the auditory neurons in the temporal lobe

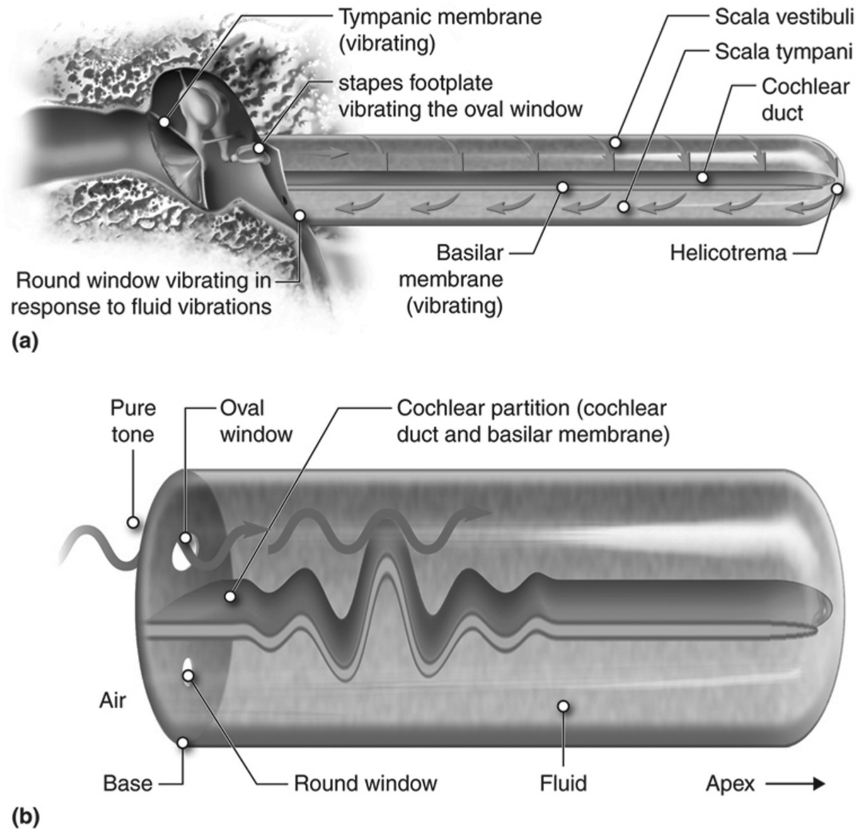

Figure 5.3 (a) Simplified Anatomy of the Cochlea: The cochlea can be modeled as a long tube running from the oval window, out to the helicotrema, and back. (b) Sound Wave Transmitted into the Cochlea: As sound is transmitted from air to the cochlea through the oval window, it creates a wave within the fluid of the cochlea (often called a standing wave). This wave creates displacement in the membranes of the cochlear duct, where sound is sensed.

of the opposite cerebrum, the auditory cortex. Part of the impulses reaches the same side auditory cortex also. It is the auditory cortex that perceives the sound and understands the meaning of what is heard.[6]

5.5 How Are Pitch and Loudness Differentiated?

As mentioned earlier, different frequencies of sound produce maximum deflections at different locations of the BM. The auditory cortex understands the pitch by noting the location of maximum deflection.

Similarly, depending on the severity of deflection, the loudness is perceived by the auditory cortex. Thus, identifying the location of maximum deflection helps in perceiving the tone or pitch of the sound, and the intensity of deflection helps in identifying the loudness. This explanation is otherwise called "travelling wave theory" and was first explained by Von Bekesy.

The basal turn hair cells perceive high-frequency sounds and apex cells perveive sound at lower frequencies. As the basal turn is situated nearest to the OW and all the sound pressure reaches here first, the damage due to excess sound (noise) is also at this location. So in noise-induced deafness, high-frequency hearing is lost early.[2]

5.6 Sensory Neural, Neural (Nerve Deafness) and Conductive Deafness

The function of the hair cell is to convert sound energy to electrical impulses, and any interference with this mechanism either due to congenital absence or degeneration of hair cells results in sensory neural deafness (SND). The deafness occurring in old age, otherwise called "presbycusis", also mostly affects the hair cells inside the cochlea and so results in SND. Apart from the genetic susceptibility, whatever noise one is exposed to in one's lifetime determines the age of occurrence and severity of presbycusis.

Damage to the spiral ganglion cells or its proximal neural connections to the brain results in nerve deafness (ND). Some of the causes of ND are infections like meningitis, degenerative diseases like multiple sclerosis, tumours like acoustic neuroma (AN) and even some of the types of presbycusis.

Generally, most of the conductive deafness which happens due to impaired transmission of sound waves to the cochlea can be treated very successfully, either by medical or surgical measures. Examples are wax in the external ear canal, secretory otitis (fluid inside the middle ear), suppurative otitis media (infection in the middle ear), otosclerosis (stiffening of the stapes ossicle) and so forth.[6]

Sensory neural deafness can be from birth or acquired (happening later in life). Common reasons for hair cell degeneration later in life are certain hereditary disorders, noise exposure either sudden or chronic, old age, drug toxicity, infections of cochlea either bacterial or viral, Meniere's syndrome, toxicity of certain drugs, lifestyle diseases like diabetes and so forth. Fortunately, most of the SNDs can be managed well either by hearing aids or cochlear implantation. Whether to go for hearing aids or cochlear implantation in such cases depends on the severity and the cause of deafness. The vast majority of congenital deafness is due to improper development of hair cells and thus responds well to cochlear implantation. Normal hearing aids work by just amplifying the sound intensity and providing a stronger stimulus to remaining hair cells.

Since in most of the cases some percentage of residual hair cells remain, most of the SNDs can be managed by providing a hearing aid. If the remaining hair cells are below a critical level, whatever stimulation we give will not be effective, and cochlear implantation is the treatment of choice.[3]

5.7 Physiology of Phonation and Speech

As we all know, speech is initiated in the larynx. This process of initiating voice is called "phonation". Even though the larynx is the voice producer, it needs further amplification, modulation and articulation for a legible speech.

The larynx is a tubular structure situated between the pharynx and the windpipe (trachea). The pharynx is the common pathway for respiration and food passage connecting the nose and oral cavity with the trachea and the oesophagus. It is through the trachea that air passes to the lungs during respiration.[7]

5.8 Structure of Larynx

The larynx is formed by seven cartilages held together by ligaments (connective tissue) and muscles. It is not only the voice producer but is also the part of the airway between the pharynx and the trachea. It also has a sphincter mechanism that protects the lungs from secretions and prevents food particles from the throat entering into the lungs. The cartilages of the larynx are thyroid (1), cricoid (1), epiglottis (1), arytenoids (2) cuneiform and corniculate (2).

The muscles of the larynx are either intrinsic or extrinsic. Intrinsic muscles connect the above cartilages, whereas extrinsic muscles connect the laryngeal cartilages with the adjacent structures such as the hyoid bone, sternum (chest bone) and so forth and help stabilize the larynx during swallowing and phonation. The larynx's inner surface (lumen) is lined by a mucus membrane and has two folds on each side, lying front to back. The upper fold is called the "ventricular band" (false cord) and the lower vocal cord (VC) is the true cord. It is the true vocal cords which are vibrating during phonation. The mucous lining of true vocal cords is different from the rest of the larynx. It is lined by multi-layered cells without cilia and is called "the squamous epithelium". This is so because the mucosa of the vocal folds is subjected to constant friction owing to the vibrations of the true vocal cords (Figure 5.4).[7]

5.9 Mechanism of Phonation

The initiation of voice in the larynx is called "phonation". This phonation in the larynx is a product of the expiratory airflow, modulated by the closure of

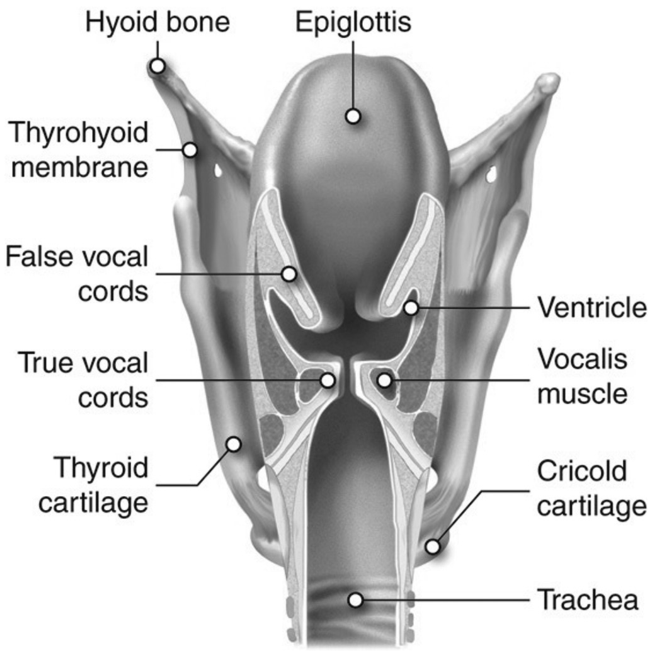

Figure 5.4 Transverse section of the larynx.

the glottis (the space between true vocal cords of both sides) and the vibrations of the true VC. The vibrations of the mucosa of the VC is an involuntary act owing to the pressure of the air flowing through the narrow glottis. To develop enough pressure below (sub-glottis), the VC has to come together with proper stiffness. It is the specialized mucosa of vocal folds which is vibrating and not the entire VC. The muscles of the VC which give stiffness to the vocal cord are called "vocalis". It is part of the thyro-arytenoid muscle which connects the thyroid cartilage with the arytenoid cartilage. The stiffness (tension) of the VC determines the pitch of the sound produced. Thus, if the VC is stiffer, the pitch of the sound also will be higher. Similarly, the length thickness of the VC also affects the pitch of the sounds. The longer and thicker the VC, lower is the pitch. That is why male voices have lower pitch compared to female voices. The force of expiratory air decides the loudness.

Thus, for the vocal cords to vibrate, two important requirements are needed:

1. The vocal cords have to come together at the midline (adduction) with a certain level of stiffness or tension.

2. The expiratory air has to pass through the space between the vocal folds with force. For this, the VC are to be held tight by the action of muscles, mainly the lateral thyroarytenoid including the vocalis part and the cricothyroid muscles. The loudness of the sound depends mainly on the force of the expiratory air passing out from the lungs. Depending upon the mass, length and tightness of the vocal folds, the pitch of the sound varies.[8]

5.10 Amplification, Articulation and Modulation of Voice

The sound thus produced by phonation is not only weak but also monotonous. It is amplified to a great extent by the resonance (synchronized vibrations) of the pharynx, nose and oral cavity including the cheek and teeth. For legible speech, articulation and modulation of the laryngeal sounds are essential. The character of the voice of a particular person depends on these factors also. As mentioned earlier, the pharyngeal muscles, the tongue, teeth, lips, soft palate and nasal structures all contribute to that person's articulation and final character of the voice.[8]

5.11 Central Control of Speech

Speech production is a highly complex process in which the cortical, subcortical brain, cerebellum and their interconnections play a very vital role. The real initiation of speech starts in the prefrontal area of the brain which receives inputs from the auditory cortex (hearing area) and the limbic system related to emotions. From the pre-frontal cortex, impulses pass to the Broca's area of the cerebrum, which by coordinating with the cerebellum instructs the motor cortex and the respiratory centre in the brain stem, thereby instructing the required movements of the muscles of the larynx, chest, pharynx and tongue and mouth.

5.12 Voice Variations Specific for a Person

Our voice is a mix of many frequencies. Each person has a characteristic voice and speech specific to him. The voice of a particular person has a specific predominant frequency called "fundamental frequency". Generally, for males this fundamental frequency lies between 80 Hz (cycles/sec) and 160 Hz. For females, it is almost double, that is between 160 and 260 Hz. Most of the time, as mentioned earlier, the voice and speech of a person can be easily identified by another familiar person. The character of the voice of a particular person depends on the fundamental frequency and the overtones produced by the larynx, its modulations and resonance by the pharynx and oral cavity. Not only the anatomical differences but also the tone, the stiffness and the contractions of the laryngeal and related muscles play their part in determining that person's speech characteristics.

5.13 Summary

The acumen of speech and hearing are very much interrelated and is the most important factor for every intellectual activity by a person. This chapter explains the complex anatomy and the mechanism of the working of the auditory system, which includes the ear (external, middle and inner ear) and the auditory cortex in the brain with its interconnections. Voice production is a very complex process first initiated in the brain with phonation in the larynx, modified by resonance and articulation by the throat, oral cavity, tongue, cheek and nasal cavity.

- The perception of the different frequencies and the loudness is by the location of maximum deflection of BM. This phenomenon was well explained by the travelling wave theory of Von-Bekesy.
- Depending upon the structures affected, hearing loss (HL) can be conductive, sensorineural or neural.
- Most of the deafness is preventable, especially middle ear infections, noise-induced deafness and so forth. Even old-age deafness (presbycusis) is preventable by avoiding exposure to loud noise.
- Both conductive and sensorineural deafness can be satisfactorily managed either by medical or surgical methods.
- Some cases of SND or neural deafness require hearing aids.
- The pitch of the voice depends upon the length and thickness of the VC.
- The loudness of the voice is decided by the air pressure developed in the subglottic area, just below the VC. This also depends upon the respiratory capacity of the individual.
- If we misuse or overuse the larynx by continuous speech or by irritants such as smoking or alcohol, the VC can fail early producing inflammation, nodules or even atrophy, resulting in temporary or permanent voice changes. If the VC is subjected to continuous irritations, it can even lead to cancer changes in the larynx.[9]

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6

MEASURING SOUND

*Prasanta Kumar Ghosh**

6.1 Introduction

Sound is a form of energy, just like heat, electricity or light. For both animals and humans, the sense of hearing helps to experience the world around them through sound. Some sounds are pleasurable, and some are annoying. All of us are subjected to different types of sound all the time. Sound waves are created by the vibration (to and fro motion) of objects. Sound waves travel through a medium (e.g., air, water). Among the many types of sounds around us, the ringing of a bell is an example of sound caused by vibration. One can experience the vibration by putting a finger on the bell after striking it. Some sounds are audible with visible vibrations causing them, while some aren't. If a rubber band is pulled, stretched and released, it moves to and fro about its central axis. This causes a sound that can be heard and seen. Sounds below 20 Hz and above 20 kHz are not audible to humans.

Learning Objectives

While all of us hear and experience sounds, many of us are often not aware how sound is measured and how the technique of capturing sound changes depending on the origin and nature of the sound. In this chapter the reader will learn the following.

- The different types of sound present in the universe
- Measurement of sound
- History of the microphone
- Microphone and its classification
- Unit of measurement

6.2 Different Types of Sound

There are different sounds present in the universe, a few examples of which are shown in Figure 6.1. These sounds come from different sources, have

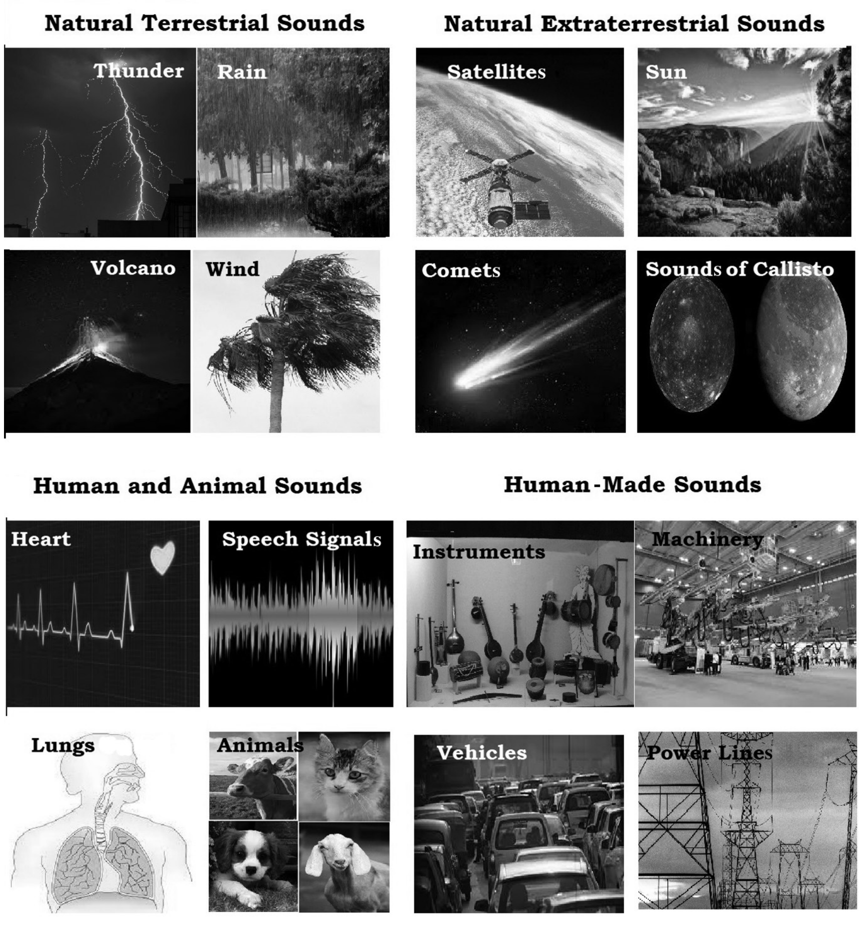

Figure 6.1 Various examples of sound sources present in the universe.

different intensities and demonstrate different characteristics in time and frequency. They can be categorised into four types. (1) Natural terrestrial sounds: The sound of thunder, rain, and wind are natural sounds with frequencies ranging from 5 Hz to 250 Hz. Volcanic sounds are infrasonic, that is, below 20 Hz. (2) Natural extraterrestrial sound: These sounds emanate from satellites, comets, sun, planets and stars with frequencies ranging from 40 MHz to 40 GHz. (3) Human and animal sounds: These include human speech and sounds from different human organs such as the heart, lungs and intestine. Animal sounds refer to the sounds of different animals, both domestic as well as wild. The frequencies of these sounds range from 20 Hz to 20 kHz. (4) Human-made sounds: These include noise and sounds made by humans involved in various activities. Examples of such sounds include the sound of traffic, power transmission lines, and musical instruments. Most of these sounds have frequencies in the audible range.

6.3 Measurement of Sound

This section explains the history of the microphone based on the patents at each stage. Almost all microphones are used to record speech signals, internal sounds of humans, noises, sounds of birds and animals, and so on.

6.3.1 History of the Microphone

Figure 6.2 illustrates the invention of various microphones with their years of invention. The invention of the very first microphone started in the early 1800s. The French physician and physicist Felix Savart created the sound level meter in 1830 which measured the noise level in decibels.[1] In the late 1800s many scientists such as Alexander Graham Bell, Elisha Gray and Ettore Majorana worked parallelly on the microphone. But the first microphone was invented by Emile Berliner and Thomas Edison in 1876, while David E. Hughes independently created the same type of carbon microphone in 1878.[2] The first carbon microphone was patented by Alexander Graham Bell in 1878. It consisted of a wire which conducted electrical current (DC). A moving armature transmitter and receiver generated and received audio signals, respectively, and transmission was possible in either direction. A liquid

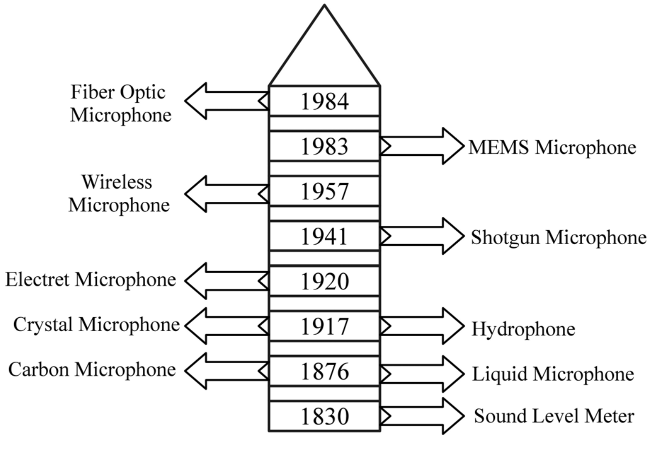

Figure 6.2 Various microphones ordered chronologically with years of invention.

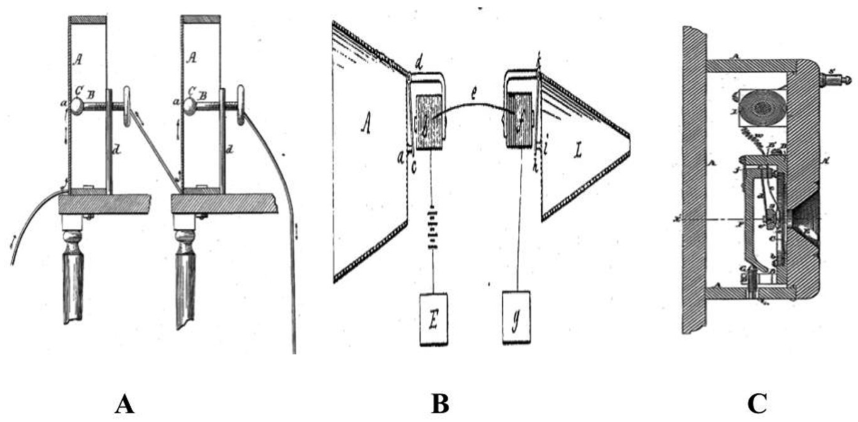

Figure 6.3 A: Bell's first microphone[3]; B: Transmitting device with liquid transmitter[3]; C: Francis Blake's microphone.[3]

transmitter was part of the second microphone invented by Bell in 1876. Later Emile Berliner patented the design based on Bell's liquid transmitter. It consisted of a steel ball set against a stretched metal diaphragm. Francis Blake developed a microphone by using a platinum bead.[3] The designs of all three microphones are shown in Figure 6.3.

In 1917 the piezoelectric microphone (crystal microphone) and the hydrophone were invented by Paul Langevin[2] and R. N. Ryan,[4] respectively. In 1920 the earliest electret microphone was invented by the Japanese scientist Yoguchi.[2] But the electret microphone is said to have been invented in the 1960s and a patent was awarded to Gerhard Sessler in 1962.[2] The shotgun microphone was invented by Harry F. Olson in 1941.[2] Later on, wireless technology became a trend and wireless microphones were invented in 1957 by Raymond A. Litke.[2] Then the USB and Lavalier microphones came into the market. In 1983 the MEMS microphone was invented by D. Hohm and Gerhard M. Sessler,[2] which became popular in the market due to its special features such as smaller size, low cost and high quality of sound. The fiber optic microphone was discovered in 1984 by Alexander Paritsky.[5]

6.4 Microphone and Its Classification

This section explains the microphone and its classification, working principle, advantages and disadvantages with the help of figures.

6.4.1 Microphone

The word 'micro' means small and 'phone' means sound. Thus, the word 'microphone' refers to a 'small sound', meaning it deals with small amounts of sound. A microphone consists of a transducer to convert mechanical energy/ sound waves into electrical energy/acoustic signals.

6.4.2 Microphone Classification

Microphones can be divided into three types based on principles, polar patterns and applications. Figure 6.4 illustrates the classification of microphones.

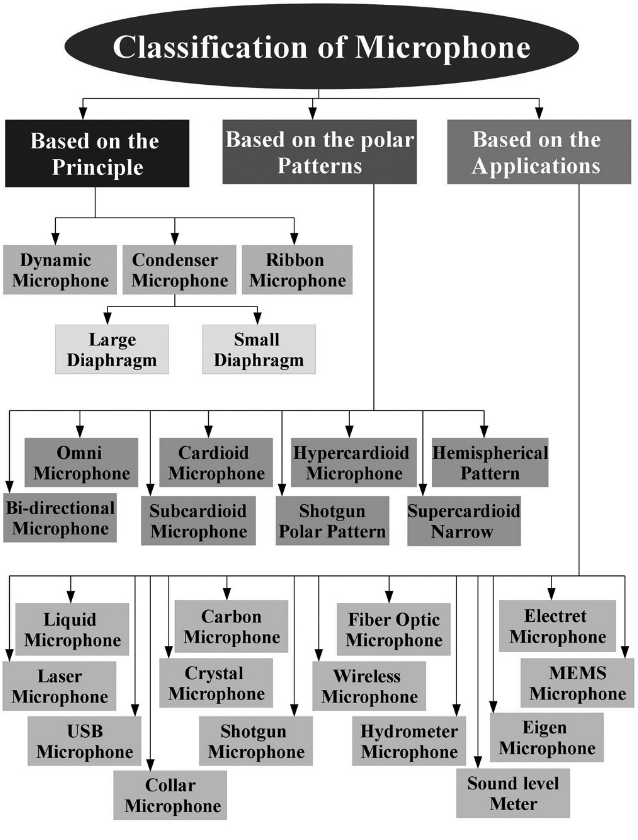

Figure 6.4 Classification of microphones.

6.4.2.1 Microphone Categories Based on Working Principle

Microphones are divided into three types on the basis of the working principle – dynamic, condenser and ribbon.

A. Dynamic microphone: This microphone consists of a diaphragm, a coil and a magnet. It works on the principle of electromagnetic induction. When a sound wave strikes the diaphragm, it moves back and forth and the coil, which is attached to the diaphragm, also moves backwards and forwards. The coil is surrounded by a magnet. It creates a magnetic field through which electric current flows. Figure 6.5(D) depicts a dynamic microphone. It is the most commonly used microphone as it captures sound from all directions while recording. It has a cardioid polar pattern and cancels out noise from its rear side.[7]

Advantages: A dynamic microphone is robust. It has the capacity to pick up high sound pressure levels and provides good sound quality. It is inexpensive and does not need power to operate.

Disadvantage: A dynamic microphone has poor high-frequency response due to the inertia of the coil, tube and diaphragm and the force required to overcome interaction between the coil and magnet. Hence it is not suitable for recording sounds of musical instruments (e.g., guitar, violin) with high frequencies and harmonics compared to the condenser microphone.[7]

B. Condenser microphone: This microphone consists of a couple of charged metal plates, one backplate which is stationary and another one which is a movable diaphragm (forming a capacitor). It works on the electrostatic principle. When a sound signal strikes the diaphragm, the distance between the two plates changes which changes the capacitance. The change in the spacing due to the movement of the diaphragm with respect to the stationary backplate creates an electrical signal. Figure 6.5(E) shows an example of a condenser microphone. Condenser microphones require an electric current to pick up signals, which is provided by either the battery or the microphone cable called phantom powering. It can operate with phantom power voltages ranging from 11 volts to 52 volts.[7]

Advantages: A condenser microphone is smaller than a dynamic microphone and has a flat frequency response. It supports a high range of frequencies due to a fast-moving diaphragm.

Disadvantages: A condenser microphone is costly, more sensitive to temperature and humidity, and there is a limitation to the maximum signal level the electronics can handle.[7]

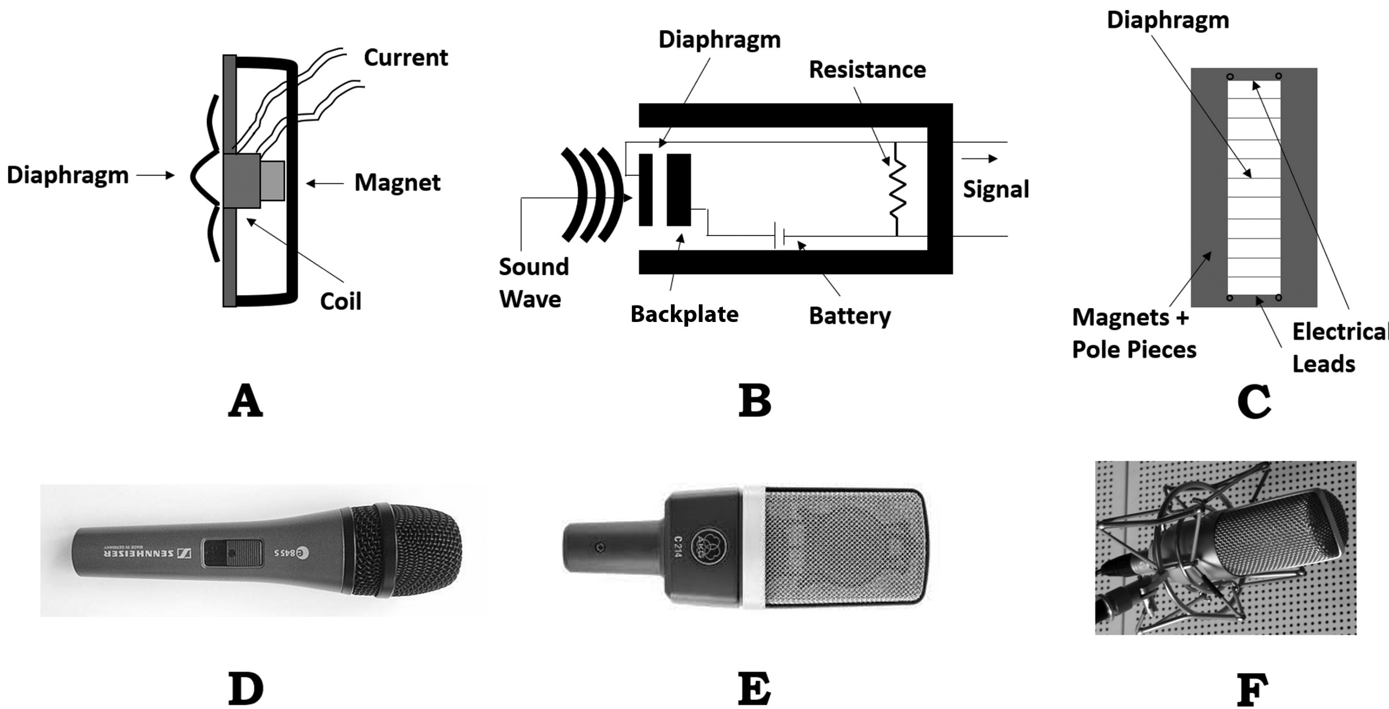

Figure 6.5 A: Dynamic microphone working principle; B: Condenser microphone working principle; C: Ribbon microphone working principle; D: Dynamic microphone;[10] E: Condenser microphone;[10] F: Ribbon microphone.[10]

Condenser microphones are divided into two on the basis of the size of the diaphragm – large (1 inch and above) and small (less than 1 inch).[8]

C. Ribbon microphone: This microphone works on the principle of electromagnetic induction. It has a thin, electrically conductive, ribbon-like diaphragm suspended within a magnetic structure. When sound waves strike the diaphragm, it moves back and forth within the permanent magnetic field inducing a signal electromagnetically across it. This microphone is most commonly used in radio stations. It picks up the velocity in the air and not just air displacement. It provides better sensitivity to higher frequencies and captures highly dynamic and high fidelity sounds.[9] A ribbon microphone is shown in Figure 6.5(F).

Advantages: Because of their sonic characteristics, ribbon microphones are favoured for various applications. These special sonic characteristics provide an advantage over other microphones for smooth, warm and natural sound.[9]

Disadvantages: Ribbon microphones are bulky because they require huge magnets. For example, magnets in a ribbon microphone such as the classic RCA 44 weigh up to six pounds. These microphones are fragile.[9]

6.4.3 Microphones Based on Polar Patterns

Microphones are classified according to the sound pick-up patterns / polar pattern and every microphone, irrespective of its working principle, has a polar pattern. There are eight types of polar patterns as summarised below.

A. Omnidirectional: The word 'omni' means uniformity in all directions. Thus, a microphone with an omnidirectional polar pattern picks up sound equally from all directions. Such a polar pattern is shown in Figure 6.6(A). Omnidirectional microphones are particularly useful for recording room ambience and capturing group vocals.[11]

B. Cardioid/Unidirectional: This polar pattern is heart-shaped, hence the name cardioid. It picks up sound from the front and offers utmost rejection at the rear which is shown in Figure 6.6(B). It has a null point at the rear (180°) and 6 dB decline at its sides, that is, 90° and 270° compared to the on-axis, that is, 0°. It is suitable for live performances and situations where feedback suppression is required. It is most commonly used in studios.[11]

C. Hypercardioid: A polar pattern in such a case has a narrow pickup pattern and also picks up sound from the rear which is shown in Figure 6.6(C).

It has null points at 110° and 250° and roughly a 12 dB decline in sensitivity at its sides, that is, 90° and 270°, and a rear lobe of sensitivity with 6 dB less sensitivity, that is, at 180°compared to the on-axis (0°). It is most commonly used in loud-sound scenarios. It has better isolation, and its feedback resistance is higher than the cardioid's.[11]

D. Supercardioid: The polar pattern in this case is similar to that of a hypercardioid microphone but with a compressed rear pickup. It has null points at 233° and 127° and roughly a 10 dB decline in sensitivity at its sides, that is, 90° and 270° and a rear lobe of sensitivity which is 10 dB less, that is, at 180° compared to the on-axis (0°).[11] Such a polar pattern is shown in the Figure 6.6(D).

E. Figure-8 or Bi-directional: The name itself describes the characteristics that it picks up sound from two directions, that is, front (0°) and behind (180°) the microphone forming a shape of the digit 8 and, hence, the name Figure-8. The polar pattern is shown in Figure 6.6(E). It has null points at its sides, that is, at 90° and 270°.[11]

F. Subcardioid or Wide Cardioid: This polar pattern lies between the omnidirectional and cardioid patterns and is shown in Figure 6.6(F).[11]

G. Lobar/Shotgun: This is an extended version of the supercardioid and hypercardioid polar patterns. It has a tighter polar pattern up front with a longer pickup range which is shown in Figure 6.6(G). It is more directional than hypercardioid. Hence, shotgun is used in filmmaking and theatre. They also make great overhead mics for capturing sounds like singing groups, chorals and drum cymbals.[11]

H. Boundary/PZM Hemispherical: This is a polar pattern that lies on the outer liner and pressure zero microphone (PZM) which is shown in Figure 6.6(H). This type of pattern is obtained by keeping the microphone capsule flush on a surface and within an acoustic space, placing the microphone itself on the boundary.[11]

6.4.4 Types of Microphones Based on Applications

Depending on the applications, there are different types of microphones which are described below.

A. Liquid microphone: Alexander Graham Bell and Thomas Watson invented the liquid microphone. It was the first of the working microphones to

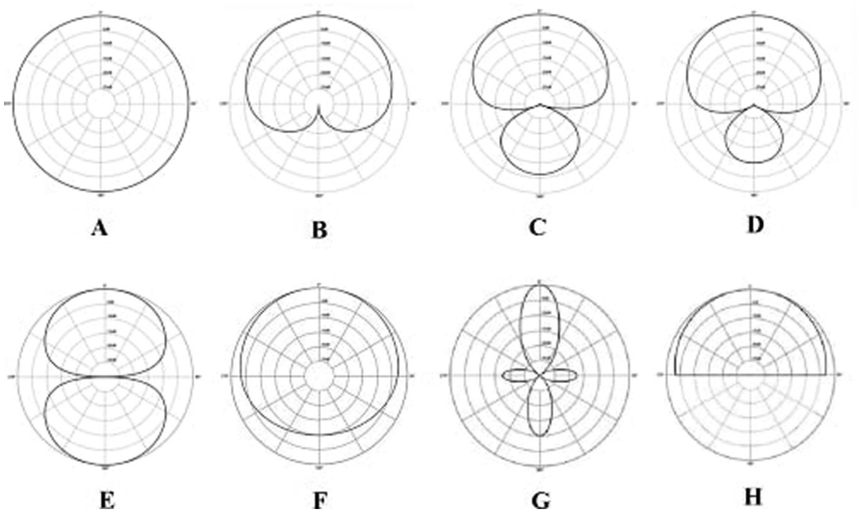

Figure 6.6 Illustration of polar patterns of A: Omni microphone; B: Cardioid microphone; C: Hypercardioid microphone; D: Supercardioid narrow; E: Bi-directional microphone; F: Subcardioid microphone; G: Shotgun polar pattern; H: Hemispherical pattern.[11]

be developed. It consists of water and sulphuric acid in a metal cup. A cup is placed on the diaphragm with a needle at the end of the receiving diaphragm. When a sound wave strikes the needle, it moves towards the water. A small electrical current passes through the needle, which is regulated by sound vibrations. The liquid microphone was never a particularly functional or efficient device, but it helped in the development of other microphones.[12]

B. Carbon microphone: Carbon microphone is the oldest kind of microphone. It has a thin metal or plastic diaphragm on one side and uses carbon dust. When a sound wave hits the diaphragm, the carbon dust gets compressed which alters its resistance and results in a flow of current. This technology was used in telephones as well. It is mostly used in the chemical manufacturing industry and mining because higher line voltages might cause explosions.[12]

C. Fiber optic microphone: It uses super-thin strands of glass rather than metallic wires to transfer the audio signals. It converts acoustic signals into light signals. Since there is no generation of electrical signals in the microphone or optic fiber cables, the fiber optic microphone gives secure and interference-free communication in electrically or chemically hazardous conditions.[12]

D. Electret microphone: It is a microphone with a condenser and an electrostatically working capacitor. Electret material is any dielectric material that maintains its electric polarisation after being subjected to a strong electric field. The microphone consists of a light, moving diaphragm, stationary backplate and electret material; these materials produce constant external and internal electric fields and can productively charge other electrical elements, such as capacitors and provide polarizing voltage. When sound waves hit the diaphragm, it results in a capacitance between the diaphragm and the backplate. It induces an AC voltage on the backplate.[12]

E. Laser microphone: In this type of microphone, a laser beam directed into a room through a gap of a window, reflects off the objects; the reflected beam is converted into an acoustic/audio signal by a receiver. As vibrations shift the surface of the vibrating object, the reflection of the laser is deflected. The receiver will find the laser deflections due to the vibrations that were originally created from an audio signal. Therefore, a receiver takes in the oscillating laser signal from a constant/fixed location. The receiver can then filter and amplify this beam signal and produce the audio output. Through this process the laser microphone successfully reproduces the audio that causes the object's vibrations.[12]

F. Crystal microphone: This microphone works on the piezoelectric effect. It produces the voltage when crystals with piezoelectric effect are deformed. The diaphragm is attached to a thin strip of piezoelectric material. When the crystal is deflected by the diaphragm, the two sides of the crystal gain opposite charges. The charges are proportional to the amount of deformation and disappear when the stress on the crystal disappears. Because of its high output, Rochelle salt was used in early crystal microphones but it is sensitive to moisture and fragile. Later microphones used ceramic materials such as titanate, lead zirconate and barium. The electric output of crystal microphones is comparatively large but they are not considered seriously in the music market because the frequency response is not comparable to a good dynamic microphone.[12]

G. Wireless microphone: Nowadays wireless microphones are a necessity. Both professionals and non- professionals use wireless microphones for various activities like live performances, concerts, classroom presentations and so on. Wireless microphones don't require wires or cables to connect the microphone to the sound system. They transmit sound via wireless channels. They are capable of delivering high-quality sound. Based on its purpose, a wireless microphone system is divided into two types – professional and consumer.

Professional systems provide high-quality audio These are used in broadcast systems, live performance and so on. On the other hand, consumer systems are used in headphones, toys and so on.

H. MEMS microphone: Microelectromechanical systems (MEMS) is an emerging technology in all the fields of engineering such as automobiles, aerospace technology, biomedical applications, inkjet printers, and wireless and optical communications. The technology integrates electronics and mechanical properties of the transducer on a single chip both to make a miniaturised structure at less cost. The size varies from a millionth of a micrometre to a thousandth of a millimetre. Due to its widespread application, this microphone has an increasing demand in the market. The materials used include ceramics, semiconductors, plastics, magnetic, ferroelectric, and biomaterials. A typical MEMS microphone is shown in Figure 6.6(H). The MEMS microphone is built on a printed circuit board (PCB) with MEMS components such as semiconductors, microactuators, microsensors and so on. In the final stage, it is protected by a mechanical cover. It uses capacitive technology, that is, the MEMS diaphragm forms a capacitor and sound wave pressure causes the diaphragm to move. It consists of an audio preamplifier which converts the changing capacitance of the MEMS to an electrical signal.[12]

I. USB microphone: A Universal Serial Bus (USB) microphone consists of a transducer which converts sound signal into analog audio signals. It has USB output implying that the output is digital, that is, a digital audio signal. The USB microphone consists of an analog-to-digital converter to convert the analog signals from its transducer element into digital signals. It has a built-in digital audio interface which connects directly to a PC or computer via USB connection/cable and hence the name USB microphone.[13]

J. Shotgun microphone: This microphone is also known as a rifle mic because like a shotgun, it points directly at its target source (person, instruments) in order to pick up the sound effectively. It works on the principle of 'waveform interference'. The slots in the tube result in the interference and hence it is also called an 'Interference Tube'. This microphone is unidirectional; it picks up the sound from the target direction with high gain when the shotgun microphone is in front of the subject/instrument or any other source.[14]

K. Hydrophone: In 1929 Reginald Fesseden invented the hydrophone. The hydrophone was earlier known as the Fesseden oscillator. It is a device that resembles a microphone in the way it works. It converts underwater sound waves into electrical signals but it is mainly used for detecting underwater acoustics waves such as those created by submarines. Most hydrophones are based on the piezoelectric effect. For better detection, an array of hydrophones is used instead of a single hydrophone. Basically, there are two types of hydrophones: (1) omnidirectional hydrophone which detects sound in all directions with equal sensitivity, and (2) directional hydrophone which has higher sensitivity to a particular direction and detects directional acoustic signals.[15] For example, a hydrophone was placed as a part of a deep ocean instrument package at a depth of more than 10,971 metres (6.71 miles). It continuously recorded the ambient sound levels of the deep ocean with a frequency ranging from 10 Hz to 32,000 Hz over 23 days.[16]

L. Eigen mic/mike: One of the most common Eigen mics is the em32 Eigen mike, a microphone array comprising many professional quality microphones placed on a rigid surface of a sphere. It has a two-step process. (1) Using digital signal processing the outputs of the separate microphones are fused to create a set of Eigenbeams. The sound field is captured by this complete set of Eigenbeams. The capture is limited by the spatial order of the beamformer. (2) The Eigenbeams are fused to steer numerous concurrent beam patterns that can be focused in particular directions in the acoustic field. Eigen mikes are used in real-time applications, multichannel surround sound recording and playback, spatially realistic teleconferencing and sound field spatial analysis. Other applications include sound production for music/film/broadcast, consumer products and gaming, security and surveillance, news or sports reporting.[17]

M. Sound level meter /Dosimeter: A sound level meter (SLM), also known as a sound pressure level (SPL) meter, noise dosimeter, noise meter or decibel (dB) meter, is used to measure the noise/sound levels by measuring sound pressure. Acoustic measurement values are shown on the display of the sound level meter. An SLM is mainly used to measure and manage noise from a variety of sources, such as industrial/factory, rail and road traffic, building construction work and so on.[18]

N. Lavalier microphone: It is a type of microphone used in television interviews, conferences, public speaking and so on which provides hands-free operation and offers uniform and clear sound without background noise. It is a wearable mic and usually people attach it to their tie, collar or lapel. It can be either wired or wireless. It is also referred to as a lapel mic, lav mic, collar mic, body mic, clip mic, personal mic and neck mic.[19]

6.4.5 Microphone Array

A microphone array is a device consisting of two or more microphones integrated over a single circuit board that works like a normal microphone. It is used in the applications of acoustic signal processing technologies such as in Automated Speech Recognition, beamforming, speech signal separation, noise reduction and so on.[20] The microphone may be a condenser, dynamic or ribbon.

There are three basic geometries in the microphone array: linear, planar and three dimensional (3-D). To create a microphone array, the frequency range and x-y-z coordinates of each microphone are required.[21] Depending on the target application, the microphones in a microphone array are arranged in a linear, circular or triangular manner, as illustrated in Figure 6.7.[22] There are a variety of other arrangements of microphone as well specific to different applications. Microphones in a microphone array record sounds simultaneously. However, it is important that the characteristics of all the microphones in the array are matched. The following three aspects are considered while selecting microphones in an array.

1. Directionality: The directionality of a microphone is the direction from which it can pick up sounds. All the microphone must have the same directionality while building a microphone array. Having a single microphone which picks up the sound from a particular direction other than picking up the sound from all directions causes imbalance and leads to disastrous sound recording.

2. Sensitivity: Sensitivity is the gain that a microphone picks up while recording an audio signal. It must be matched across all microphones in an array otherwise one microphone will be louder than the others, creating an imbalance in sound recording. Therefore, a sensitivity difference of ±1.5dB to 3dB is allowed in microphone arrays.

3. Phase: Phase means the time that every microphone in an array starts and stops recording the signal. Signals recorded at different times when the microphones have different phases results in unsynchronised and undesired recordings.[20] Hence, it is recommended that all microphones in an array be phase matched.

If the microphones in an array are dissimilar, problems such as variation of gain, phase and sensitivity will occur leading to poor quality in audio applications. Hence, microphones must have similar or closely matched microphones to meet certain specifications to avoid uneven sound recordings.[20]

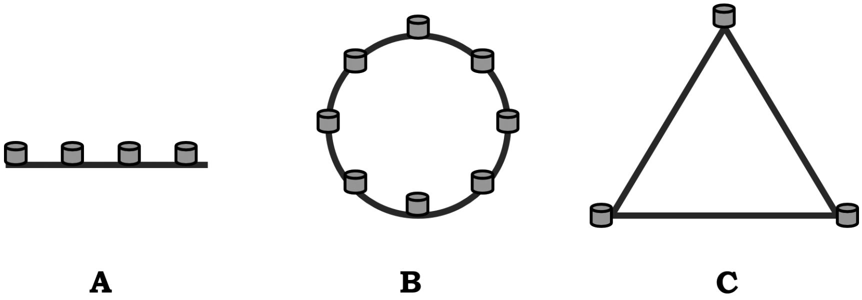

Figure 6.7 Different geometries of microphone array.[22]

6.4.5.1 Applications of Microphone Array

1. **Noise detection and measurement techniques:** Noise can be detected and measured using beamforming techniques. A microphone phased array is used to measure the far field noise, that is, in the open-jet and hybrid test section. Spectra are determined by using the source power integration technique of conventional beamforming maps. An experiment was carried out in the University of Twente in a closed test section, where wall-mounted microphones were used to reduce the self-noise and to improve the signal-to-noise.[23]
2. **Audio enhancement:** While capturing audio, nearby noise can often ruin a recording. The recording must be digitally altered to enhance the sound, remove noise and save only the desired audio. In order to distinguish which parts of a recording are from the desired source, it is often necessary to take multiple recordings from different locations and compare the results. The source of the desired audio and each source of noise can be identified later so that only the unwanted sound is removed.[24]
3. **Spatial audio object capture:** This refers to the collection and protection of spatial information of an acoustics from multichannel or stereophonic sound recording and reproduction. Headphones or multiple loudspeakers are employed to permit the listener to distinguish the directions of each sound source, keeping the original sound scene. It provides a more realistic sensation and experience in the gaming field from multichannel audio. Furthermore, teleconferencing applications use spatial audio to develop an immersive and natural communication between two or more subjects.[25]
4. **Enhancing the recording quality:** The differences in time lag between recordings can also be used to differentiate different sounds being heard by the microphone array. Each microphone picks up the

sources of sound with varying delays and volumes. By comparing the differences in sound content among the microphone recordings, specific sounds can be isolated and amplified or removed. Unwanted sounds can be strategically removed, almost entirely, and the enhanced audio to be processed can be more clearly and accurately analysed.[24]

5. **Separation of multiple speakers talking:** Identifying and enhancing non-stationary speech targets in various noise environments, such as a conference, classroom meeting, cocktail party and so on, is a significant issue for real-time separation of speech from multiple speakers. By using microphone arrays and beamforming technique, separation of multiple speakers can be achieved.[26]

6.4.6 Pop Filter

It is used to eliminate certain kinds of noise during recording. Sudden air pressure causes the microphone to get overloaded due to plosives (/p/ /t/ /k/ /b/ /d/ /g/). In order to reduce overloading a pop filter is used. It also acts as a protective shield from vocalists' saliva. Saliva is corrosive in nature so a pop filter provides longer life to the microphone. Pop filters, as shown in Figure 6.8, are connected and placed in front of the microphone to eliminate noise due to fast-moving air.[27]

6.5 Unit of Measurement

Sound is measured in terms of its intensity/pressure level. The unit of measurement is decibel, denoted by dB. Basically 'deci' means ten and 'B' denotes Bell. This means decibel uses base ten logarithms. The applications of dB are widespread in scientific and engineering areas, especially within electronics, acoustics and control theory.[28] Devices such as a decibel meter (as shown in Figure 6.9) or audiometer are used to measure the level or intensity of sound. Table 6.1 presents examples of sound intensity.

6.6 Discussion

The need for measuring sounds with various intensities and time frequencies led to the development of a variety of microphones. The medium of recording, size of the device, sound quality and target applications also influence the variety of microphones. An array of such measuring devices is also used due to its capacity to remove unwanted sounds when recording in open spaces.

Depending on the specifications, various sound measuring devices are available in the market at different prices. The graph in Figure 6.10 illustrates

Figure 6.8 Pop filter.

the different types of sound measuring devices with their cost. The cost of the devices is taken from various online marketing/shopping websites and may vary according to location/offers/availability. It is clear that a stethoscope, used for listening to internal body sounds like the heart, lungs and so on for clinical purposes, is relatively cheap. However, devices like Eigen microphones that capture spatial sounds are the most expensive among the ones shown in Figure 6.10. It is also worth noting that the price of every device depends on its manufacturer and its applications. Thus, a user needs to decide which measuring device he/she would like to purchase depending on all these factors.

While the choice of the right device plays an important role in measuring sound, it is also equally important to pay attention to how the recorded sound samples are stored for further use, analysis and processing. For example, a magnetic tape or a hard disk drive (HDD) in a computer can be used to store sound. While magnetic tape has been used in the last few decades to store recorded sound, HDD, particularly solid state disk (SSD) drives are more widely used at present. These come in various forms, namely, pendrives, SD cards, SATA drives and so on. Data from such a storage medium needs to

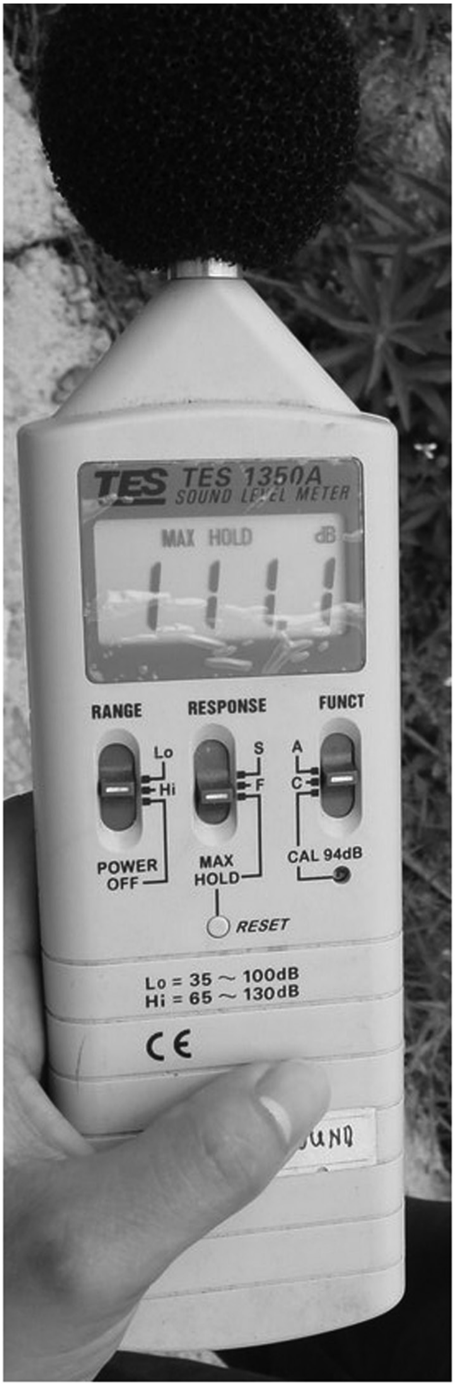

Figure 6.9 Decibel meter.

Table 6.1 Intensity levels and intensities of sound[29]

Sound intensity level β in (dB)	Intensity I in (W/m^2)	Example
0	1 × 10–12	Threshold of hearing at 1000 Hz
10	1 × 10–11	Rustling of leaves
50	1 × 10–7	Soft music
60	1 × 10–6	Normal talk / conversation
70	1 × 10–5	Busy traffic, noisy area
80	1 × 10–4	Loud noise
100	1 × 10–2	Factory siren at 30 m
140	1 × 102	Jet aeroplane at 30 m
160	1 × 104	Bursting of eardrums

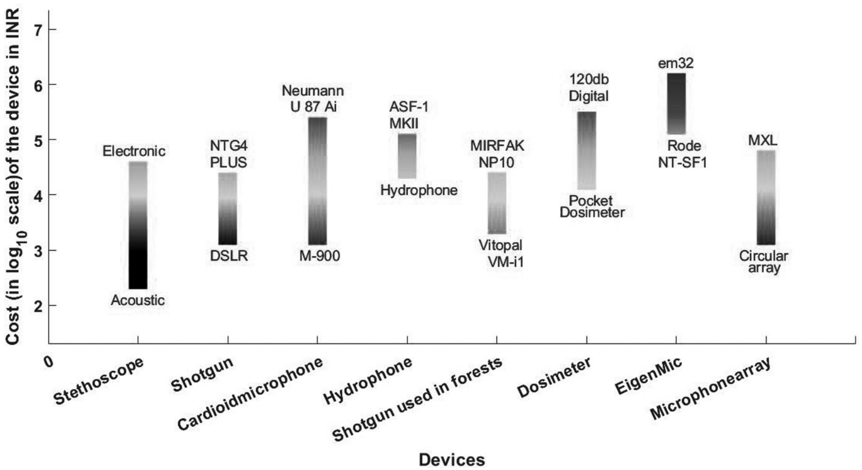

Figure 6.10 Different sound measuring devices with cost. The cost on the y-axis is in log scale. For example, a value 4 in the y-axis is equivalent to 10^4 = 10000 INR.

be retrieved for further processing of recorded sounds. Thus, storage and retrieval of data is an integral part of sound measurement. A large number of engineering solutions exist for such data transfer and storage.[30]

6.7 Conclusion

Devices for recording various sounds have seen drastic changes in design, quality, characteristics and price. In 1827, the word 'microphone' was coined by Sir Charles Wheatstone. In the 19th century interest in and development of the microphone increased and in 1916 the condenser microphone was patented by E. C. Wente. Radio broadcast became the foremost source of entertainment for everyone. Hence, scientists started working more on the microphone and discovered the ribbon microphone which suited radio broadcasting. In the 21st century researchers have worked more on MEMS, Eigen mike and array microphones. In 2010 the Eigen mike came to the market and played a vital role in capturing sound from different directions. Microphone arrays have been ruling the audio industry because of the dynamic surround sound recording that they allow. MEMS microphones focus mainly on miniature and portable devices including headsets, cell phones and laptops. There has been a recent demand for sound measuring devices for smart wearable, smart homes/buildings and automobile technology which may also lead researchers to discover and develop various microphones in the coming days.

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7

PRINCIPLES OF QUANTIFYING IMPACT OF NOISE AND MUSIC ON HEALTH

Ramesh A.

7.1 Introduction

This chapter intends to describe the principles involved in quantifying the effects of noise and music on health and well-being. The main principle of quantification is defining and operationalizing the variables. The independent variables (variables that cause the impact) may be classified as those related to characteristics of noise and music. The other set of dependent variables are measures of impact on health and well-being. We will create a comprehensive and unified template to guide practitioners and researchers to quantify the impact of noise and music on health and well-being. The variables can be categorized as physical and affective domains. Physical attributes can be directly measured, whereas affective attributes are evaluated using surrogate measures. Hearing thresholds is a physical variable that can be measured using auditory brainstem response. Annoyance to high noise is an affective variable that is measured indirectly by estimating performance levels. The list of variables associated with noise, music and health is enumerated. The method to standardize and operationalize the variables will be explained. The concept of bias and strategies to limit the errors are described. The steps of developing a validated measurement tool are also explained. The last section deals with application of artificial intelligence in quantifying the impact of noise and music on health and well-being.

Learning Objectives

1. Method to operationalize dependent and independent variables in the physical and affective domains relevant to noise, music and health
2. Describe bias and strategies to limit errors due to bias
3. Steps to develop a psychometrically validated measurement tool
4. Application of machine learning and artificial intelligence in this context

7.2 Operationalizing Variables

Measurement is a precise activity. The variables that need to be measured can be of two types: those in the physical domain and those in the affective domain. Tangible variables are called physical variables. For example, blood pressure has an absolute zero, so it is a variable in the physical domain. Motivation is a variable that is measured indirectly based on behavioural output. There are scales to measure motivation, but there is no absolute zero. This important principle has to be applied while operationalizing to measure the impact of noise and music on health. The main steps to operationalize a variable are defining the variable, deciding the tool to measure, identify sources of bias and plan strategies to limit them and finally summarize using descriptive and inferential statistics. The last two steps namely descriptive and inferential statistics have been explained in Chapter 22 on framework to conduct research on sound and health.[1] The reader may refer to Chapter 22 for further details. All the variables commonly described in literature with relevance to noise, music and health will be defined and method to operationalize are described in the following sections.

7.2.1 Variables in the Physical Domain Relevant to Noise – Music – Health

Loudness of sound (independent variable): The intensity of sound or music is called the loudness of sound. Decibel is the physical unit of measurement. The reader can refer to Chapter 6 on measurement of sound for more details on all aspects of sound measurement. Phon is the perceptual equivalent for loudness.

Dosage of sound (independent variable): The total sound energy that a person is exposed to is defined as the dosage. L equivalent (L_{eq}) is the physical unit to measure this variable. An integrating sound level meter is used to measure the dose of exposure.

Frequency characteristics of sound (independent variable): The frequency characteristics of sound or music is measured in hertz (number of cycles per second). Pitch is the perceptual equivalent of frequency. Pure tones are sounds with a single frequency. They are easy to quantify. Complex sounds and music have a spectrum of amplitudes and frequencies which vary with time. Quantifying them is a complex task. A process called fast Fourier transform (FFT) is used to quantify these variables. The reader may refer to Chapter 3 on physics of sound to understand FFT. Timbre is the perceptual measure of these complex sounds.

Quality of sleep (dependent variable): The quality of sleep is measured based on sleep latency (time to sleep after you go to bed which is usually 30 minutes), sleep waking (frequency of getting up during sleep), wakefulness (duration of time spent awake after you first go to sleep, usually limited to 20 minutes) and sleep efficiency (amount of time actually spent in sleep after going to bed, which is usually 85% of the total time). Sleep studies are an objective method to measure the quality of sleep. If done in the home setting, they are more representative than hospital settings. [2]

Neural plasticity (dependent variable): This is defined as the capacity of the nervous system to modify itself functionally and structurally in response to experience and injury. This can be measured in real time using functional MRI (Magnetic resonance imaging).[3]

Biomarkers (dependent variable): Various biochemical markers associated with noise and music are dopamine, serotonin, endorphin, cortisol, oxytocin, leukocytes, cytokinin, salivary immunoglobulin, interleukins, tumour necrosis factor, testosterone, brain derived neurotrophic factor, free radicals, NADPH oxidase, nitric oxide synthase, renal angiotensin aldosterone, catecholamine, kinins, serotonin, histamine, cholesterol, blood sugar, blood viscosity, coagulation parameters and cortisol. All these are biochemical parameters. The laboratories where they are estimated should calibrate their equipment to ensure accurate measurements. Many of these parameters have a diurnal variation. This has to be factored and all measurements should be done at a pre-fixed time of the day.

Blood pressure and heart rate (dependent variable): These variables have to be measured by automated and calibrated equipment to limit intra– and inter–observer variability.

Vertigo (dependent variable): Vertigo is a sense of rotation when the body is in reality static. It can be quantified using electronystagmogram or videonystagmogram. These equipment measure the degree of nystagmus (jerky eye movements) and qualify the type of nystagmus.

Auditory threshold shifts (dependent variable): Hearing threshold shifts are measured using audiometry in a sound treated room. The threshold for hearing in each frequency ranging from 500 Hz to 8 KHz (Hz is hertz, a measure of sound frequency). Audiometry is a subjective evaluation method as the person responds to the sound heard through the ear phones. Auditory brainstem response, where sound is presented to the ear and electrical response from the brainstem is measured from electrodes placed on the scalp is an objective measure of hearing thresholds.

Atherosclerosis (dependent variable): Thickening of blood vessels is termed as atherosclerosis. Digital subtraction angiography where a radio-opaque dye is injected into the blood vessels is the most reliable measure of this thickening.

Histopathological changes in the inner ear (dependent variable): It is not possible to evaluate the histopathological (microscopic) changes in the inner ear in a living person exposed to noise. Usually, after consent, the inner ear is harvested after the person dies. There are repositories where the inner ear specimens are harvested and examined to understand the pathological basis of inner ear damage in those exposed to loud noise.

Oxidative stress (dependent variable): This is defined as the imbalance in production of free radicals and antioxidants in the body. The free radicals can damage the tissues. Precise biochemical assays are used to measure the imbalance and detect excess of free radicals.

Healthy life years (dependent variable): This is defined as the number of years the person is expected to live a healthy life. It is a health utility measure. It is used to measure burden of disease.[4]

Productivity (dependent variable): This is measured by the output at the end of particular time period for an assigned activity.

Verbal fluency (dependent variable): Verbal fluency is measured using language specific scales.

Fatigability (dependent variable): This measures perception of fatigue by a person. Based on the activity being measured, the person involved is asked to respond.

Interpersonal relationship (dependent variable): This is a very complex area with multiple facets. There are well-established scales to measure each aspect of this domain. They are broadly classified as relationship between family members, friends, colleagues and romantic partners.

Classroom learning (dependent variable): This measures scholastic performance in the classroom. Marks obtained in the tests and examinations are the best method to evaluate classroom learning. Scales to measure specific aspects of learning can be designed for a particular context.

Reaction time (dependent variable): The time between stimulus and response is called reaction time. It can be measured best by video recording the sequence of events and measuring the time.

7.2.2 Operationalizing Variables in the Affective Domain Relevant to Noise – Music – Health

Variables in the affective domain are based on the perceptions of the person. There is no objective method to measure these domains. Psychometric scales are attempts to standardize these measurements. Method to develop these scales are described in the following sections.

Pain (dependent variable): Pain is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage.

Visual analogue scales are the most appropriate method to estimate pain perception.

Concentration (dependent variable): It is defined as the ability to focus your thoughts on the work being performed at that particular time. Measuring productivity is a surrogate measure of concentration.

Cognitive performance (dependent variable): Cognitive performance is based on various abilities like learning, thinking, reasoning, remembering, problem solving, decision making and attention. There are validated scales to measure each of these abilities and the researcher should collaborate with a clinical psychologist to measure cognitive performance.[5]

Motivation (dependent variable): Motivation is defined as the process that initiates, guides and maintains goal-oriented behaviours. Productivity is a surrogate measure of motivation.[6]

Endurance (dependent variable): The ability to withstand a difficult situation is defined as endurance. Measuring productivity in adverse situations is a measure of endurance.

Creativity and creative thinking (dependent variable): The ability to generate innovative ideas that solve problems is called creativity. Solving complex problems is an appropriate measure of creative thinking.

Emotional regulation (dependent variable): The ability of a person to appropriately manage emotions in challenging situations is defined as emotional regulation. It consists of attentional control, cognitive reappraisal and response modulation. Productivity in challenging situations is an indirect measure of emotional regulation.

Socio-cultural bonding (dependent variable): The ability to develop powerful and long-lasting relationships with peers and colleagues is socio-cultural bonding. It is a very complex domain and challenging to measure. Nevertheless, number of friends and feedback from peers is an effective method to measure this aspect.

Relaxation and stress relief (dependent variable): Methods to reduce stress is defined as relaxation. A pre–post evaluation using a scale to measure stress is a good method to measure relaxation.

Mood (dependent variable): The state of mind is defined as mood. There are eight primary moods namely anger, sadness, fear, joy, interest, surprise, disgust and shame. In each of these domains a spectrum of emotions exists. Various scales are used to measure the emotions but they are very subjective and standardization is challenging. Visual scales or numerical ranges are the best to evaluate each emotion.

Tinnitus (dependent variable): Hearing sounds in the absence of any external sounds is defined as tinnitus. It is a very subjective feeling. In certain other conditions it may be an objective phenomenon. It can be measured using various scales. The researcher should collaborate with otolaryngologists (ENT specialists) and audiologists (Hearing evaluators) to quantify this variable.

Annoyance (dependent variable): Annoyance is a derivative of the primary emotion of disgust. Various scales exist to measure annoyance and the researcher should collaborate with a clinical psychologist to measure annoyance.

Intelligence (dependent variable): The ability to think effectively and solve problems efficiently is a measure of intelligence. There are many theories of intelligence that put forth varying facets of intelligence. Based on each theory, a scale to measure it exists. It is critical that the cultural context is taken into account to choose the items used to measure intelligence. A clinical psychologist is an important specialist required to measure intelligence.

7.3 Identifying Variables that Can Cause Misleading Results and Strategies to Limit

After defining and operationalizing the independent and dependent variable, the associated variables that can create erroneous results have to be identified. Then the strategy to limit these errors have to be selected. If we are evaluating the effect of noise on stress levels then personality, age and prior exposure to loud noise are possible variables that can bias the results. Brainstorming by experts and reviewing literature is a method to identify these variables. Various strategies to limit these errors are explained in the following sections.[7, 8]

Bias: Bias is understood as systematic variation of measurements from their true values that may be intentional or unintentional. A well-defined research protocol is the most appropriate method to limit bias.

Chance: Random variations without obvious relation to other measurements or variables is chance error. It is usually intentional. Having a control group is best method to limit chance error.

Natural history: The natural course of a disease may cause error while measuring the results. Here again a control group limits this error.

Regression to mean: Improvement of symptoms irrespective of the intervention due to natural healing is called regression to mean. Having a control group limits this error.

Placebo effect: In interventional studies even the placebo can cause an effect due to expectation that the treatment will work. This type of error can be limited by employing a control group.

Halo effect: In certain situations the attention and care of the healthcare provider is therapeutic. This is called halo effect. Here again a control group will assist in limiting the error.

Confounding: The results can be distorted by other unknown factors beyond our control. This phenomenon is known as confounding. Randomization or adjustment by multivariate analysis is the best method to limit this type of error.

Allocation (susceptibility) bias: At times the more favourable cases are allocated to the intervention group, which is called allocation bias. Here again, randomization and adjustments by multivariate analysis assists to limit error.

Ascertainment (detection) bias: During analysis, the researcher may at times round up the numbers to favour the treatment group. This type of bias is called ascertainment bias. Masking (blinding) during outcome analysis is employed to limit this type of error.

7.4. Developing a Psychometrically Validated Measurement Tool for Affective Domains Relevant to Noise – Music – Health

In the previous section, we have classified the variables under physical domain and affective domain. This section will explain the method to develop a standardized measurement tool for variables in the affective domain.[9],[10] Figure 7.1 depicts the process of developing a standardized tool for measuring an effective domain. The first step is to identify the challenging situation in the area of noise – music – health where a measurement tool needs to be designed. To further illustrate this critical step we will take an example. It is a known fact that persons working in noisy environment do not comply with wearing ear protection devices. If we could device a tool to measure the various factors that constitute the perception of comfort, then we can use it to predict the utilization of these devices. So the target populations are persons working in noisy environments who are prescribed ear protection devices. The action we intend to accomplish is adequate compliance with ear protection devices. The next step is to define the domains and facets of the tool. For this, we need to visit the site where the workers are employed. An ethnographic observation of the situation along with in-depth interviews and focus group discussions have to be performed to understand the various facets that constitute perception of comfort while wearing ear protection devices. Ethnography is structured observations to understand the real time situation. In-depth interviews and focus group discussions are one to one and group conversations to understand views, perceptions and experiences of wearing ear protection devices. Based on the responses, a set of affective constructs that constitute comfort perception is listed. Then questions or probes to elicit responses for each facet or domain are created. Each item (question) should be simple, single barreled, culturally appropriate and clearly address the domain. At least 100 items should be created for the first draft of the tool. The responses can be in the form of increasing or decreasing degrees of agreement (strongly agree to strongly disagree). Visual scales in the form of numbered lines are another method to elicit responses. There should be at least 5 grades of responses. Try avoiding the choice 'neither agree nor disagree' to avoid neutrality. Following this, stakeholders are requested to evaluate the items for content and face validity. Content validity ensures that the item elicits information relevant to all attributes of the domain being evaluated. Face validity ensures that the item resembles the domain being evaluated. The stakeholders, rate the items on a scale of relevant to irrelevant. Items that score less than 50% validity are discarded. The next step is to reduce the number of items. Construct and criterion validity is the technique used to reduce the number of items. Construct validity measures ability of the items to distinguish two different groups. Criterion validity is based on the performance of the items when compared with reference criteria. For example, construct validity for scale measuring comfort levels while wearing ear protection devices should clearly distinguish between those who are perceiving comfort from those in discomfort. Criterion

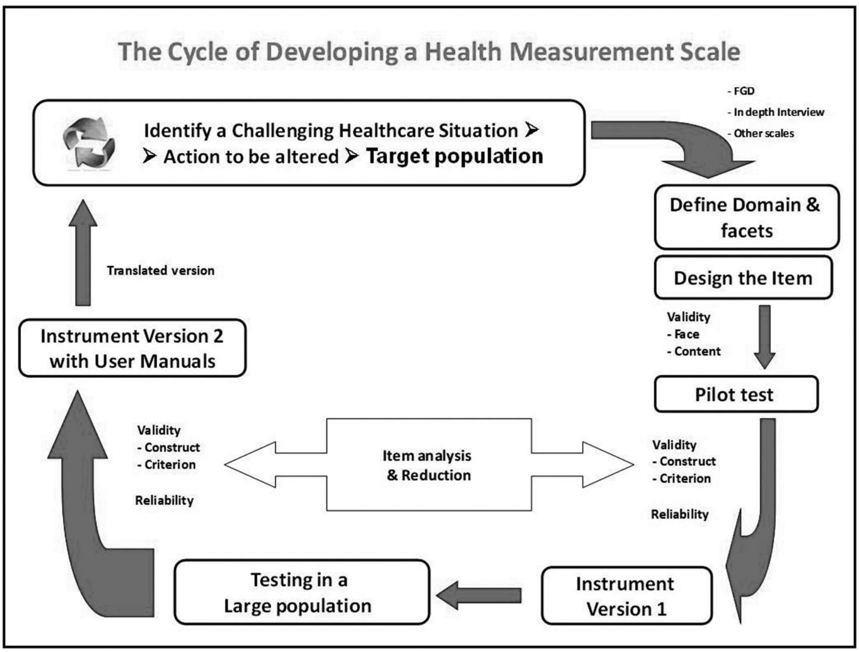

Figure 7.1 Steps of developing a standardized measurement tool.

validity, measures the tool's score with pressure exerted by the ear protection device on the ear canal. A statistical method called principal factor analysis is employed for identifying the items that are measuring a similar domain and those that measure diverse domains. Statisticians will assist in performing these tests. The reader may read advanced texts on tool development if they are actually planning to construct a standardized tool. Then the second version of the tool is ready for pilot testing on persons in noisy environment who are prescribed ear protection devices. The first testing gives information for further reducing the number of items and also intra– and inter–observer reliability. The next level of testing is done in a large population and the final draft of the tool is created. User manuals are written. If the inventors intend to translate the tool to another language other than English, then an elaborate process of translation and back translation that will preserve the psychometric properties of the tool has to be followed. The components of ensuring equivalence are conceptual, semantic, technical, cultural and measurement equivalence.

Various ways of administering the tool are face to face interview, telephonic interview, mailed questionnaire method and computer assisted. **Co**nsensus based **s**tandards for the selection of health **m**easurement **in**struments (COSMIN) is an internationally accepted standard to assess the quality of the measurement tool.[11] After the tool is made available for use by researchers, at regular intervals the tool is further refined by the inventors.

7.5. Applications of Machine Learning and Artificial Intelligence in Measurements Related to Noise, Music and Health

Noise and music are complex signals. Quantifying and qualifying them is a challenging task. Measuring the effect of noise and music on health is surrounded by many confounding factors. Extracting the clear effect on health is possible only to the extent we are able to control or adjust the bias using strategies described in Section 7.3. Linear analysis has its limitations in these situations. With the advent of data mining and machine learning extracting signals in the presence of noise (here noise denotes confounding factors, not the noise as we understand in this book) has become more accurate. Artificial intelligence is an amalgamation of these principles. Artificial Neural Networks (ANN) can assist in these complex tasks. The fundamental premise on which neural networks are based, is the fact that humans solve problems by pattern recognition. The process of pattern recognition is by parallel and distributed processing that occurs in the neural networks of the human brain.[12] The same principle is used to create ANN. The network is then trained to recognize patterns and arrive at solutions for a given problem. The characteristics of human intelligence are robustness and fault tolerance, flexibility, ability to recognize patterns that are fuzzy–probabilistic–noisy–inconsistent and parallel processing. While we develop artificial neural networks, these functional aspects need to be recreated. Further explanation of artificial intelligence is beyond the purview of this chapter. The reader is advised to refer advanced texts mentioned in the reference section.

7.6 Conclusion

Quantifying the effects of noise and music on health is a challenging task. The complexity of quantifying and qualifying noise and music is compounded by multiple confounders around measuring the effect on health. In this background the researcher should apply the following principles to quantify the effects of noise and music on health. The guiding principles are

1. Defining and operationalizing the dependent and independent variable
2. Identify the factors that can bias the results
3. State the strategy to limit various types of bias
4. Perform linear and parallel processing methods (employing artificial intelligence) for data analysis
5. State unadjusted (without limiting bias) and adjusted (after limiting bias) results for the readers to make their clinical decisions

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Part III

DELETERIOUS EFFECTS OF NOISE ON HEALTH

8

AUDITORY EFFECTS

Sandeep Maruthy

8.1 Introduction

Exposure to hazardous sounds is a common cause of hearing loss in adults. The sources of sound that commonly lead to noise-induced hearing loss (NIHL) include occupational noise (as in factory workers, army men), environmental noise (as in traffic police), music (as in professional musicians & habitual music listeners), and firecrackers.

Learning Objectives

- Learn the effects of hazardous noise on the structure and function of the human auditory system.
- Understand the signs and symptoms of noise-induced auditory damage, the definition of hazardous noise, ways to identify the auditory damage, and the methods to assess individual susceptibility for noise-induced damage of the auditory system.

8.2 Damage Risk Criteria

Before we dwell into the details of auditory effects of noise, it is necessary to understand the definition of "a hazardous noise". Simply stated, it is a noise that results in any kind of health hazard/s. History reveals that one of the unexpected byproducts of the industrial revolution was the increased prevalence of hearing loss. The occupational noise that the persons were exposed to was causing permanent hearing loss. To minimize this health hazard, measures were taken to understand the relationship between exposure levels and their effect on hearing. Eventually, National Institute for Occupational Safety and Health (NIOSH) defined the damage risk criteria (DRC) for persons with occupational noise exposure in terms of sound intensity and duration of exposure. According to NIOSH, DRC is 85 dB A (decibels measured using A weighted network of sound level meter) for 8 hours. This is the combination of noise exposure level and duration that no worker exposure shall equal or exceed. If exposure exceeds DRC, the person is at risk of developing permanent hearing loss. This hearing loss, however, will not happen in a day or two, but will take several years of such exposure. There is also a systematic trade-off of permissible exposure duration with an increase in exposure intensity, the specific details of which can be found in Publication No. 98–126, (June 1998) of NIOSH. In any case, no exposure to either continuous, varying, intermittent, or impulsive noise shall exceed 140 dBA. These standards of permissible noise exposure are based on data from several large-scale demographic studies of hearing loss in industrial workers (Baughn, 1973; Burns & Robinson, 1978).

Exposures beyond the DRC are likely to result in noise-induced auditory damage. It can either be one exposure to loud impulse noise of intensity 130dBA and above or routine exposure to continuous noise having intensity 85dBA and above. Although the auditory damage caused by both types of exposures can be referred to as noise-induced damage, the one caused by one-time exposure to very loud impulse noise is specifically referred to as "Acoustic trauma." In an acoustic trauma, in addition to permanent damage to the inner ear, one may find rupture to the eardrum and dislocation of the ossicular chain in the middle ear. Whereas exposure to continuous occupational noise over the years results in damage of only the inner ear. The subsequent sections of this chapter primarily deal with this second type of occupational noise exposure, which is more prevalent.

8.3 Pathophysiology of NIHL

Pathophysiology of noise-induced hearing loss (NIHL) has been extensively studied. The primary pathological basis of NIHL is the mechanical stress to cochlear structures. The cochlea is the hearing organ of the inner ear and houses the organ of Corti, within which are thousands of specialized sensory cells. Figure 8.1 shows the different parts of the ear highlighting the cochlea and sensory cells of the cochlea. These cells mediate between mechanical forces in the middle ear and electrical impulses of the cochlear nerve (Eighth cranial nerve). The noise exposure induces mechanical forces that drive the basilar membrane of the inner ear to vibrate. Excessive movement of the basilar membrane due to overexposure to noise causes structural changes in the sensory cells and supporting cells of the cochlea, in turn compromising cochlear function. Although overexposure to noise affects both peripheral and central auditory systems, the cochlea suffers the maximum damage. Also, it doesn't cause significant changes in either the outer or the middle ear. Within the cochlea, outer hair cells are specifically damaged. Outer hair cells of the inner ear are necessary to hear the sounds below 70dBSPL, and through their nonlinear properties, they expand the dynamic range of hearing. In other

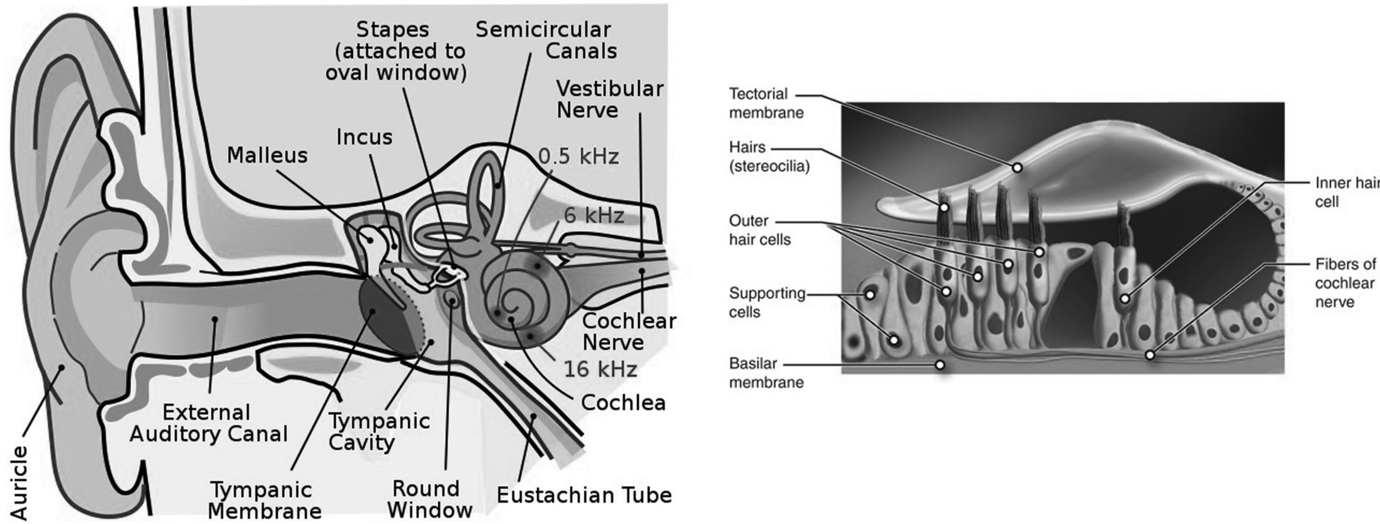

Figure 8.1 Different parts of the ear. Cochlea is a part of the inner ear and houses the sensory cells responsible for hearing.

Source: https://commons.wikimedia.org/wiki/File:Anatomy_of_Human_Ear_with_Cochlear_Frequency_Mapping.svg; https://www.coursehero.com/study-guides/nemcc-ap/special-senses-hearing-audition-and-balance/

words, in the absence of outer hair cells, one can have hearing loss up to 70dB and issues with loudness tolerance.

Individuals with NIHL have demonstrated disruption of stereocillia of outer hair cells of the cochlea, swollen nuclei of hair cells, abnormal mitochondria, cytoplasmic vesiculation, and vacuolization (Kim et al., 2014; Spoendlin, 1985). Metabolic damage is attributed to the formation of free radicals and glutamate excitotoxicity, leading to cell death (Yamane et al., 1995). Noise exposure can also increase free calcium (Ca2+) in outer hair cells (Fridberger et al., 1998), which in turn can trigger apoptotic and necrotic cell death pathways (Orrenius et al., 2003). Apart from these direct effects on the auditory system, noise exposure also causes psychological as well as physiological stress. The hypothalamus-pituitary-adrenal activity, which can modulate auditory sensitivity, is activated by noise-induced stress (Canlon et al., 2007), thereby can contribute to a reduction in hearing sensitivity.

8.4 Clinical Signs of Noise Induced Auditory Damage

The damage caused by hazardous noise may result in hearing loss, tinnitus (ringing sensation in the ear), blocking sensation in the ear and dizziness. Among these symptoms, hearing loss and tinnitus are more prevalent (Masterson et al., 2016). NIHL can either be temporary or permanent and is always of sensorineural type. If temporary (technical term is temporary threshold shift — TTS), hearing loss will be sudden in onset, mild in degree, and recover within a few hours or a couple of days (Humes & Durch, 2005). On the contrary, permanent hearing loss (typically referred to as occupational NIHL) will be gradual in its onset, can be severe in degree, and is irreversible. It takes several years of noise exposure for the NIHL to occur. NIHL is typically bilateral (occurs in both ears) and symmetrical between the two ears.

In these individuals, hearing sensitivity is assessed using pure tone audiometry. An audiologist tests their ear-specific hearing sensitivity in an acoustically insulated double room suite. The hearing thresholds at octave frequencies will be tracked in the air conduction (using headphones/insert phones) and bone conduction (using bone vibrator) modalities. A classical NIHL case shows a notch at 4 kHz in the pure tone audiogram (Boiler's notch). Hearing thresholds at frequencies between 3 kHz and 6 kHz will be at least 15dB poorer than the lower frequencies and that at 8 kHz (as depicted in Figure 8.2). If the exposure continues, hearing loss at 4 kHz increases, and there would be gradual involvement of the lower frequencies (depicted in curves 2, 3 & 4 of Figure 8.2). However, hearing loss at low-frequencies limits to about 40dB, while the hearing loss at high frequencies goes up to 70dBHL, even in extreme cases. If

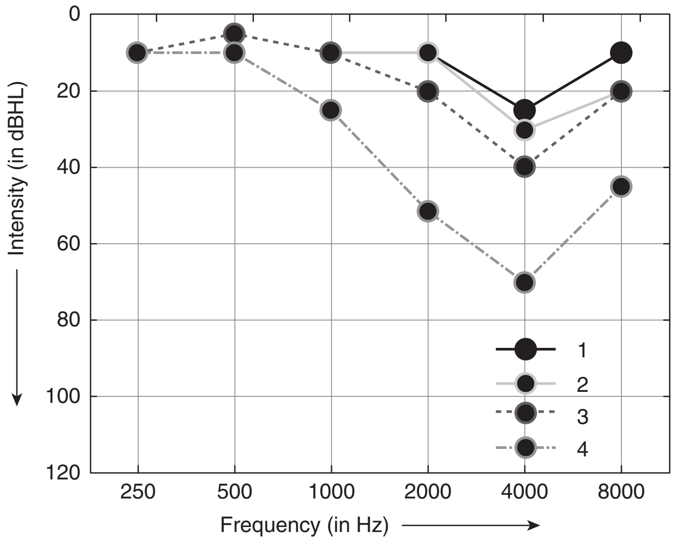

Figure 8.2 Pure tone audiogram indicative of NIHL. The audiogram shows a notch at 4 kHz. The notch grows deeper and wider with the increase in the number of years of noise exposure.

noise exposure is discontinued, there won't be a substantial further progression of hearing loss.

It is not necessary that every NIHL shows a 4 kHz notch in the audiogram. In instances of exposure to impulse noise, one may show a notch at 6 kHz instead of 4 kHz. If one only tests for hearing at octave frequencies in the pure tone audiometry (0.25, 0.5, 1, 2, 4 & 8 kHz), the notch in the audiogram will be missed out in such cases. Therefore, it is recommended that hearing thresholds be estimated at 3 kHz and 6 kHz also in those with a history of noise exposure. This ensures identifying NIHL with higher accuracy. Similarly, it is not necessary that every 4 kHz notch is indicative of only the NIHL. Some of the other causative factors of hearing loss, such as ototoxic drugs and acoustic neuroma, may also manifest with a 4 kHz notch in the audiogram. Therefore, obtaining the case history on noise exposure also becomes crucial in the accurate diagnosis of NIHL.

It is important to note that, with continuous noise exposure, there would be progressive covert damage to outer hair cells of the inner ear much before it is reflected as hearing loss. If the damage can be detected at this stage and subsequent noise exposure can be minimized, the occurrence of hearing loss can be prevented. Thankfully, it is possible to detect such covert damages using otoacoustic emission (OAEs) test. OAEs are low intensity sounds (below

30dBSPL) emitted by normal functioning outer hair cells. They can be evoked by an external stimulus and are recorded using a sensitive microphone placed in the ear canal. The test takes only a minute for each ear and is an objective test (doesn't need the active participation of the patient/subject). The mere presence of OAEs with good amplitude indicates that the outer hair cells are functioning normally: OAEs with reduced amplitude or absent OAEs suggest abnormal functioning of outer hair cells. Therefore, absence or weak OAEs can serve as an early indicator of noise induced damage to the inner ear and in turn help prevent of NIHL. Therefore, it is advised that persons exposed to hazardous noise regularly monitor the status of their inner ear functioning by undergoing OAE test.

There are four types of OAEs. Among them, transient evoked OAEs (TEOAEs) and distortion product OAEs (DPOAEs) are more used for the early detection of noise-induced damage to the auditory system, owing to their technical ease of recording and specificity rate. Both TEOAEs and DPOAEs give frequency-specific information i.e., one can assess the functioning of outer hair cells at each octave/mid-octave frequency similar to that in a pure tone audiogram. Considering that noise maximally impacts the 3 kHz to 6 kHz region, OAEs will show deterioration in this region first and eventually show a reduction in the other frequencies. However, deterioration in OAEs will occur a few years earlier to any such evidence in pure tone audiogram. TEOAEs and DPOAEs are generated by the outer hair cells, but the generation mechanisms are quite different between the two OAEs. It is unanimously accepted that TEOAEs are more sensitive to noise-induced auditory damage and can detect it earlier than DPOAEs.

8.5 Cochlear Synaptopathy and its Behavioral Consequences

Apart from damage to the inner ear, studies have shown evidences of deviant neural functioning in the auditory system due to noise exposure. Hair cells of the inner ear are innervated by the afferent and efferent fibers of the eighth cranial nerve (Spoendlin, 1985). The afferent fibers carry information from hair cells to the auditory cortex. Acoustic overstimulation compromises the structural and functional integrity of nerve innervations to hair cells. It results in degenerative changes in the synaptic junctions and the nerve fibers secondary to hair cell damage: swollen afferent dendrites have been found beneath the inner hair cells (B. Canlon, 1988; Goulios & Robertson, 1983). Such changes are likely to occur within 24–48 hours of overexposure to noise (Liberman & Mulroy, 1982) and are linked to the excessive release of glutamate (Puel et al., 1998), which is the principal neurotransmitter in the inner hair cells.

The changes in synaptic junctions and the nerve fibers have been technically termed "Cochlear Synaptopathy." The functional consequences of cochlear synaptopathy are found in the form of deviations in some of the suprathreshold measures of hearing and are typically subclinical in nature. Persons with cochlear synaptopathy will show normal hearing in pure tone audiometry, yet will have reduced central auditory processing abilities. They will have good speech perception abilities in a quiet environment but show poorer abilities when the same speech is presented in the presence of noise. The condition is referred to as "Hidden hearing loss" by one group of researchers. It is important to note that most daily listening environments are noisy, due to which persons with cochlear synaptopathy are likely to face challenges in understanding speech despite having normal hearing sensitivity. Kumar et al. (2012) found poorer temporal auditory processing and speech in noise perception abilities in normal hearing train drivers, exposed to occupational engine noise of more than 80dBA compared to their control counterparts. The evidences of cochlear synaptopathy have also been found in terms of deviant latency and amplitude of auditory brainstem responses (Pushpalatha & Konadath, 2016). A take-home message would be that the functional impairments in the case of cochlear synaptopathy are subtle, yet they can compromise the individual's quality of life. Even though pure tone audiometry will surely miss cochlear synaptopathy, it can be identified with special audiological tests. Effects similar to occupational noise exposure have been found in individuals who regularly use personal music systems. Kumar and Deepashree (2016) found that large proportions of young adults listened to their personal music systems at levels higher than the safety limits prescribed by regulatory bodies. They also found that those who listened at levels higher than 80dBLAeq showed reduced hearing sensitivity at extended high frequencies, reduced TEOAE amplitudes, reduced auditory processing abilities, and poor speech in noise perception.

Further, a few animal studies have investigated the effects of noise exposure levels below the DRC on auditory functioning (Noreña et al., 2006; Zhou & Merzenich, 2012). These studies have used noise levels that are lower than 80dB, which typically should not result in hearing loss. The findings reveal that even exposure levels below DRC have effects on central auditory processing, in spite of hearing being unaffected. Specifically, they have evidenced structural and functional changes in the auditory cortex. Maruthy et al. (2018) found that humans exposed to below-DRC levels of occupational noise tend to have poor stream segregation abilities than their control counterparts. This hints at the possible speech perception difficulty they may have in the presence of background noise. In summary, these evidences support that even the noise levels below DRC are deleterious to the auditory system. The DRC, when derived, was primarily based on the effects of noise exposure on pure tone hearing thresholds. The then scientific evidences were limited to hearing sensitivity. However, the current scientific evidences show that several subclinical structural and functional deviations occur much before the reduction in hearing sensitivity. These deviations can affect the persons' speech understanding in challenging listening environments, ability to appreciate music, and in general, their quality of life. It is time that we revisit the DRC on account of the current scientific evidences.

Scientific attempts have also been made to understand whether noise exposure at young age accelerates age-related hearing loss. One exposed to hazardous noise at a young age is likely to develop age-related hearing loss at an earlier age and develop a higher degree of hearing loss at an equivalent age than their counterparts who are not exposed to noise. While animal studies reveal that TTS at young age accelerated age-related hearing loss (Kujawa & Liberman, 2006), human studies offer only weak support for such a relationship (Gates et al., 2000).

8.6 Individual Differences in the Susceptibility to NIHL

Researchers have observed that, despite the nature of noise exposure being constant, there is a large variability in the resultant degree of NIHL: ranging from 10 to 70dB. This large variability is true for temporary as well as permanent threshold shifts. Several factors have been tested to verify whether they serve as predictors of susceptibility. They include TTS, age, gender, eye color, ototoxic drugs, middle ear muscle reflex, efferent auditory functioning, and genetic predisposition (Henderson et al., 1993). Most of these factors are poor predictors of susceptibility, except ototoxic drugs and middle-ear muscle reflex. Some ototoxic drugs such as aminoglycoside antibiotics and antineoplastic agents can interact significantly with noise resulting in greater hearing loss than could be caused by either agent alone. That is, if a person exposed to occupational noise consumes ototoxic drugs, he is likely to be more susceptible to inner ear damage, in turn to develop the NIHL. Ototoxic drugs as well as noise exposure results in increase of free radicals around the sensory cells, leading to cell death. Similarly, those with elevated acoustic reflex thresholds or absent acoustic reflexes are found to be more susceptible for NIHL than ones with normal acoustic reflexes. Studies in mice have revealed genes that underlie susceptibility to NIHL. However, their generalization in human cohort is debatable.

8.7 Noise Induced Tinnitus

Tinnitus refers to a ringing sensation in the ear in the absence of any such external sound source. Persistent tinnitus is a sign of deviant functioning in the auditory system. Abnormality anywhere in the auditory system can result in tinnitus, and noise-induced damage to the auditory system is no exception. Nearly one-fourth of persons exposed to occupational noise report significant tinnitus, and the prevalence is alarmingly high in military persons. The majority of persons with NIHL present with bilateral tinnitus, and the severity of tinnitus may vary with the degree of NIHL. The tinnitus either in isolation or along with NIHL can negatively impact the quality of life of the affected person.

8.8 Conclusions

Noise has harmful effects on the human auditory system. The exposure levels above the DRC can lead to permanent hearing loss by damaging the cochlea. However, if the noise exposure is inevitable, the damage can be minimized either by cutting down the noise at the source or by using hearing protective devices. The DRC holds true even for music exposure. The audiological tests such as otoacoustic emissions can determine the individual susceptibility to develop NIHL as well as detect the damage to the ear early. The persons exposed to noise in their routine shall consult Audiologists to understand the risk and monitor their hearing status.

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9

CARDIOVASCULAR EFFECTS

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9.1 Introduction

Robert Lacey once stated, "Of all the varieties of modern pollution, noise is the most insidious." The 21st century is witnessing, among other things, wars, burning of fossil fuels, increasing presence of vehicles, and industrialization resulting in the loss of natural quiet. Insights from epidemiological studies show that exposure to traffic noise (from aircraft, road vehicles, and trains) is associated with increased cardiovascular morbidity and mortality.[1]

Although medical and scientific efforts have focussed primarily on the diagnosis, treatment, and prevention of traditional cardiovascular risk factors (e.g., diabetes, smoking, arterial hypertension, hyperlipidaemia), recent studies indicate that the risk factors in the physical environment may also facilitate the development of cardiovascular disease.[2] Epidemiological and observational studies done by Munzel et al. demonstrated that persistent noise can trigger elevated levels of stress hormone (epinephrine) and this is supported by the Noise reaction model introduced by Babisch. During normal metabolic processes, the cells in our bodies produce unstable compounds known as free radicals and also antioxidants that neutralize these free radicals, hence maintaining the equilibrium. However, owing to certain factors such as diet, lifestyle, and the environment, the body's immune response gets triggered causing an imbalance and inflammation which ultimately leads to oxidative stress. These vascular changes have been found to contribute directly or indirectly to the initiation and progression of cardiovascular disease.[2,3]

With industrialization and globalization, the importance of new environmental factors such as noise pollution and its impact on the cardiovascular system is becoming increasingly evident.

Learning Objectives

- Understand the mechanism of cardiovascular system
- Review the molecular levels changes in the human body due to noise

- Study the adverse effects of noise on the human body
- Discuss the implementation of safety measures

9.2 Mechanism of the Cardiovascular System

In 1972, Saphiro and Baland were the first to record the intensity of noise and noise pollution and describe it as the "third pollution" after air pollution and water pollution.[2,3] As the intensity of sound moves northwards on the decibel scale, its ill effects on human health result in more severe and chronic health issues such as headaches, irritability, nervousness, fatigue owing to hypertension, increased heart rate, atherosclerosis, and cardiovascular disease.

Blood in the human body flows in a continuous movement through the capillaries that permeate every tissue and cell. The vital role of the cardiovascular system in our body is to maintain homeostasis, which depends on this controlled movement of blood.[4] Numerous control mechanisms help to regulate and integrate the diverse functions and various parts of the cardiovascular system to supply blood to specific parts of the body according to need. These mechanisms ensure a constant internal environment surrounding each body cell regardless of their differing demands for nutrients or production of waste products.[5,6]

The arterial system is regulated by three mechanisms: the autonomic nervous system, kidneys (Renin angiotensin – aldosterone), and endocrine system (catecholamines, kinin, serotonin, histamine).The autonomic nervous system is a part of the nervous system that controls involuntary actions such as heartbeat, blood flow, breathing, and digestion. This system consist of two divisions– sympathetic and parasympathetic –that work in unison to maintain balance.[6] The autonomic nervous system functions by receiving information from the environment and other parts of the body. The sympathetic and parasympathetic divisions tend to have opposing actions in which one system (sympathetic) stimulates a response while the other (parasympathetic) inhibits it.

Sympathetic efferent nerves are present throughout the atria (especially in the SA node) and ventricles, including the conduction system of the heart. Sympathetic stimulation of the heart increases heart rate and conduction velocity whereas parasympathetic stimulation of the heart has the opposite effect.[7,8]

In the blood vessels, sympathetic activation constricts arteries and arterioles, which increases vascular resistance and decreases distal blood flow. When this occurs throughout the body, the increased vascular resistance causes arterial pressure to increase. The overall effect of sympathetic activation is to increase cardiac output, systemic vascular resistance of both arteries and veins, and arterial blood pressure. Enhanced sympathetic activity is particularly important during exercise and emotional stress.[9]

9.3 Noise Effects at the Molecular Level

Noise is a nonspecific stressor that activates the autonomous nervous system and endocrine signalling. Such chronic stress can cause high cholesterol, high blood glucose, high blood pressure, increased blood viscosity, and activation of blood coagulation – leading to cardiovascular risk factors.

Blood vessels are lined with endothelial cells that produce powerful vasoconstricting and vasodilating substances such as the radical nitric oxide ($NO^{\cdot}$). Nitric oxide is a free radical which causes relaxation of the inner muscles of the blood vessels causing them to widen and increase circulation.

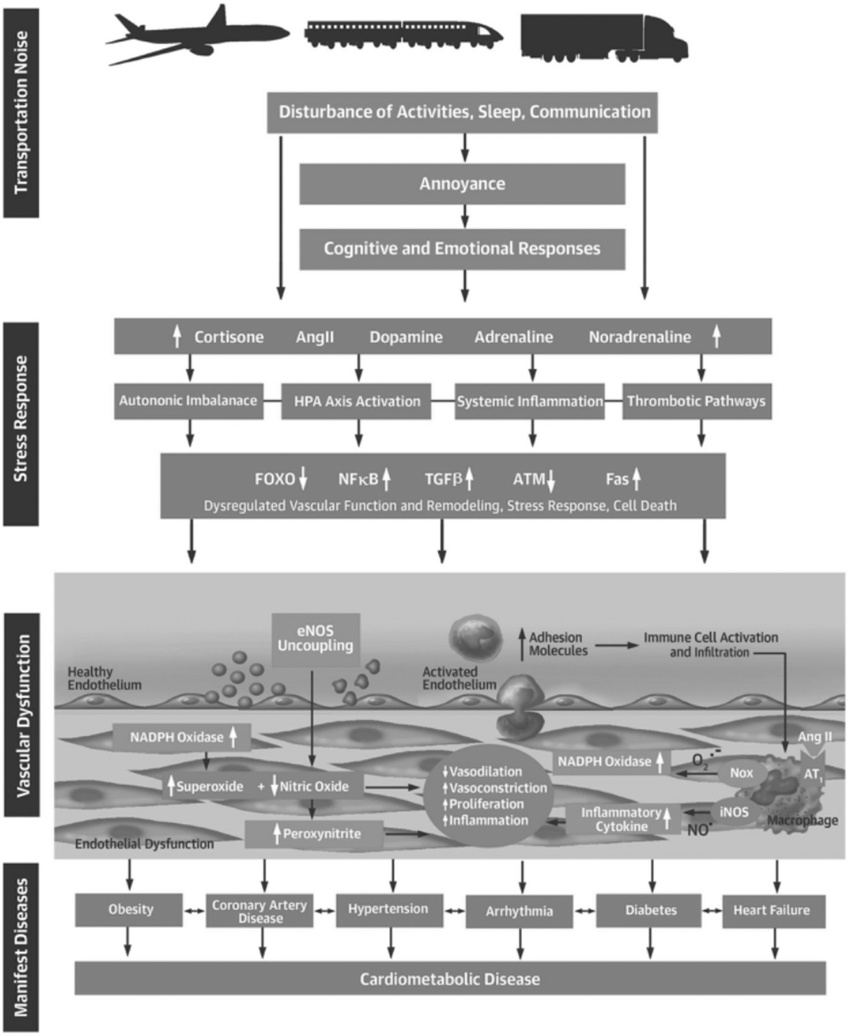
Stress induced by noise can also increase the permeability of the endothelium to inflammatory cells such as macrophages, leading to endothelial dysfunction and prothrombotic and inflammatory pathways. If stress persists for a prolonged period, it leads to a build-up of cholesterol and immune cells below the endothelium, which leads to plaque formation and, eventually, accumulation of smooth cells and lipids. Hence, acute noise stress can cause a physical disruption of the plaque, leading to cardiovascular events.[10]

Two enzymes play an important role in the induction of vascular function disorders –nicotinamide adenosine dinucleotide phosphate oxidase (NADPH oxidase) and nitric oxide synthase (NOS).The molecular effect of enzymes like NADPH oxidase and NOS due to noise, results in decreased bioavailability of the radical nitric oxide produced in the body, leading to deterioration of the endothelial function.[10,11]

9.4 Adverse Effects of Noise

Babisch, who proposed the noise reaction model, described two pathways – direct and indirect –for determining the adverse effects of noise on health. The nonauditory or indirect pathway, with an exposure of low-level noise ranging from 50–60 dB in the form of conversations, interferes with communication, concentration, daily activities, and sleep, resulting in annoyance, mental stress, and subsequent sympathetic and endocrine activation (Figure 9.1).[11]

It was this pathway that Babisch suspected to be the central player for noise-induced cardiovascular effects. He hypothesized that if the exposure is persistent and chronic, noise contributes to pathophysiological changes that are characterized by increased stress hormone levels, high blood pressure, and accelerated heart rate.[11]



Ang Il = angiotensin II; AT| = angiotensin receptor type 1; ATM = ataxia telangiectasia mutated; NOS = endothelial nitric oxide synthase; Fas = cell death signalling molecule (CD95); FOX = Forkhead box O; HPA = hypothalamic-pituitary-adrenal; iNOS = inducible nitric oxide synthase; NADPH = nicotinamide adenine dinucleotide phosphate; Nox = NADPH oxidase; NO = nitric oxide; O2 = oxygen; TGF = transforming growth factor.

Figure 9.1 Proposed pathophysiological mechanisms of noise-induced cardiometabolic disease.[21]

As a consequence, the body generates its own cardiovascular risk factors, including high cholesterol and glucose levels, increased blood viscosity, and activation of blood coagulation. If stress persists for years, cardiovascular diseases such as hypertension, coronary heart disease, heart failure, arrhythmia, and stroke can begin to manifest, along with mental stress or related disorders such as depression and anxiety, which are themselves known to negatively affect cardiovascular health.[12]

Hence, it has been proven that occupational noise exposure can produce adverse effects on the cardiovascular system including hypertension, ischemic heart disease (IHD), and stroke.

Hypertension

Blood pressure, or systemic arterial pressure, refers to the pressure measured within large arteries in the systemic circulation. This splits into systolic blood pressure and diastolic blood pressure. Systolic pressure refers to the maximum pressure within the large arteries when the heart muscle contracts to propel blood through the body. Diastolic pressure describes the lowest pressure within the large arteries when the heart muscle relaxes between beats.

The principal mechanism regulating arterial pressure within the blood vessels in the body is the baroreceptor reflex. Most studies have shown that long-term exposure to occupational noise significantly raised systolic blood pressure (SBP) and diastolic blood pressure (DBP) and increased the prevalence of hypertension.[11]

A study done on a subsample of HYENA (Hypertension and Exposure to Noise near Airports) data (n = 149) showed a non-dipping effect of diastolic blood pressure at night, which has been previously identified as an independent risk factor for cardiovascular disease with a more pronounced dose-response relation for men and affecting the middle-age group.[12]

Similarly, a meta-analysis of 24 studies by van Kempen and Babisch revealed that road traffic noise is associated with an elevated risk of the occurrence of high blood pressure starting at 45 dB and per increase of 5 dB. However, this analysis was restricted to cross-sectional studies.[13]

Atherosclerosis

Hyperlipidaemia, or high cholesterol, is a condition where there is high fat content in the blood. This is one of the most common risk factors for atherosclerosis.

Noise is found to be an environmental stressor that is believed to activate the endocrine system. Hence, elevated stress hormones in the body may stimulate an increase in blood lipids causing atherosclerosis which in turn leads to coronary heart disease, degenerative changes in the myocardium, and atherosclerotic changes in arterial blood vessels.[14]

One historical cohort study included male workers in high-level (n=154) and low-level (n=146) noise exposure groups and found a significant relationship between noise exposure and triglyceride concentrations in the two groups. Workers exposed to noise greater than 90 dB without ear protection appear to have increased triglyceride levels.[14]

Heart rate

The negative association between noise and endothelial function are seen more in patients with established coronary artery disease and can also cause altered heart rate. Some evidence shows that occupational exposure to noise may lead to increased heart rate in workers.[15] Data from the large, population-based Gutenberg Health Study (n= 15010 persons resident in Mainz and the Mainz–Bingen region) showed that the stress reaction to various sources of noise during the day and while sleeping at night is associated dose-dependently with an increased risk of atrial fibrillation.[16]

Increased cardiovascular risk was also confirmed in studies such as the Netherlands Cohort Study on Diet and Cancer, and Stockholm Heart Epidemiology Program which has acknowledged noise as one such potential agent along with air pollutants.

Beelen et al. investigated several cardiovascular diseases mortality end points in the Netherlands Cohort Study on Diet and Cancer using modelled noise levels.[17] For the highest noise exposure category (>65 dB L_{DEN}) they found increased relative risk (adjusted) for all cardiovascular diseases (1.25, 95% CI 1.01-1.53%) and heart failure. The study found, in addition, that the risk of ischemic heart disease and dysrhythmia were also elevated, but neither of the latter effects was statistically significant.

Selander et al. confirmed an increased risk for acute myocardial infarction morbidity in the Stockholm Heart Epidemiology Program.[18]

Stress

Noise has been found to trigger a stress response in the limbic system of the brain consisting of the amygdala, a region of the brainstem. This response from the brain is perceived as danger and sends a distress signal to the hypothalamus, a gland in the brain which controls the hormone system. The reaction triggers a release of cortisol (a stress hormone) which results in increased heart rate and blood pressure, a rapid release of energy in the bloodstream, reduced metabolism with a decrease in salivary and gastrointestinal activity, and activation of some immune functions.[18]

Insomnia

Sleep is an essential function during which the mind and body are recharged and is of vital importance for human development, optimal health, and overall well-being.

Sleep restriction has been found to be associated with decreased insulin production, inadequate pancreatic insulin secretion, changes in appetite regulating hormones, increased sympathetic tone, and venous endothelial dysfunction.

When individuals fail to obtain adequate duration or quality of sleep, they may experience reduced performance, measurable changes to different organic systems, especially to cardiovascular system, and increased risk of accidents and death.[19]

9.5 Conclusion

Noise is found to have ill effects on the human body and its consequence range from headache and anxiety to insomnia, obesity, diabetes, hypertension, atherosclerosis, and cardiovascular disease. It is also associated with oxidative stress, vascular dysfunction, mental stress, and metabolic abnormalities resulting in increased susceptibility to cardiovascular events.[19]

Measures should be taken to minimize noise by employing protective measures such as imposing standardized safety and health policies with regard to urban planning and industries.

Policies should work to bring noise exposure levels in line with the new guidelines developed by the World Health Organization, which lowered the recommendations for mean daily noise sound pressure levels to 45 dB for aircraft noise, 53 dB for road traffic noise, and 54 dB for railway noise, with even stricter limits for night-time hours to reduce the burden of disease from noise.

Along with this, the state and local governments should work towards providing adequate laws to prevent noise pollution near residential areas. Rolling noise in the form of the sound generated by the interaction of tires and road surface is the dominant noise source. This can be counteracted with the installation of quiet road surfaces, promotion of low-noise tires, and speed reductions in densely populated areas. Another strategy applied in some countries is the introduction of driving bans for trucks during the core night-time hours.

Public should also be made aware of the fact that loud sounds can be reduced by the use of barriers such as trees and fences, and by insulating buildings.[20] With these measured small steps, the overall ill effects of noise can be reversed over time.

9.6 Key Takeaways

- Prolonged exposure to excessive noise is now considered a health hazard.
- Occupational noise exposure can produce adverse effects on the cardiovascular system including hypertension, ischemic heart disease, and stroke.
- Noise is also associated with oxidative stress, vascular dysfunction, mental stress, and metabolic abnormalities
- Measures should be taken to minimize noise by implementing protective measures such as imposing standardized safety and health policies.

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10

NEUROPSYCHOLOGICAL EFFECTS

Topoti Baruah and Shantala Hegde

10.1 Introduction

Noise is unwanted sound but omnipresent in the modern world. Persistent loud noise in the environment leads to a deleterious effect on the nervous system and negatively impacts our health (1). Neurocognitive functions are the mental processes that helps us to receive, choose, store, modify, generate and recover information that are being absorbed from the external and internal sources. It includes functions such as attention, language, memory, concentration, and learning that enable us to adapt to the environment and function to an optimal level are most commonly affected by noise.

Learning Objectives

1. Understand how sound is processed and perceived by the brain.
2. Summarize the deleterious effect of noise.
   - 2.1. Identify the effect on cognition due to disturbance caused by noise.
   - 2.2. Explain how noise can serve as a barrier to communication.
3. Describe the impact of noise on the developing foetus during pregnancy.
4. Comprehend the effect of environmental noise on children and their school performance.
5. Compare the impact of road, aircraft, and railway noise exposure on children.
6. Predict how noise is affecting the aging population.

Key Terms

1. Auditory Cortex – part of the brain that processes auditory information.
2. Cranial Nerve – group of nerves that arises from the brain to provide motor and sensory information to the head and neck.

3. Superior Olivary Complex – major station in the ascending auditory pathway, which processes sound and binaural cues for sound localization.
4. Lateral lemniscus – tract of axons in the brainstem that carries information about sound from the auditory nerve to various brainstem nuclei and ultimately the contralateral inferior colliculus of the midbrain.
5. Brain Stem – The area at the base of the brain that connects the uppermost portion of the brain with the spinal cord.
6. Inferior Colliculi – A paired structure in the midbrain, which serves as an important relay point for auditory information as it travels from the inner ear to the auditory cortex.
7. Medial Geniculate Nucleus – principal relay nucleus for the auditory system between the inferior colliculus and auditory cortex.
8. Thalamus – located above the brain stem that relays sensory impulses from receptors in various parts of the body to the cerebral cortex
9. Neurodegenerative Disorder – it encompasses a wide range of incurable and debilitating conditions resulting from progressive damage to neurons or cells of the nervous system.
10. Somatic – relating to the body, distinct from the mind.
11. Psychosomatic – physical illness caused due to mental conditions such as stress, anxiety, depression etc.
12. Hippocampus – brain area primarily responsible for learning and memory.
13. Slow-wave Sleep – deepest phase of sleep considered responsible for memory consolidation.
14. Positron Emission Tomography (PET) – Neuroimaging techniques that uses a radioactive drug to study the metabolic and biochemical function of tissues and organs
15. Rapid Eye Movement (REM) – phase of sleep characterized by rapid movement of the eye, low muscle tone and vivid dreams.
16. fMRI – It is a non-invasive neuroimaging technique that measures brain activity by detecting changes associated with blood flow.
17. Parietal Lobe – One of the four lobes, that processes sensory information being received from external stimuli, primarily related to touch, taste, and temperature.
18. Oxidative Stress – it is an imbalance between free radicals and antioxidants in the body as a result of which the oxygen free radicals attack biological molecules such as lipids, proteins, and DNA
19. tau and β-amyloid (Aβ) – These are protein fragments, that gets accumulated in the brain causing damage and destruction of synapses that mediate memory and cognition.
20. Phosphorylation – A biochemical process that involves the addition of phosphate to an organic compound.

10.2 Sound Perception by the Brain

The *auditory cortex* in the *temporal lobes* is primarily responsible for auditory perception in the brain. The eighth *cranial nerve* (the auditory nerve) from the cochlea carries the auditory information, through the *superior olivary complex* and *lateral lemniscus* of the *brain stem*. The information then passes through the *inferior colliculi* involved in sound localization, then to the *medial geniculate nucleus* of the thalamus, where interaction between attentional processes and auditory information takes place. Finally, the information reaches the primary auditory cortex of the temporal lobes *(refer to* Figure 10.1*)*. The primary auditory region receives bilateral input – ipsilateral and contralateral inputs. The right ear transmits auditory information to the left cerebral cortex and vice versa (2). The primary auditory area is spatially organized, which means that different auditory frequencies are progressively anatomically represented. High frequencies are received and analysed in the anterior-medial portions and low frequencies in the posterior-lateral regions of the superior temporal lobe.

Language is primarily processed in the left temporal lobe, whereas the right temporal lobe is involved in the identification and recognition of nonverbal environmental acoustics (e.g., wind, rain, animal noises, prosodic-melodic nuances, understanding emotional meanings of sounds and music) (2). It has long been known that, under most circumstances, cognitive processing is easily disturbed by environmental noise and non-task compatible distractors. This effect is believed to be due to competition for attentional resources between the distractor and the target stimuli.

The ability to sort out and focus on meaningful auditory messages from a complex background of sounds is referred to as the cocktail party effect (3). The cocktail party phenomenon is an example of selective attention, which first occurs in the superior olivary nucleus. Selective attention enhances activity in one part of the sensory cortex and reduces it in other parts (2).

10.3 Deleterious Effect of Noise

Noise is unpleasant and unwanted indistinguishable sound. It can have an adverse effect on the various cognitive and neuropsychological functioning either directly or concomitantly. For instance, noise directly impairs attention and concentration. Moreover, noise can affect the quality of sleep that indirectly has a negative impact on attention and concentration. Noise is considered as a noxious stimulus and modern transportation and products of the latest technology emit extensive noise pollution of varying intensities all round the clock, causing annoyance, disrupting sleep, concentration and, other cognitive and biological functions (1). Noise is believed to affect physical health, specifically hypertension, heart disease and the release of stress hormone.

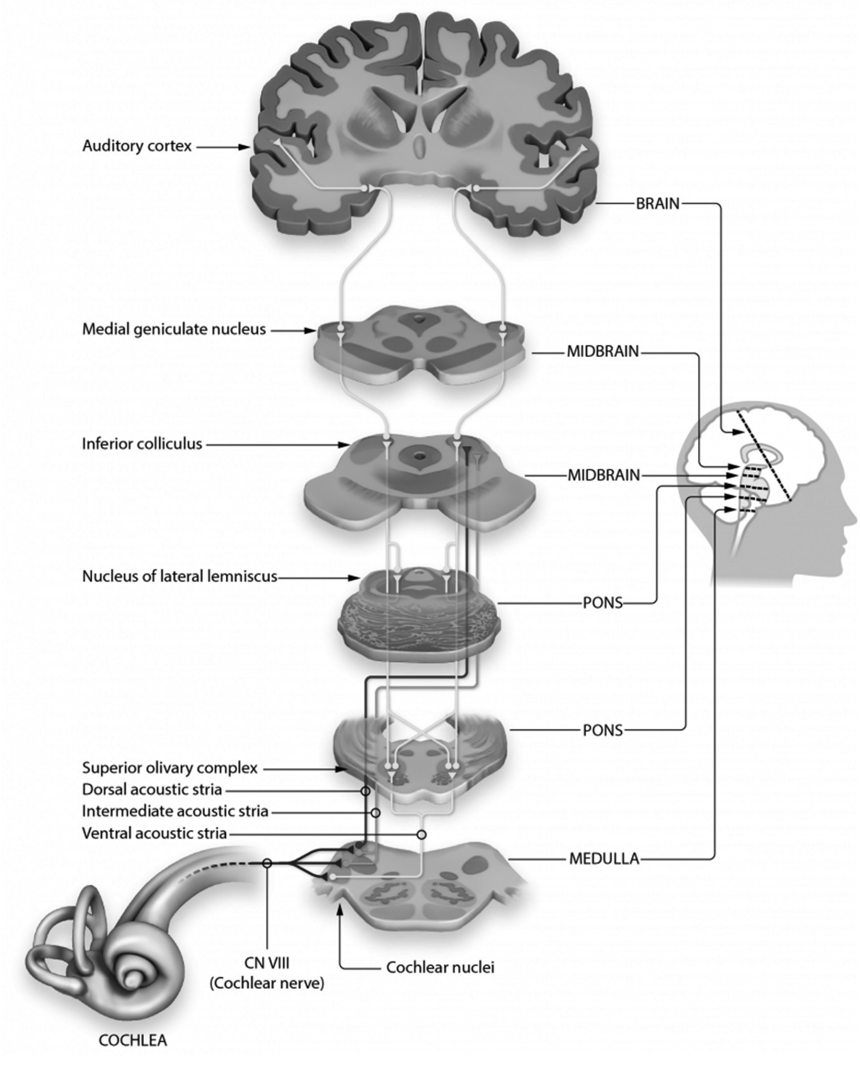

Figure 10.1 Schematic figure of the auditory neural pathway.

Source: https://osf.io/wuxh3

The impact of noise pollution on the cognitive and brain functioning of humans has often been ignored. Noise is considered as a risk factor for cognitive impairment and *neurodegenerative disorder*. It is considered that noise can affect health in either of the two ways. Firstly, noise can have a negative effect on health by causing annoyance in both adults and children. Annoyance is the feeling of uneasiness that does not encompass the number of negative reactions associated with noise, including, anger, exhaustion, helplessness, distraction. An inability to control the noise can escalate these affect, causing stress response and result in *somatic* and *psychosomatic* health issues. Low frequency (between 10 Hz to 200 Hz) noise along with vibrations are found to cause greater annoyance (1). The second way, noise can affect health is by disruption of sleep, resulting in poor quality of life and cognitive impairment.

Noise can interfere with cognitive processing and cause problems in both occupational and non-occupational environments. It can cause workplace accidents in roles requiring high levels of cognitive functioning as they need to maintain efficient performance while being exposed to high-intensity noise. Research evidence has shown that noise can lead to cognitive impairment and oxidative stress in the brain and has also been observed to negatively trigger the central nervous system causing stress, anxiety and memory defects. Attention is one of the primary cognitive functions on which other cognitive functions rely and can be significantly affected by noise. Furthermore, attention is responsible for various other activities such as motor movements, emotional responses and perceptual functions. Due to lack of adequate information processing, the attentional system controls human behaviour based on spatial and time-related characteristics, due to which strategic responses are not efficient, subsequently, degrading performance. Noise can also affect working memory performance but not performance speed. Other cognitive functions that are affected by exposure to noise are reaction time, memory, intelligence and concentration, to name a few. These affected cognitive functions can lead to increased error and accidents, resulting in reduced performance and productivity. Performance deficit can lead to both health and economic repercussion (1). However, certain research studies have demonstrated that noise can improve performance in sleep-deprived workers by enhancing arousal. Relevant literature has conflicting reviews on the effect of noise on cognitive performance. One review study conducted by Gawron (1982), on the effect of noise on cognitive performance, revealed that out of 58 studies, 29 studies reported having a negative impact on cognitive performance, whereas 22 has no effect and 7 has a positive effect. It has been found that loud noise at 100 dBA in comparison to 70 dBA elevates central visual stimuli processing but degrades peripheral stimulus processing. Parameters such as the characteristic of noise, exposure time, type of task, gender, age and sensitivity to noise collectively affect the cognitive performance of an individual (4).

10.3.1 Effect of Noise Disturbed Sleep on Cognition

Our hearing mechanism remains active even during sleep, therefore noise can be perceived subconsciously in sleep. The quality and quantity of sleep have a large impact on our day-to-day functioning. Lack of uninterrupted sleep is detrimental to our mental as well as physical health. Sleep disturbances resulting from noise can be primarily in the initiation of sleep, recurrent awakenings and difficulty in maintaining sleep, waking up earlier than usual and diminished REM sleep. These disturbances are considered to have the most deleterious effect on our cognitive function. One of the key roles of sleep on our cognition is the consolidation of various types of memory as well as insightful, abstract thinking. Neuroimaging studies have revealed that the *hippocampus* responsible for memory formation, remains active during a learning task, subsequently becomes reactivated during sleep, particularly *slow-wave sleep*. It was examined with *Positron Emission Tomography (PET)* by measuring cerebral blood flow to the hippocampal areas (5). Therefore, many researchers concluded that the recently encoded memories are activated and replayed again during sleep, hence, mediating memory processing. According to Stickgold (2009), slow-wave sleep stabilizes recently encoded memory and REM sleep integrates the memory into the larger neuronal networks. It has been suggested, in terms of exposure to noise during sleep that, continuous noise tends to interrupt REM sleep whereas intermittent noise exposure disrupts slow-wave sleep (6).

The importance of sleep in neuropsychological functioning has been demonstrated in several research studies. In one study by Van Dongen and colleagues (2003) subjects were restricted to 4, 6 or 8 hours of sleep time for 14 days. They were then assessed for attention, concentration and working memory several times during the day. It was found that the performance of the subjects obtaining 4 and 6 hours of bed-time deteriorated steadily, and after 14 days their performance was comparable to those who are sleep-deprived for 24 to 48 hours (7). A similar study showed that, in addition to attention, concentration and working memory, sleep-deprived subjects are found to have impairment in executive functions, verbal fluency, creative thinking and planning. Deficit in cognitive functioning was also observed in real-life circumstances requiring a high level of performance, e.g., medical interns. One study using *functional magnetic resonance imaging (fMRI)* has demonstrated that the areas of the brain that are activated in sleep-deprived subjects during the performance of an arithmetic task are far less than the areas activated in those with the rested condition while performing similar task. However, in the case of verbal memory, in a sleep-deprived state, additional brain areas including the *parietal lobe* get activated during the task performance, even though the overall performance remains comparatively poor (8). It indicates the compensatory role of the newly activated brain area. Therefore, sufficient evidence implicates that sleep disturbance is highly associated with poor cognitive functioning and noise pollution is one of the primary hindrances to quality sleep.

10.3.2 Noise as a Barrier to Communication

Understanding normal speech is obstructed by noise pollution resulting in a number of personal and behavioural difficulties. It involves concentration, fatigability, ambiguity, poor self-confidence, anger, irritation and misunderstanding, lack of working capacity, strained interpersonal relationships and stress reaction. Subsequently, it may result in increased chances of accident, impaired classroom learning, leading to poor academic performance (1). Noise pollution also affects task performance at school and at work, resulting in an increased error and reducing motivation. Domains that are most adversely affected by noise are reading, problem-solving and memory. Experimental research has primarily identified two domains of memory post noise exposure, namely, recall of subject content and recall of incidental details (1). It has been found that in a noisy home environment, children's cognitive and language development is decreased.

10.4 Impact of Noise during Pregnancy

In contemporary times, pregnant women are exposed to sound and noise, which could have an influence on the developing foetus, thereafter affecting the cognitive function of the new born (9). The central nervous system goes through structural and functional growth, during early mammalian life and hence, is more vulnerable to environmental stimuli such as noise. Hippocampus is an important structure of the brain responsible for memory formation and learning novel tasks. Another, primary structure of the brain includes the inferior colliculi which processes auditory information and relays it to the auditory cortex. It is believed that noise is transmitted via the inferior colliculi to areas of the hippocampus, influencing its function. Therefore, it can cause *oxidative stress*, which is highly implicated in cognitive impairment.

Conducting studies on human subjects to understand the effect of high decibel sound on the developing foetus during pregnancy has its limitation (9). Hence, animal studies are considered for the same. Cheng and colleagues (2011) conducted a study on mice to understand noise-induced cognitive impairment and its underlying mechanism. The study revealed that pre-natal exposure to noise can cause a reduction in the formation of new neurons in areas of the brain called the hippocampus, which is responsible for memory and learning, and the inferior colliculus which acts as a relay station in the auditory pathway. Thus, resulting in cognitive impairment (10). A similar study showed growth impairment, reduced neurogenesis in the hippocampus, and impaired spatial learning ability in pups due to noise exposure during pregnancy. Hippocampus is also regarded as a key structure for spatial learning and memory. In an experiment, conducted on one-day-old chicks, it was found that exposure to noise at 110dB, resulted in impaired spatial behaviour like spatial learning, memory and orientation (9).

10.5 Effect of Environmental Noise on Children

Children are considered as the most vulnerable group to the deleterious effects of noise, as childhood is the most crucial developmental age for cognitive development. Furthermore, children are less equipped to manage and exercise control over noise and the damage caused due to noise exposure can likely be irreversible. Each year 45,000 healthy life years are lost due to cognitive impairment in children aged 7–19 years, as computed by the World Health Organization in western European countries (11). Mechanisms by which cognitive functions are affected in children includes communication problem, stress, annoyance, frustration and sleep disruption, as children have less developed coping strategies than adults. Research studies have consistently revealed that environmental noise can affect cognitive performance of children. Children residing in deprived social conditions experience a higher level of noise and perform worse on tests assessing cognitive functions than do children not socially deprived. And it has been found that healthy normal children with fragmented sleep showed lower performance on neuro-behavioural functioning and behavioural problems (12).

10.6 School Performance

Studies have also revealed that children exposed to noise during school hours experience impairment in cognitive performance including central processing, reading comprehension and memory (13). Impairment has been found in sustained and visual attention (13). Similarly, reports collected from school teachers have revealed that children exposed to noise struggle concentrating in contrast to children studying in a quieter school environment. Auditory discrimination and speech perception is also found to be retarded in children experiencing chronic environmental noise, moreover, they also have a high demand for processing due to poor memory. Eventually, they tend to have poor reading ability and performance in school. Numerous pathways have been believed to be associated between noise exposure and impairment in children's cognitive functioning, namely; teacher and pupil frustration, learned helplessness, impaired attention, increased arousal, indiscriminate filtering out of the noise (14).

The first naturalistic study that was ever carried out in the '70s was by Cohen, Glass, and Singer, (1973) to investigate the effects of chronic noise exposure on primary school children living in a four 32-floor apartment buildings next to a busy road. The findings revealed that children living on the lower floors had greater impairment in comparison to children living on the higher floors in auditory discrimination and reading level. As children living on the lower floor are more exposed to road traffic noise than those living on the upper floors in the building (15).

10.7 Impact of Road, Aircraft and Railway Noise Exposure on Children

Several studies have shown that chronic rail, aircraft or road traffic noise exposure leads to a damaging effect on children's learning outcomes and cognitive performance. One such naturalistic field study by Hygge and colleagues (1996) (16) was carried out in Munich in the 1990s when the currently existing Munich airport was closed down and shifted to another location. In this longitudinal study, the effect of exposure to noise on children with a mean age of 10.8 years was investigated. Data collection was done at both the old and new airport sites on three occasions: first, before the old airport is shut down and the new airport is opened and two subsequently. Results of the first data analysis revealed that long-term episodic memory and reading comprehension are affected in children at the old airport site. The longitudinal results showed that after three sessions of testing, improvement was shown in children at the old airport in the domain of long-term memory, indicating that the effect caused is reversible. Children at the new airport were manifesting deficits in long-term memory and reading comprehension, supporting strong evidence for a causal link between noise pollution and cognitive deficits.

One of the largest multi-centre studies comparing the effect of road traffic and aircraft noise on the cognitive performance of children was conducted by Stansfeld and colleagues (2005) in the Netherlands, Spain and the UK. The result revealed no significant association between chronic road traffic or aircraft noise exposure on cognitive performance except reading comprehension (17). Therefore, the results of this study along, with other findings indicate that noise has a negative impact on reading comprehension or could be justified by other mechanisms such as learned helplessness, attention difficulty and frustration in both teacher and pupil. Children adapt to noise by filtering out unwanted noise and this filter may then be applied to situations devoid of any noise, leading to inattention and subsequent learning deficit.

Intervention studies have shown that reducing the noise level by either insulation or closure of airports is connected to the alleviation of cognitive functions, suggesting that noise reduction can reverse the negative impact caused by noise on cognition. One comparative study was carried out by Bronzaft and McCarthy (1975), to understand the effect of railway noise on children in comparison to children who are not exposed to any kind of environmental noise in a school. The findings reveal a significant difference in reading scores between the two groups of children. Further, the noise-exposed children's mean reading age was 3–4 months behind that of the children not subjected to noise (18).

10.8 Environmental Noise and Aging

The aging process has been found to be driven by environmental exposure such as noise pollution and is considered as one of the risk factors for dementia in the aging population. There is a large intersection of cardiovascular disease risk factors with cognitive decline and dementia. However, the degree to which noise pollution exposure directly affects cognitive decline, resulting in dementia is poorly comprehended. Dementia and cognitive deterioration are the primary health concern of the geriatric population, with a consequent increase in economic and social burden for the caretakers. The accumulation of *tau and β-amyloid (Aβ),* which are a type of protein, is considered to be the underlying cause of most nonvascular dementia and cognitive impairment. Animal studies have revealed that the high-level exposure of noise for long-term influences tau pathology and increased production of Aβ, and evocation of aberrant auditory input in the brain, resulting in abnormal changes in the cortex and the hippocampus (10). Oxidative stress in the brain due to noise exposure is also been suggested by most studies (19). It is not known whether there is a relevant period of noise exposure exists for late-life cognitive decline, however, exposures extending over decades or the entire life span are believed to affect these outcomes (19).

One long-term study by Nubaum et al., 2020, investigated the association of noise pollution with neurocognitive test performance and brain atrophy in older adults between 55 to 85 years of age. It was found that noise pollution has a damaging effect on higher neurocognitive functions such as vocabulary, verbal fluency and short-term/working memory, with local atrophy of the fronto-parietal network (20). A similar study conducted by Tzivian (2016), found a negative correlation between noise pollution and the scores of neuropsychological tests measuring verbal fluency, immediate and delayed recall

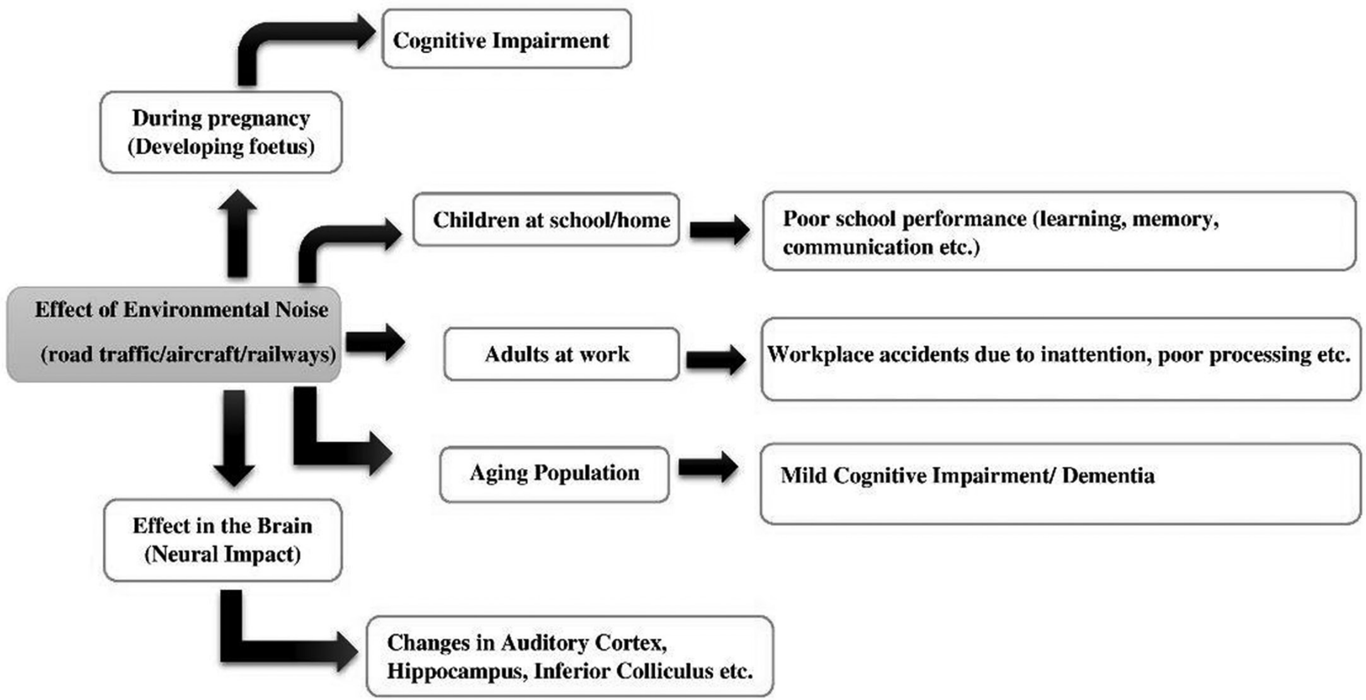

Figure 10.2 Effect of environmental noise exposure throughout life span.

tests, problem-solving and processing speed (21). Additionally, air pollution was found to be strongly associated with mild cognitive impairment, an earlier stage of dementia, for highly noise-exposed subjects, but not with participants who are not exposed to noise.

It has been hypothesized that chronic noise exposure affects the central nervous system in two proposed ways. First, sleep disturbance due to noise decreases vigilance in the daytime and increases oxidative stress in the brain mediating *phosphorylation* of tau protein, considered one of the earliest changes in the brain in Alzheimer's disease. Secondly, noise induces a series of signalling through the release of the stress hormone, causing changes in the auditory system, cortex and hippocampus. It is regarded as one of the significant neurochemical changes in Alzheimer's disease.

10.9 Conclusion

The impact of noise on our neuropsychological functioning is tremendous.

- Noise can have a detrimental effect on cognitive functioning across the lifespan. It can affect our cognitive functioning by disrupting sleep, causing annoyance, inattention and decreasing concentration.
- Noise can also indirectly affect productivity at work by reducing the quality of life.
- Exposure to noise during pregnancy can have a negative effect on the developing embryo leading to growth impairment in the brain structures.
- Children are the most vulnerable group of the population affected by noise exposure, as they are not able to exercise control over noise, unlike adults.
- Noise can also have a massive impact on the development of various late-life neurological conditions including Mild Cognitive Impairment and dementia.

  Noise can not only cause annoyance but it also affects our brain in many ways. Noise is inevitable in our daily life, and it is almost next to impossible to live in a completely noise free environment. However, being aware of the negative consequences of prolonged noise exposure on our neuropsychological functioning can help us make informed decision in modifying our living conditions to limit our exposure to noise and provide awareness to others as well.

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11

IMMUNE AND ENDOCRINE EFFECTS

Spurgeon R., Sanjana T. R. and Santosh B.

11.1 Introduction

Noise is one of the fastest growing environmental stressors with well-established direct and indirect effects on the human body. Low frequency noises (<100 Hz) have the potential to harm the human body, including the Endocrine and Immune system. Noise between 70–120 dB has the capacity to stimulate the release of the stress hormones apart from affecting the cardiovascular system like the increased heart rate and the blood pressure. Chronic noise exposure, with sustained physiological arousal, and the continuous effort to cope with this puts an individual at the risk of developing diseases because of the change in the hormonal milieu in the body.[1]

Learning Objectives

- To understand the basic concepts of endocrine and immune systems and their inter-relationship.
- To know the important effects of noise and music on these systems and their association with disease causation and overall well-being.

Key Terms

- Endocrine system: It is a messenger system in the human body, consisting of many organs called as glands. These glands produce substances/mediators called as hormones, which travel in the blood-stream to different tissues and have many important functions in the body.
- Receptors: These are chemical structures present on the target cells to which a specific hormone binds and exerts it's effect.
- Immune system: It is a complex network of cells, tissues and organs that help the body fight against infections and other diseases. It consists of different cells and organs.

- Pathogens: It is an organism that can cause disease in a human body. One such pathogen is micro-organisms, which are very small like bacteria, virus, etc.
- Cytokines: These are small proteins which are produced mainly by immune cells. They have an important function in maintaining the immunity of the body apart from some other functions.
- Auto-immune diseases: A condition in which the body's immune system attacks its own healthy cells, causing a disease

11.2 Overview of the Endocrine System

In simple terms, the endocrine system is the communication network in the body. It consists of a series of organs called glands, which are located throughout the body, and these help in regulating the important functions. Hypothalamus and pituitary in the brain, thyroid and parathyroid in the neck, pancreas, adrenal and gonads in the abdomen are some of the endocrine glands in our body. These glands release the chemical messengers called the hormones, in response to various stimuli, into the blood stream. The messengers travel through the blood to reach the different target organs and attach to the specific receptor sites like the lock and key system. Only the organs which have the specific receptors will respond to the particular hormone released in the blood stream.

The hypothalamus is an important gland in the brain. It plays a crucial role in producing the hormones that controls the functioning of the pituitary, the master endocrine gland of our body. Pituitary is a tiny gland, weighing about 500mg, but is the main regulator of the secretion of hormones from all the other endocrine glands in the body (thyroid, adrenal, testis and ovary). Few of the most important hormones such as cortisol and catecholamines (epinephrine and norepinephrine), which regulate the immune system and respond to stress, are secreted from adrenal gland.

The hypothalamic pituitary adrenal (HPA) axis is one of the most important neuroendocrine links. The hypothalamus releases the corticotrophin releasing factor (CRF). When this CRF binds to the CRF-receptor in the pituitary, a hormone called adrenocorticotrophic hormone (ACTH) is released. The ACTH binds to receptors in the adrenal cortex (outer part of gland) and releases cortisol (steroid hormone). The classical effects of cortisol are increasing blood glucose concentration and blood pressure, inhibiting growth and reproduction and regulating the immune system. Once a certain blood concentration is achieved, cortisol exerts negative feedback to the hypothalamus and the production of hormones seizes.

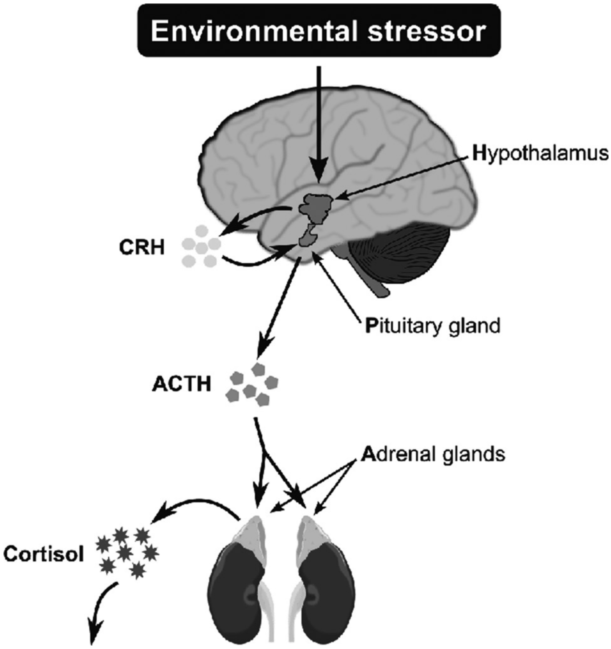

Figure 11.1 Hypothalamic – Pituitary – Adrenal Axis.[2]

– CRH: Corticotropin releasing hormone
– ACTH: Adrenocorticotropic hormone

Similarly, another system called the sympathetic adrenal medullary (SAM) axis is present. It is also known as the fight-or-flight system and is mediated by catecholamines, which are secreted by the adrenal medulla (inner part of gland). Catecholamines activate numerous beneficial responses like increased blood flow to muscles, heart and lungs while inhibiting processes like digestion. This system is very important for a human being to fight against any immediate threat.

The thyroid is another important gland, which is situated in the neck. It is also regulated by hypothalamus (through TRH – thyrotrophin releasing hormone) and pituitary gland (through TSH – thyroid stimulating hormone). The thyroid gland produces hormones called T3 and T4, which circulate to various parts of the body and are responsible for many important functions in the body like regulating body metabolism, maintaining body temperature, heart and bone health, menstrual cycles, brain development, etc.

The parathyroid glands are present in the neck behind the thyroid gland and are necessary for maintaining the calcium levels in the body. The ovary and testis are the glands present in females and males respectively, which play an important role in sexual development and reproduction.

11.3 Overview of the Immune System

Every day, the human body is exposed to several disease causing microorganisms. The ability of the body to protect itself from these pathogens is called immunity. This task is handled by the immune system.

The immune system is comprised of billions of cells that travel through the bloodstream. The most important of these are the white blood cells, specifically lymphocytes (B and T cells) and phagocytes. The B cells develop in the bone marrow, get activated on contact with foreign particles or pathogens (disease causing agents) and produce antibodies. While the T cells also originate in the bone marrow, they develop in a gland known as the thymus. They further differentiate into helper cells, cytotoxic cells and regulatory cells.

There are two types of immunity: Natural and Acquired. Acquired immunity is gained over the lifetime. It is specific to particular pathogen and mediated by antibodies or lymphocytes. The antibody mediated reaction is called the humoral immune response. The cellular immune response is initiated by the helper T cells, which release cytokines. Cytokines are small protein molecules that are the mediators of the inflammatory response. They initiate a call to action and attract other immune cells to take part in the reaction. The cytotoxic T cells release toxins and promote death of pathogens or unwanted cells, while the regulatory T cells control this immune response.

11.4 What Happens When the Body Is Stressed Due to Noise?

The brain responds to stress by sending a distress signal to the hypothalamus. The hypothalamus activates the SAM system by stimulating the release of catecholamines from the adrenal glands. As the initial surge of the catecholamines subsides, the hypothalamus activates the second component, the HPA system resulting in the release of the stress hormone called the Cortisol. Individuals under stress tend to have disturbed, fragmented sleep that leads to further increase in cortisol levels.[3]

Noise Stress Model[4]

Henry and Stephen proposed the link between the noise and the stress and how the hormones play a role in this. This was based on the psycho-physiological stress model. There are three types of reaction that will be elicited in response to the exposure of the noise at different intensities.

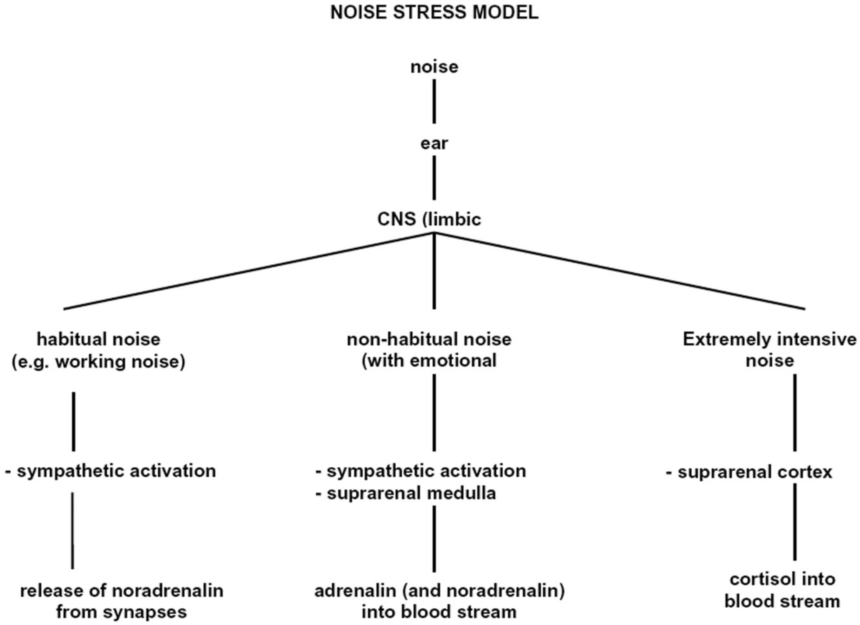

Figure 11.2 Noise Stress Model: Effect of Noise on Hormones.

Exposure to the loud habituated or non-habituated noise >90dB (A) stimulates the sympatho – adrenal system and release the adrenaline and noradrenaline from the sympathetic synapses. Whereas the extremely intense noise or above the threshold of pain will stimulate the release of cortisol by the activation of HPA system.

Acute and chronic endocrine effects of noise on animals and humans has been studied and was found that the acute noise exposure causes the increase in the levels of catecholamines; while extremely intense acute noise equivalent to threshold of pain, caused an increase in release of cortisol.[4]

A recent study showed that the suppression of the cellular and humoral response to noise stress was related to neuroendocrine changes. In this study they found that mice exposed to 4 weeks of 90 dB (A) white noise had a significant increase in cortisol and epinephrine along with a significant reduction in splenic lymphoproliferation, CD4 T cells and serum IgG levels.[5]

11.5 Interaction between the Endocrine and Immune Systems

The influence of the neuroendocrine system on the immune system is bi-directional. Not only does the neuroendocrine system affect the immune function, but the immune responses also have profound effects on the neuroendocrine system. The link between the two systems is due to the sharing of receptors and mediators. Hormone receptors have been found on immune cells while cytokine receptors have been found in both endocrine glands and nervous system.

Stress is known to influence the immune system via activation of the HPA axis and secretion of cortisol. Similarly, cytokines released by an immune response have effects on the hypothalamic control of hormones like ACTH and growth hormone.[6]

11.6 Health Effects of Noise

11.6.1 Endocrine System

Chronic low levels of stress keeps the HPA axis activated and also causes resistance to the negative feedback signals leading to over-production of stress hormones.

Diabetes Mellitus

The effect of stress on diabetes is multifactorial. However, the main culprit is the excess secretion of cortisol. Cortisol increases the blood glucose levels by converting the protein to glycogen and also by stimulating the catecholamine induced breakdown of this glycogen to glucose. It also induces the resistance to the action of insulin in different tissues like muscle and fat tissues, thereby increasing the blood glucose levels. High levels of cortisol can also result in the increase of body fat tissue and weight, which are risk factors for diabetes. Stress induced poor sleep affects glucose metabolism by reducing glucose tolerance and insulin sensitivity. In adults, there is a well-established relationship between stress and poor diabetic control.

Thyroid Disorders

Thyroid hormones are the regulators of body metabolism. Stress causes down-regulation of thyroid function by cortisol-induced inhibition of the secretion of TSH from the pituitary gland thereby leading to reduced production of thyroid hormones causing hypothyroidism.

Stress induced immunological disturbances can lead to production of thyroid receptor antibodies, causing autoimmune thyroid disorders such as Graves Disease (over active thyroid) and Hashimoto's disease.

Reproductive Disorders

Exposure to stress can lead to impairment of reproductive functions while prolonged exposure can cause infertility. Reproductive functions are regulated by the hypothalamic pituitary gonadal (HPG) axis which functions like the HPA axis. Cortisol can suppress this pathway leading to reduced circulating levels of testosterone and estrogen. Decreased levels of testosterone in males lead to reduced sperm count and motility. In females, reduced estrogen can cause anovulation, amenorrhea and other menstrual irregularities.

Besides these, excess production of the Cortisol secondary to stress can cause failure to thrive and psychosocial dwarfism in children. It is also implicated for the cause of obesity (over-weight) in children.[7]

11.6.2 Immune System

Chronic stressors are deleterious to immune system and leave the body more vulnerable to infections and other diseases.[8, 9, 10]

Infectious Disease

A chronically stressed individual is more prone to develop infections, especially viral infections. Individuals exposed to stress showed an increase in the rates of infection (74–90%) and also the reactivation of infections such as HIV and Herpes, which have remained dormant in the B cells, is more common with increased stress. The occurrence of common cold also increases (27–47%). This is due to the stress induced dysregulation of the humoral and cellular immune response to pathogens, which cause suppression of the host's resistance to infection. Stress is known to alter the antibody production and T cell response to antiviral vaccinations resulting in suppressed immune responses.

Wound Healing

Wound healing is a process that occurs during recovery from an injury or surgery. Inflammation is a pre-requisite for this process. Cellular immunity, through inflammatory cytokines and chemokines, plays an important role in the regulation of wound healing. Stress disrupts the production of these pro-inflammatory cytokines causing significant delay in the healing process.

Inflammation and Ageing

An increased level of IL-6, a pro-inflammatory cytokine was seen in chronically stressed individuals. IL-6 is associated with premature ageing of cells, increasing the risk of several age-related diseases like cardiovascular (heart) disease, arthritis, osteoporosis and frailty. It is also associated with higher mortality.

Cancer

Chronic stress, by increasing inflammation and altering the protective immune responses, increased the susceptibility to certain types of cancer. Increased levels of catecholamines have been associated with occurrence of cancer and metastasis (spread of cancer to other organs). Besides, several inflammatory mediators are involved in tumour growth and progression.

Autoimmune Disease

Noise related sleep disturbances was shown to increase risk of auto-immune disorders like rheumatoid arthritis (RA), systemic lupus erythematosus (SLE) and systemic sclerosis (SS), by suppressing the activity of regulatory T cells and production of cytokines. An increased level of IL-17 was associated with RA, SLE and inflammatory bowel disease (IBD). Increased activity of addictive habits like smoking have an indirect risk of certain autoimmune diseases like RA, SLE, SS, Grave's disease and primary biliary cirrhosis.

11.7 Benefits of Music

The therapeutic use of music is well-documented. Numerous studies have found that listening to pleasant music has a calming effect on the body. Happiness trifecta is a term used to define the positive emotions and mood the body experiences and this is driven by certain hormones like dopamine, serotonin and oxytocin. Music has a strong correlation to elevate these hormones causing the feeling of happiness and relaxation.

The music reduces the stress levels in the body. It is known to reduce the levels of cortisol and catecholamines. This leads to decreased incidence of cardio-vascular diseases. There is some evidence that classical music has a beneficial effect on the thyroid hormones. Besides, music also improves the immunity of a person and reduces the occurrence of infections and some of the auto-immune diseases.[11]

11.8 Conclusion

Stress is a part of life. The body responds to environmental noise similar to other non-specific physical stressors by activation of the HPA and SAM systems, apart from changes in other organs of endocrine system.

- The deleterious effects of exposure to noise on the endocrine and immune systems are mediated mainly by increased levels of cortisol. This, in long term, can result in increased occurrence of diseases like diabetes, hypertension, heart diseases, etc.
- Exposure of noise can affect the other endocrine glands and cause thyroid dysfunction, reproductive problems in both males and females.

Music on the other hand is shown to have some beneficial effects on the endocrine and immune systems of the body by reducing stress levels and its associated complications.

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12

IMPACT OF INFRASOUND

Bhujanga Rao Vepakomma and Badari Datta H. C.

12.1 Introduction

It is documented in many text books that human beings have the ability to hear sounds with the frequencies ranging from 16 to 20,000 Hz and that sound is inaudible below 16 Hz.[1] But the fact is hearing sensation does not suddenly cease at 16 Hz and ear responds to sounds with much lower cut off of 1.5 Hz. Since hearing sensitivity decreases with frequency, humans perceive infrasound when sufficient sound pressure level exists as necessary stimulus. Infrasonic sound therefore refers to sound wave with a frequency varying from 0.01–16 Hz. Watnabe and Moller (1990)[2] have demonstrated that at high stimulus levels, humans can hear sound as low as that of 4 Hz. Till this was published people thought that the hearing of human ear starts at 20 Hz. But the stimulus pressure level required for the ear to feel the hearing sensation has to be more by 28 dB compared to pressure level at 20 Hz.

Table12.1 gives threshold levels of hearing from 4 to 200 Hz by healthy human beings. Sounds between 16 Hz and 500Hz are classified as "Low frequency noise" and it is common to combine together the "infrasound and Low frequency" noise (ILFN) due to the unique characteristics of this particular frequency range in interaction with human body. This chapter will deal mostly with the effects of sound in this ILFN range.

Sources of infrasound in nature which include infrasonic sound sometimes results from severe weather, surf, lee waves (mountain size waves), avalanches, earthquakes, volcanoes, bolides (a large meteor when explodes), waterfalls, calving of icebergs, aurorae (caused by charged particles from sun entering into earth's magnetic field and stimulating particles in the earth's atmosphere), meteors and lightning. etc., are known to lie between 0.1 to 1.0 Hz. Human activities also produce infrasound, like running by sports persons, sonic booms, explosions, machinery such as diesel engines, wind turbines and specially designed industrial vibration tables etc. which generally goes up in the range up to 500 Hz. A number of species of animal kingdom such as whales, elephants, hippopotamuses, rhinoceroses, giraffes, okapis, peacocks, and

Table 12.1 Frequency and the threshold levels

Freq (Hz)	4	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200
Level (DB)	107	100	97	92	88	79	69	60	51	44	38	32	27	22	18	14

Source: https://journals.sagepub.com/doi/pdf/10.1260/0263-0923.28.2.79

alligators are known to use infrasound to communicate over long distances. They use sounds in the infrasonic and low frequency range for their habitation and survival. For example, baleen whales can produce sounds of 10–31 Hz, which potentially travel hundreds of kilometers in underwater.

Learning Objectives

- To understand the origin of natural and manmade infrasound and ILFN
- To understand the generation, transmission and attenuation of infra sound.
- To understand the basis for infrasound-human body interaction through the cellular model based on tensegrity structure.
- To understand how infrasonic waves interact with the human body.
- To understand the symptoms and pathology of vibroacoustic disease.

12.2 Infrasound Propagation Characteristics

Sound waves at low frequencies suffer less attenuation while travelling in any media and therefore will travel farther. Low frequency sound easily passes through barriers like walls, headphones etc. with less reflection and less attenuation unlike it happens at high frequencies of sound. The low frequency sounds bend over the wall and return to the ground due to large wavelength. The wavelengths of sound frequencies audible to the human ear (10 Hz–20 kHz) are thus between approximately 34 m and 17 mm. To design a barrier to protect the body from this sound, one has to design it to a thickness 8.5 m which is not practical to realize. It is a very difficult to protect by closing a door or building a wall or wearing an ear plug against infrasound waves. These waves easily penetrate all obstacles to almost full strength. Special sound absorbing ear defenders can offer some protection to one's hearing.

12.3 Infrasounds and Animal Communication

Infrasounds, though out of easily perceivable audible range for humans, are used for communication in many animals in nature. Whales, giraffes, peacocks, rhinos, hippopotamuses, elephants, tigers and alligators are some of the animals known to us that use infrasounds for communication. The purr of felines is reported to cover a range of 20–50 Hz, and the roar of a tiger itself has an incredibly low frequency of only 18 Hz! Researchers have found a tiger roars at 18 HZ frequency producing a sound that can make its prey to go disoriented making it is easy to paralyze the victim with fear.[3] Natural infrasounds can also work as a navigational aid in case of many migratory birds.

It is a known that 7HZ infrasound has the capacity to create theta wave in the brain which is known to be associated with meditation and harmony. This 7HZ musical products are known to take human beings into a kind of musical trance. Infrasound is also known as sound of fear. Scientists discovered that low frequencies in infrasound can effect humans and animals in several ways causing discomfort, dizziness, blurred vision (by vibrating eyeballs), hyperventilation and fear possibly leading to panic attacks.

12.4 Cellular Model to Understand Pathology by ILFN

The traditional model of the biological cell presumes it to be an elastic cortex surrounded by a viscous cytoplasm which holds an elastic nucleus at the center. For the past 30 years, the Ingber lab at Harvard medical school[4] has been showing that this balloon model of the cell is grossly inappropriate. Instead, a cellular model based on tensegrity architecture has been proposed and has been successfully explaining many cellular and tissue behaviors, both during normal metabolic activity and in disease alike. The new cellular model is important in understanding the type of pathology developed by ILFN-exposed organisms because only the tensegrity model appropriately explains how mechanical signals are transduced over cells and tissues. In this model of tensegrity (tension integrity) model, there are some structural components in tension and some structural components in compression and together they form a cellular structure to handle mechanical loads.

Infrasonic sounds are produced in human body as vital sign in the 1–16HZ frequency range caused by the mechanical movement of the heart and can be recorded non-invasively with simple instruments. Ballistocardiography (BCG) is a known technique for graphically studying the repetitive motions of the human body caused due to ejection of blood into the blood vessels with each heartbeat. Similarly other techniques, such as seismocardiogram (SCG), are used to understand abnormalities of heart related aliments combined with machine bearing algorithms.

12.5 Interaction of Infrasonic Waves with Human Body

Phenomenon of resonance occurs when an excitation frequency of an external vibratory force coincides with natural frequency of human body. At resonance, the human body absorbs the energy with high efficiency and experiences high vibration amplitude causing discomfort and/or damage to the human body. The damage could be at cellular level or tissue level or even an organ level.

The natural frequencies of a healthy average human body is given in Table 12.2 below.

Human body has some rigid hard structures like head, spine and some flexible tissue filled structures like thoracic cavity and heart. The natural frequencies of these parts vary according to their stiffness and distributed mass. The natural frequencies of other parts such as pelvic cavity, abdomen etc. remain in between.

If a human body is exposed for a longer period of such ILFN of varying frequency, the body will go into resonant vibration problems, which may slowly lead to urinary, digestive, nervous and cardiovascular system diseases culminating into serious physiological disorders.

Thus, the sensation we feel inside the body is not necessarily through the ears but because of the resonance effect in the body. The natural frequency of a big building is in the range of fraction of 1 Hz to 3 Hz, which is close to that of the body's. This explains why infrasounds commonly present, annoy/affect people living in big buildings. The feeling of unpleasantness or uneasiness that some people experience in some older churches is found to be due to the harmonics of sound created in giant organ pipes at the infrasound frequencies. The long-term effect of infrasound waves on human beings who live close to such sources of sound include headache, laziness, dizziness, nausea, irritability etc. If the intensity level is high these problems may precipitate into respiratory impairment and aural pain. The frequencies associates with these problem is given in Table 12.3.

Excessive exposure to ILFN can cause Vibro-Acoustic disease (commonly known as VAD),[6] a systemic pathology characterized by the abnormal proliferation of collagen and elastin fibers without the presence of any inflammation. It has also been found in people exposed to natural/environmental ILFN in Industries like sheet metal fabrication, ship building industry, aircraft industry,

Table 12.2 The main part of the human body's natural frequency[5]

Body part	**Natural frequency (Hz)**
The whole body	7.5
Body torso	7–13
Head	8–12
Thoracic cavity	4–6
Heart	5
Abdominal cavity	6–9
Spine	10–12
Eye	17–19 Hz
Pelvic	6 Hz

Table 12.3 Sound (frequency) and its effect on the body

Freq (Hz)	Effect on the body
4	Respiratory difficulty
9 – 10	Vomiting Sensation (Nausea)
17 – 19	Anxiety & Fear, Visual disturbances, Altered sensorium and Chills

etc. Simultaneously, other populations occupationally exposed to ILFN were also studied like helicopter and military pilots.[7] It was found that the fundamental agent of disease to which aircraft personnel were exposed was ILFN.[7] All aircraft technicians presented abnormal pericardial and/or cardiac valve thickening.[8]

In 1993, during a scientific meeting, the term "vibroacoustic" was proposed for this pathological entity and "vibroacoustic syndrome" became the new name for the ailment seen in aircraft technicians and now, also in aircraft and helicopter pilots.[9]

Additional neurological disorders were found in ILFN-exposed populations, such as the existence of the palmo-mental reflex, usually only seen in primates, newborns, and the elderly (balance disturbances and facial dyskinesia induced by auditory stimuli).[10] The first human pericardial fragments were studied in VAD patients who needed cardiac bypass surgery for other reasons. Abnormal amounts of collagen as well as the neo-formation of an extra layer of tissue was shown to be the cause underlying the pericardial thickening, supplying anatomical confirmation of the autopsy and echo-imaging observations.[11]

Other ILFN-exposed professionals were also studied, such as civil aviation pilots and cabin crewmembers, confirming echocardiography results of aircraft technicians and military pilots.

More neurological pathology was found: VAD patients were found to be unable to hyperventilate when in the presence of excessive CO_2.[12]

Mechanically induced cellular death was found in the pericardia of VAD patients and it was hypothesized that this situation could be related to the large incidence of auto-immune disorders in these patients.[7]

All bronchoscopic examinations of VAD patients showed lesions that, upon analysis, proved the existence of abnormal amounts of collagen and neo-formation of vascular beds. Disrupted collagen fibers were seen and correlated with a positive testing of anti-nuclear antibodies, providing a deeper understanding of auto-immune processes.[12]

12.6 ILFN Exposed Animal Studies

- Animal studies showed that the respiratory tract could be considered a primary target for ILFN: abnormal amount of fibrosis/collagen was ubiquitous in trachea, lungs and pleura; damaged (sheared) tracheal and bronchial cilia; fused actin-based microvilli of tracheal and bronchial brush cells. The atypical cases of pleural effusion were partially explained by morpho functional impairment of pleural microvilli[13] as well as of pleuralphagocytic capabilities.
- Wistar rats were chosen as animal models to investigate the effects of ILFN exposure on the respiratory tract, to explain the atypical cases of pleural effusion, of unknown etiology.
- The genotoxicity of ILFN was proved in both human and animal models and was confirmed by teratogenic features in mice.[14]

Further rat studies suggested that fusion of cochlear cilia (actin-based structures) may supply a biomechanical explanation for noise intolerance or annoyance.[7]

12.7 Symptoms and Stages of VAD

(The below data in Table 12.4 is based on research conducted on 140 individuals working in an aeronautical industry. ILFN exposure time (years) refers to the amount of time it took for 70 individuals (50%) to develop the corresponding sign or symptom[12]).

Table 12.4 Stages of VAD

Stage I-Mild (1–4 years)	Light mood swings, indigestion and heartburn, mouth/throat infections, bronchitis
Stage II-Moderate (4–10 years)	Chest pain, definite mood swings, back pain, fatigue, fungal, viral and parasitic skin infections, inflammation of stomach lining, pain and blood in urine, conjunctivitis, allergies
Stage III–Severe (4–10 years)	Psychiatric disturbances, haemorrhages of nasal, digestive and conjunctive mucosa, varicose veins and haemorrhoids, duodenal ulcers, spastic colitis, decrease in visual acuity, headaches, severe joint pain, intense muscular pain, neurological disturbances

Aural Pain: This is known to occur when displacements of the middle-ear system undergoes beyond its comfortable limits. It is researched that persons with hearing ability and hearing loss and with normal middle ears experience aural pain at similar intensity levels of about 165 dB at 2HZ.[13]

12.7.1 Pathology Associated with VAD[7,15]

i. Pericardial thickening— In human beings affected by VAD, it was found that there is pericardial thickening, without any pericarditis or inflammation.
ii. Actin-based structures—
    - Brush cell (BC) microvilli and cochlear cilia: it was found that among rats exposed to ILFN, clustering of the microvilli occurred, and on prolonged exposure, fusing of the microvilli occurred.
    - It was also found that the cochlear stereo cilia are also fused among themselves and to the upper tectorial membrane.
    - The appearance of respiratory tract epithelium is such that they appear clipped, sheared or shaggy.

12.7.2 Some Important Considerations on Behalf of VAD Patients[16]

Hearing impairment is the only pathology that can develop due to excessive noise exposure. Therefore, occupational physicians rarely see VAD symptoms as caused by excessive noise exposure. In fact, given the multitude of symptoms associated with VAD, often physicians regard the patient as a malingerer or hypochondriac. This is also collaborated by the fact that routine medical tests (e.g.: blood chemistry analysis, Electrocardiography (ECG) and electroencephalography (EEG)) do not confirm the existence of any pathology. The reason for this is that most of the medical diagnostic tests are based on biochemical, and not biomechanical pathways. In the case of occupational exposure to ILFN, workers can develop some disabilities which call for early retirement. Usually, ILFN environments are associated with machinery that, in an ever-changing technological environment, often becomes obsolete within a few years' time. Hence, the VAD developed by many individuals cannot be proven since many of the ILFN sources no more exist to correlate easily.

12.7.3 Diagnosis of VAD[16]

A specific characteristic of VAD is pericardial thickening with no diastolic dysfunction. Therefore, to identify this, an echocardiogram would be a preferred means to evaluate thickening of pericardium and cardiac valves. However, this will only suffice for an informal diagnosis due to the limitations of echo-imaging procedures. A legal or forensic proof for the presence of VAD can only be provided by more invasive procedures like bronchoscopic examination and other complementary tests such as brainstem auditory evoked potentials, brain MRI, PCO2 rebreathing test, cognitive evoked potentials, blood coagulation factors and a thorough neurological examination.

Given below are some key symptoms of VAD as expressed by patients, which can aid in its diagnosis:

- People may complain of being extremely sensitive to noise, and not being able to stand any type of noise. Loud noises cause much mental disturbance, making them uneasy when exposed to any sound.
- Patients may also report prolonged fatigue and waking up tired despite enough hours of sleep
- Patients may also experience shortness of breath in public spaces such as malls or restaurants and have a strong feeling that they cannot breathe and must get out of there
- Patients may also experience heart palpitations for prolonged periods as well as with high intensity
- They may also report having a cough, though they don't smoke. The patient may also report having a hoarse throat and constantly irritated throat with over-the-counter-medication being of no use.

Or if the patient enters with one of the following diagnoses:

- Late-onset epilepsy
- Auto-immune disease, particularly systemic lupus erythematous and vitiligo
- Balance disorders
- Recommendation for cardiac bypass surgery
- Migraine
- Respiratory tract tumor, especially if a non-smoker

12.8 Safety Standards for Infrasound

It is to be stated that there are no proper standards or recommendations from national and international agencies for protection of humans from infrasound. The main reason for this state of affairs is the difficulty in the measurement of sound wave intensities at infrasonic frequencies. World Health Organization

(WHO) has also recognized that the general assessment measures for environmental noise are deficient for evaluation of noises with large low frequency components.[17]

There are four causative factors of human disease and illness. They are biological, chemical, physical and psycho-social. The infrasound or low frequency noise come under the physical causes of disease. For this reason WHO classifies it as inanimate mechanical force as the damage is done by a physical force.

12.9 Conclusion

Infrasound is clearly audible up to a lower cut off frequency of 1.5 Hz but the threshold of hearing is comparatively high at infrasonic frequencies. Infrasounds and low frequency noise form important sources of disease and ill-health among individuals. Due to mechano-vibratory effects, it can cause multiple pathologies like thickening of pericardium, changes in the microvilli structure of respiratory epithelium etc. on the human body.

- Sources of infrasound include low-frequency natural occurrences, low-speed machinery sources like wind turbines, diesel engines etc. and these sources become causative factors of ill health only when they exceed certain stimulus level which need to be established properly.
- The routine measurement of infrasounds is grossly inadequate and it is important to know the ill effects of infrasounds, collectively known as vibroacoustic disease.
- The physicians need to be sensitized about the symptoms and signs of vibroacoustic disease.
- Significant research and proper legislation are needed to mitigate the effect of infrasound and low frequency noise (ILFN) on humans to reduce effect on health due to exposure to ILFN.

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Part IV

PREVENTING DELETERIOUS EFFECTS OF NOISE

13

AN OVERVIEW OF NOISE POLLUTION AND NOISE CONTROL MEASURES

Alexander Thomas and V. C. Shanmuganandan

13.1 Introduction

Even as recently as the mid-19th century, most of the sounds on planet Earth were mostly of a natural origin. In a matter of just over three quarters of a century, most of the sounds on the planet are now being caused by man's technological inventions which not only disrupt the natural environment but also have a direct and deleterious effect on the health of the human and animal population of this planet. However, as technological progression seems inevitable, noise is becoming an integral component of present-day life, especially in urban areas as compared to the rural. Realizing the fact that noise pollution is becoming a matter of great concern the World Health Organization (WHO) has declared noise as the second largest environmental cause of health problems, just after the impact of air pollution.

This chapter attempts to provide a broad view on the definition of the term 'noise pollution', its effect on health and the legal options available in our country to ensure that noise in our environment is kept within acceptable limits. It also includes details of how individual citizens can play a part in this endeavour.

Learning Objectives

- Recognizing noise as one of the causes of pollution
- Understanding measurement of noise and its value in determining noise pollution
- Sources of noise pollution
- Ways and means of combating noise pollution (noise control)
- Legal options available in India for noise control
- Ways to become a responsible citizen and contribute towards noise control in an individual capacity

13.2 Noise and Noise Pollution

The word 'noise' is derived from a Latin word 'nausea', meaning a condition wherein one feels like vomiting. According to WHO's findings, noise is the second largest environmental cause of health problems, just after the impact of air pollution and that "noise must be recognized as a major threat to human wellbeing". In common man's language noise refers to unwanted sound and, in fact, noise pollution is a type of energy pollution in which distracting, irritating or damaging sounds are freely audible. Normal sound becomes undesirable when it disturbs our normal activities such as working, sleeping and conversations.

In 2018 (the latest year for which data is available) Chennai was ranked as the noisiest among India's six metros with average noise levels during the day being 67.8 dB.[1] The Government of India mandates that noise levels in residential areas should not exceed 55 dB during the day and 45 dB at night. In the 13 monitoring stations in residential areas across the six cities, this limit was violated during both day and night throughout 2018. Even designated silent zone areas around hospitals, for instance, do not meet noise pollution standards; the area around Paradise Junction in Hyderabad, a major commercial hub and traffic choke point, is India's loudest at 79 dB.

As with other forms of energy pollution (e.g., heat and light), noise pollution contaminants are not physical particles, but rather waves that interfere with naturally occurring waves of a similar type in the same environment.

Sound has both volume and pitch, and is measured in terms of its intensity or loudness (often referred to as volume) in units called decibels (dB). The unit is named in honour of Alexander Graham Bell, the inventor of the telephone and audiometer. Pitch is the number of times per second that a sound pressure wave repeats itself. The unit of frequency is called Hertz (Hz). It is named after Heinrich Rudolf Hertz, a German physicist.

Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz. Frequencies above 20,000 Hz are known as ultrasound. The quietest noises the human ear can perceive are around 10 dB, whereas sounds of 130 dB are considered painful. Sound travels at a speed of 343 metres per second in air and 1484 metres per second in water. Table 13.1 provides a list of activities and the corresponding noise levels.

Noise pollution could be caused by the following.

1. Road Traffic Noise
    - Traffic noise has increased in recent years with an increase in the number of vehicles.
    - Narrow streets and tall buildings augment traffic noise through reverberation of sound waves.

Table 13.1 Activity-wise permissible noise limits[2]

Activity	**Sound level in decibels (dB)**
Quiet library or soft whisper	30
Normal conversation	50–60
Busy traffic or noisy restaurant	70
Heavy city traffic / factory noise	80
Noise in industrial plants or call centres	90
Trains travelling at 28 kmph	93
Stereo headphones, night club, pneumatic drill	100
Loudest sound that can be tolerated by the human ear	120
Rock concert in front of speakers	120
Fireworks, gunshot, jet plane	140
Sound at a rocket launching pad	180

2. Aircraft noise
    - Low-flying aircraft including military aircraft add a new dimension to community discontent.
    - As a result of aircraft noise 12,500 school children suffer from reading impairment, according to *Environmental Noise in Europe – 2020*, No. 22/2019.
3. Noise from construction and civil engineering sources include pneumatic hammers, air compressors, bulldozers, loaders, dump trucks and pavement breakers.
4. Noise from industries
   Neighbours of noisy manufacturing plants can be disturbed by sound they create. Interior noise sources have a significant impact on industrial workers among whom noise-induced hearing loss is unfortunately common. Humans also damage their ears if they are exposed to noises that are less loud, but that are heard more often. For example, office workers who endure noise from telephones and loud machines daily may suffer some hearing loss over time. Workers in loud factories also experience hearing loss.
5. Noise in buildings
    - When apartments are poorly designed and constructed, internal building noise from plumbing, boilers, generators, air conditioners and so on can be audible and annoying to the occupants.
    - Improperly insulated walls and ceilings can transmit sound of amplified music, voices, footfalls and noisy activities from neighbouring units.

6. Noise from other sources
    - Events, weddings, public gatherings, use of loudspeakers and so on
    - Neighbourhood noise – gadgets, household utensils, musical instruments, transistors and so on
    - Unnecessary usage of horns

Playing loud music on a personal stereo can also damage hearing. Noise hurts more than just hearing. When people are exposed to loud noise, their bodies react as if in danger resulting in increased heart rate, stress, eye conditions, muscle tension, elevated cholesterol levels and hormone secretion, high blood pressure, and migraines. Noise also impairs concentration; studies have shown that children's learning and achievement can be affected.

Long-term exposure to noise affects the health of an individual in a variety of ways.

- Hearing loss
- Sleep disturbance
- Negative effects on cardiovascular and metabolic systems
- Cognitive impairment in children
- High blood pressure
- Stress

According to the European Environment Agency report *Environmental Noise in Europe – 2020*, 20 per cent of Europe's population is exposed to long-term noise levels which have harmful effects on their health. Environmental noise pollution contributes to 48,000 new cases of ischemic heart disease every year as well as 12,000 premature deaths; 22 million suffer from chronic high annoyance and 6.5 million suffer from chronic high sleep disturbance.

According to WHO, South Asia already has the highest prevalence of hearing loss in the world among children and the elderly.

13.3 Economic Effects of Noise Pollution

Noise pollution can also affect the economy of a country. Properties located in noisy areas are sold and rented at lower prices.

Certain sectors can become less attractive (as very few sectors can operate in noisy surroundings there would be few takers) and productivity may decrease due to the effects of noise on health.

Noise at night affects the quality of sleep, which is an important determinant of well-being and productivity. Even during day time, working in a noisy environment affects productivity. An experiment in Kenya found that a 10 dB increase in noise reduces productivity by around 5 per cent. [3]

13.4 Noise Control

Noise control, also known as noise mitigation, comprises a set of actions aimed at reducing noise pollution or reducing the impact of noise, outdoors or indoors.

Noise control measures and effective social awareness programmes should be implemented at personal, industrial and community levels to highlight the ill effects of noise pollution on the health of individuals and the urgent need to ensure that noise pollution does not become a menace.

The Central Pollution Control Board under the Ministry of Environment and Forest, Government of India, recommends noise control measures to be deployed as appropriately applicable at the source of noise, along the path of the noise and at the receiving end in accordance with R. A. Bolt and K. U. Ingard's source path receiver model.[4]

13.4.1 Noise Reduction at Source

1. Reduction of the exciting forces, for example, noise reduction of impacts or impulsive forces, balancing of moving masses, reduction of frictional forces by proper alignment and lubrication, and so on
2. Reduction of the response of various components of the system to these exciting forces, for example, by application of vibration-damping materials to the radiating surfaces
3. Changes in operating procedure, for example, a factory adjacent to residential areas should suspend or reduce noise-generating operations at night
4. Maintenance of automobiles
5. Prohibition on the use of loudspeakers
6. Speaking in a low voice
7. Selection and maintenance of machinery
8. Control of vibrations

13.4.2 Noise Control along the Path of Transmission

Controlling the transmission path of noise so as to reduce the energy that is communicated to the receiver can be achieved in a number of ways.

1. Increasing the distance between the source and the receiver
2. Path deflection using barriers
3. Properly designed enclosures
4. Providing sound-absorbing material in a room where both the source and the receiver are present. Most of the reflected sound can be avoided.

5. Constructing buildings with suitable noise-absorbing materials for the walls, windows, doors and ceilings
6. Planting of bushes and trees along the roads to help in controlling noise pollution by absorbing high frequency sound waves

13.4.3 Protective Measures at the Receiver's End – Details of the protective measures to be deployed at receiver's end are provided in section 14.4 of Chapter 14

1. Use of personal protective equipment, for example, ear plugs, ear muffs, noise helmets and so on
2. Educating the public, for example, creating public awareness regarding noise pollution
3. Exposure control, for example, rotation of personnel so that work assignments in the noise-intense area are for a limited period only
4. Factories and industries to be located far from residential areas

13.5 Legal Aspects of Noise Control

Apart from the Indian Penal Code (detailed in chapter F – Regulations and Implementations), other laws pertaining to noise control in India include the following.

1. **Criminal Procedure Code**
   Under Section 133 of the Criminal Procedure Code, whenever a District Magistrate or a Sub Divisional Magistrate or any other Executive Magistrate specially empowered in this by the state government on receiving the report of a police officer or other information and on taking such evidence (if any) as he thinks fit has the power to make a conditional order requiring the person causing nuisance to remove such nuisance.
2. **Factories Act, 1948**
   The Factories Act does not contain any specific provision for noise pollution control. However, the third schedule under Sections 89 and 90 of the Act mentions 'noise induced hearing loss' as a notifiable disease. Under Section 89 of the Act any medical practitioner who detects any notifiable disease including noise-induced hearing loss in a worker has to report the case to the Chief Inspector of Factories along with all other relevant information. Failure to do so is a punishable offence.
3. **Motor Vehicles Act, 1988, and Rules Framed Thereunder**
   Sections 119 and 120 of the Central Motor Vehicle Rules, 1989, deals with reduction of noise.

Table 13.2 Permissible noise limits emanating from various motor vehicles[5]

S.No.	Type of Vehicle	Noise Limits from 1st January, 2003, dBA
1	**Two-wheeler**	
	Displacement up to 80 cm^3	75
	Displacement more than 80 cm^3 but up to 175 cm^3	77
	Displacement more than 175 cm^3	80
2	**Three-wheeler**	
	Displacement up to 175 cm^3	77
	Displacement more than 175 cm^3	80
3	**Passenger car**	75
4	**Passenger or commercial vehicle**	
	Gross vehicle weight up to 4 tonne	77
	Gross vehicle weight more than 4 tonne but up to 12 tonne	80
	Gross vehicle weight more than 12 tonne	82

- Section 119 Horns.

Every motor vehicle shall be fitted with an electric horn or other device approved by the Bureau of Indian Standards and the registering authority for use by the driver of the vehicle and should be capable of giving audible and sufficient warning of the approach or position of the vehicle.

Every motor vehicle shall be so constructed and maintained to confirm to the noise standards as approved by the Bureau of Indian Standards from time to time.

- Section 120 silencers.

Every motor vehicle shall be fitted with a device (hereinafter referred to as silencer) which by means of an expansion chamber or otherwise reduces as far as practicable the noise that would otherwise be made by the escape of its exhaust gases from the engine.

Every motor vehicle shall be so constructed and maintained so as to conform to noise standards as indicated in Table 13.2 and these standards shall be tested as per Indian Standards IS 3028.

4. Law of Torts

Under the law of torts, a civil suit can be filed claiming damages for nuisance. Nuisance as a tort means an unlawful interference with a person's use or enjoyment of land or some right over or in connection with it.

5. **The Air (Prevention and Control of Pollution) Act, 1981**
   Noise was included in the definition of air pollution in the Air (Prevention and Control of Pollution) Act by an amendment in 1987. Obviously, all the provisions of the Air Act become automatically applicable in respect of noise pollution also. Ambient noise standards have been notified under the Air Act, 1981.
6. **The Environment (Protection) Act, 1986**
   The Ministry of Environment and Forest notification on Noise Pollution (Regulation and Control) Rules, 2000 (Annexure 1), covers various aspects of noise pollution. Earlier noise standards for various sources were notified under the Environment (Protection) Act, 1986.
7. **Regulations on loudspeakers / public address systems**
   Many states have their own regulations on loudspeakers / public address systems.
   a. The Union Territory of Delhi Loudspeakers (Licensing and Controlling) Regulations, 1980
   b. The Orissa Firework and Loudspeakers (Regulation) Act, 1958
   c. Madhya Pradesh (Control of Music and Noise) Act, 1951

The Central Pollution Control Board tracks noise level through monitoring stations spread across India's major cities.

Some of the other measures that could be adopted towards ensuring noise reduction in metros could include the following.

1. Road noise
   - Use of noise barriers
   - Newer roadway surface technology
   - Traffic control
   - Limiting time for heavy duty vehicles
2. Providing quiet tyres for public transport
3. Promoting electric buses and cars
4. Promoting active travel walking or cycling
5. Designating quiet areas with strict adherence to maintaining low noise levels
6. Better urban and infrastructure planning
7. Changes in people's behaviour

13.6 Frequently Asked Questions

1. **What is meant by 'Day time' and 'Night time' under Noise Pollution (Regulation and Control) Rules, 2000?**

   a. Day time shall mean from 6.00 a.m. to 10.00 p.m.
   b. Night time shall mean from 10.00 p.m. to 6.00 a.m.

2. **What is the silence zone?**
   A silence zone is an area comprising not less than 100 metres around hospitals, educational institutions, courts, religious places or any other area which is declared as such by the competent authority.
3. **How many decibels can the human ear handle?**
   Immediate and irreversible nerve damage can be caused by sounds at 140 dB or higher (120 dB in young children). However, damage also occurs at lower sound levels, and this harm accumulates over time. Any sound above 85 dB can cause wear and tear of your ears which reduces your hearing acuity over time.
4. **What are the restrictions on using loudspeakers or musical systems at night?**
   A person cannot play a loudspeaker, public address system, sound-producing instrument, musical instrument or sound amplifier at night time except in closed premises like auditoriums, conference rooms, community halls or banquet halls.
5. **What is the noise level for using loudspeakers or public address systems?**
   Any person using loudspeakers or a public address system shall maintain the noise level and restrain it from exceeding 10 dB (A) above the ambient noise standards for the area specified or 75 dB (A), whichever is lower.
6. **What is the noise level for a private sound system?**
   A person owning a private sound system or a sound-producing instrument shall not let the noise exceed 5 dB (A) above the noise standards specified for the area in which it is used.
7. **What are the restrictions on bursting firecrackers?**
   A person shall not burst sound-emitting fire crackers in silence zones or during night time.
8. **What are the restrictions on noise-making construction equipment at night near residential areas?**
   A person is restricted from using sound-emitting construction equipment during night time in residential areas and silence zones.

9. **What are the prohibitions on violating the silence zones?**
A person shall not undertake the following acts in silence zones.

- o Play any music or use any sound amplifiers
- o Play a drum or tom-tom or blow a horn, either musical or pressure, or trumpet or beat or play any instrument
- o Conduct any musical or other performance to attract a crowd
- o Burst sound-emitting firecrackers
- o Use a loudspeaker or a public address system

10. **What is the restriction on using horns in silence zones?**
A person shall not use a horn in silence zones or during night time in residential areas except during a public emergency.

11. **What are the consequences of any violation in the silence zones?**

a. Anyone who contravenes the provisions of the Noise Pollution (Regulation and Control) Rules, 2000, shall be punished with imprisonment for a term which may extend to five years or with fine which may extend to one lakh rupees, or with both, and in case the failure or contravention continues, an additional fine which may extend to five thousand rupees for every day during which contravention continues.

b. If the person continues contravention beyond a period of one year after the date of conviction, the offender shall be punishable with imprisonment for a term which may extend to seven years.

13.7 Interesting Developments in the Field of Noise Control [1]

1) In Japan, the Yokohama Tyre Company has introduced a new high-performance tyre that gives a quiet ride.
2) Korean engineers have developed an anti-noise system for computers that reduces a typical noise level of 30 dB to a nearly undetectable 20 dB.
3) Researchers in the United States have invented a new composite consisting of alternating layers of sound-absorbing foam and sound-containing vinyl that can be placed in machinery housings to reduce noise.
4) At the Georgia Institute of Technology an inventor has developed a quiet curtain for nursing home patients who cannot sleep that is made of noise-absorbing materials that can reduce noise by 12 dB.
5) In Germany roads are paved with materials that reduce sound, and tyres are manufactured to whine less. Also, lawnmowers and other equipment are designed to operate quietly.

13.8 Anti-noise

In order to counter the impact of increasing amount of noise (which seems inevitable) some companies are developing a new technology called anti-noise. This technology is based on creating a sound that exactly matches the noise. When the sound waves from the anti-noise device meet the sound waves from the noise-causing device they cancel each other out. In other words, humans do not hear any noise.

Even if we cannot eliminate noise pollution, it may be possible to use anti-noise devices to escape some of the damage that can be caused by noise.

13.9 Conclusion

Consequent to WHO categorizing noise as the second-largest environmental cause of health problem, noise pollution and the need to ensure that the noise level is kept within allowable limits as per the location is gaining importance globally. Though scientific innovation contributes towards noise generation on the one hand, on the other hand it simultaneously finds innovative ways and means of reducing noise levels.

As far as India is concerned noise pollution across metros is a reality that needs to be addressed on an urgent basis to ensure the well-being of our citizens, especially children and the elderly. Noise problems cannot be properly evaluated and addressed without producing noise maps of our cities and drawing up action plans accordingly. It is interesting to note that the Mumbai police have launched a novel 'Honk More, Wait More' scheme at traffic junctions. If any impatient driver honks at signals, waiting time is prolonged.

- Noise pollution in Indian metros *is indeed a major concern*
- Urgent steps are to be taken by the Ministry of Environment, Government of India, to reduce noise pollution to safeguard the health of the citizens of our country, especially children.
- Noise mapping of areas where noise pollution is beyond acceptable limits.
- Strict enforcement of law and increase in fine for violation
- Improving the civic sense of the population and motivating them to respect law in their own interest and in the interest of others.

It is only through a combination of different measures, evolved to suit our culture and environment, along with the application of technological improvements and ensuring strict adherence to the law, that we can save ourselves from noise pollution and help towards building a healthy nation.

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14

INDUSTRIAL SETTINGS – ORGANIZED SECTOR

N. Devi and B. Ravichandran

14.1 Introduction

The human ear has an extraordinary capacity to receive and perceive any type of signal, sound or noise present in the environment. Noise is usually defined as any unwanted or undesirable sound. Nowadays noise is present all over the world.

Learning Objectives

- To know the different types of noises and permissible noise levels in the environment
- To identify and measure the different sources of noise in industry (organized sector)
- To get familiar with the Hearing Conservation Education Program (HCEP)

14.2 Sources of Noise and Permissible Noise Levels in the Environment

There are a variety of sounds all around us. Outdoor noise sources include vehicles, domestic buildings, machinery from industries, construction sites, commercial buildings, public places, and public address systems. Indoor noise sources include banging of doors; moving of furniture; television; household gadgets such as pressure cookers, vacuum cleaners, washing machines, sewing machines, mixer grinders and air conditioners; and office equipment. These noises can range from 40 dB (A) to 120 dB (A). Though the range of the noise sources is high, not all sounds from these sources are hazardous to the ear. The World Health Organization (WHO) defines noise pollution as sounds or noises that are above 65 dB.[1] Sound or noise becomes hazardous when it exceeds 75 dB and excruciating above 120 dB.[2,3] Hence, it is advisable that the noise level be lower than 65 dB during the daytime and not more than 30 dB of ambient noise at night. The Central Pollution Control Board (CPCB) has stipulated the permitted noise levels for different areas in India. The permissible limit in industrial areas is 75 dB for daytime and 70 dB at night. In commercial areas, it is 65 dB and 55 dB, while in residential areas it is 55 dB and 45 dB during daytime and night-time, respectively.[4] State governments have declared 'silent zones' which include areas that lie within 100 meters of the premises of schools, colleges, hospitals, and courts. The permissible noise limit in this zone is 50 dB during daytime and 40 dB at night. Noise pollution and its sources are addressed by the Noise Pollution (Regulation and Control) Rules, 2000. The standards for noise emitted by motor vehicles, air conditioners, refrigerators, diesel generators, and certain types of construction equipment are prescribed in the Environment (Protection) Rules, 1986. Noise emanating from industries is regulated by the State Pollution Control Boards (SPCBs) / Pollution Control Committees (PCCs) for States / Union Territories under the Air (Prevention and Control of Pollution) Act, 1981.[5]

14.3 Different Types of Industry and the Sources of Noise

'Building machines to build the product' occupies the key position in the country's industrial development. India is one of the foremost exporters of industrial machinery required for steel, mining, fertilizer, cement, petrochemical, and heavy engineering. However, the production and use of these machines can cause serious health problems, including hearing loss.

14.3.1 Measurement of Noise Sources from Industrial Machinery

Different types of machinery produce different noises. The sound pressure level of the noise varies depending on the usage of single or multiple machines in the factories. It also depends on the sort of noise source, distance from the source to the ear, and the kind of employee work atmosphere.[7] The various sources and their sound pressure includes compressors emitting greater than 105 dB (A), large electric motors 106 dB (A), woodworking machines 106 (A), pneumatic tools 110 dB (A), electric hammers 88 to 103 dB (A), and planing wood machines 96 dB (A) to 101 dB (A). For effective occupational hygiene practice, the noise emitted from the source needs to be measured using a sound level meter. The noise source measurement needs to have a detailed narrow-band frequency analysis to determine the specific frequency component of the sound, root mean square (RMS) detection of the sound, wide range of amplitude of the intensity of the sound, record the characteristic of the short as well intermittent noises and also the reverberation and vibration if any. However, the maximum permissible sound level recommended by the National Institute of Occupational Safety and Health (NIOSH, 1998)[8] is 85 dB (A) for 8 hours per day using a 3 dB exchange rate at the worker's ears. The maximum permissible level depends not just on the intensity of the sound source but also on parameters such as frequency, duration, and the spectrum of the sound. When these parameters are above the permissible limit, noise can cause severe damage to the ears. It can also cause other physical and psychological problems.[9] A noise dosimeter can be used when the noise is impulsive, intermittent, and variable to determine the average exposure of a worker's ears to noise. The optimal position of the microphone of the noise dosimeter is the mid-top of the shoulder near the ear more exposed to the noise.[10]

14.3.2 Noise Survey

A noise survey may be required to identify the noisy areas in various industries. Such a survey can measure noise levels at selected locations or sections where the noise is generated. Surveying of noise includes sketching a map of the location of the workers and of the machines emitting noise.

Hence, based on the noise survey reports, if a worker is going to be exposed to more than the permissible limit of noise according to the noise regulations, the hearing conservation education program (HCEP) needs to be implemented.

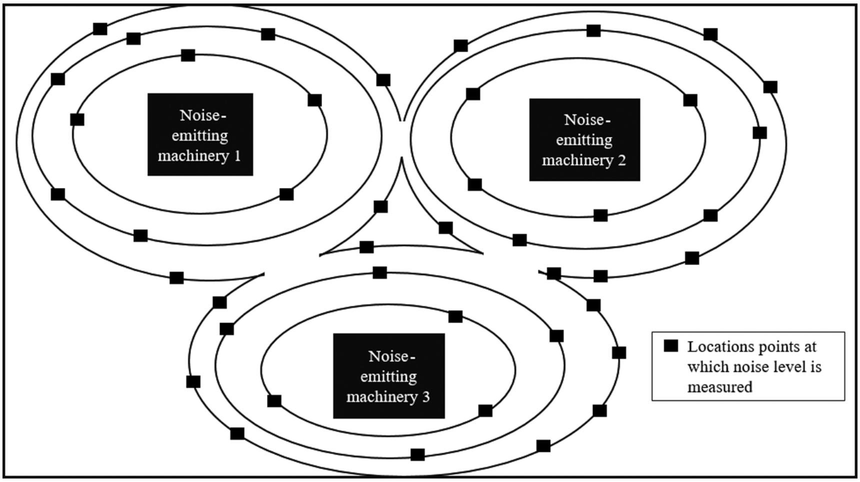

Figure 14.1 The noise survey points of the source of sound and the worker.

14.4 Hearing Conservation Education Program

The HCEP requires employers to monitor noise exposure levels in a way that accurately identifies employees exposed to noise at or above 85 dB averaged over eight working hours, or an 8-hour time-weighted average (TWA). The HCEP includes:

- Annual and periodic monitoring of noise exposure
- Noise control measures
- Hearing protection devices – selection, use, and maintenance
- Periodic audiometric testing
- Education, motivation, and training
- Record keeping

14.4.1 Annual and Periodic Monitoring of Noise Exposure

When there is an indication that any employee in an organized sector is exposed to a noise level of 85 dB (A) for 8 hours, the employer of the organization has to notify the Health and Safety Officer of the sector to initiate and execute a noise monitoring program. As a part of the program, a noise survey is undertaken using a sound level meter and a noise dosimeter evaluates personal exposures. Monitoring the noise level exposure has to be repeated periodically. The noise pressure levels are measured whenever there is any change in the manufacturing process, equipment, maintenance of the equipment, or if the ear protectors being used by employees are not suitable.

14.4.2 Noise Control Measures

Noise control measures are a systematic process. The hierarchy of noise control procedures needs to be followed by the occupational safety and health professionals in the employment sector to implement a viable and effective control of the noise. The program involves engineering and administrative control measures. The preeminent method to reduce noise is to block the delinquent at the source.

14.4.2.1 Engineering Control Measures

These measures include maintenance, modifying equipment, substitution of equipment, and isolation. The best-preferred approach is to remove the hazard by eliminating the equipment, device, procedure, machine, or material that is the source of generation of the noise, or installing 'silencers' (mufflers and baffles) on equipment. Suppose exclusion is not practical, substitute, or supplant unique equipment, substance, or process with another. Hazards can sometimes be 'engineered out' by redesigning the worksite, workstations, processes, and occupations. Hazards can also be isolated through restraint or enclosure or automated or mechanized. There is also a nationwide 'Buy Quiet' drive to get corporations and the military to buy noiseless machinery and specify the acceptable sound output in the order process during procurement. The 'Buy Quiet' approach requires employers of the sector and engineers to obtain noise production statistics or information before procuring the quietest available and affordable equipment. Though quieter equipment compromises the price, its high efficiency makes it worthwhile. Choosing soundless or noiseless equipment, systems, tools, and so on in the initial stages of procurement is the preeminent way to reduce noise at source. The second option would be reducing the noise in the path between the noise source and the receiver. This would generally involve adding barriers or obstacles, enfolding the equipment in sound-absorbing materials. The best engineering control measure to protect hearing is by constructing an acoustic barrier wall that can dampen sound from nearby machinery. However, this provides only a little reduction in the noise. If engineering controls cannot eradicate or control noise exposure, administrative controls can be used.

14.4.2.2 Administrative Control Measures

These controls do not remove the hazard as do engineering control measures. Some of the administrative control measures can include harmless work practices, rotation of employees' work, restraining the period of certain operations of machinery, or hampering areas or work processes, work/rest rosters to reduce worker exposure to hazardous substances or conditions, limiting hours of work, replanning hazardous work during times when exposure, wet methods as opposed to dry sanding or sweeping. If the sector cannot incorporate a silencer (noiseless equipment) or acoustic barrier, or incorporate other engineering controls due to lack of practicality, or if the worker cannot be steered away from the noise source completely, the last way to dampen noise is by stopping the noise with hearing protection devices (HPDs) for the receiver.

14.4.3 Hearing Protection Devices – Selection, Use, and Maintenance

The selection of hearing protection need will depend on the characteristics and features of the noise source, employee preference, and attenuation required. Different types of HPDs are available, including earplugs, semi-inserts, earmuffs, and helmet with earmuffs. The different earplugs include pre-molded earplugs, custom earplugs, disposable plugs with cushions, shooters' earplugs, reusable plugs, sound-isolating earplugs, musicians' earplugs, and filter earplugs. These earplugs have attenuation levels ranging from 10 dB to 40 dB. There is high variability in the attenuation provided by these ear protective devices across frequencies. Hence, the selection of HPDs is a huge challenge. However, double / dual hearing protection using custom-made communication earplugs worn under a headset or a helmet appears to be the best. Unlike other HPDs, this combination does not interfere with speech intelligibility. Overall, HPDs do not eradicate all sound, which would be unrealistic and possibly dangerous. However, if appropriately used, they reduce noise to harmless and safer levels at ear level. Thus, HPDs features at the bottom of the pyramid of noise control approaches and should not be relied upon as the crucial means of noise control. Rather, they should be treated as the last alternative for monitoring noise exposure—only to be used as a temporary or supplementary measure where other measures higher up the hierarchy of noise control strategies are pending application or where they have been attempted and proven insufficient, unsuccessful, or impossible.

14.4.4 Audiometric Testing

A very important aspect of the HCP is audiometric testing. It is mandated that an audiologist perform audiometric testing to determine if a worker is losing his hearing or if such a loss has been prevented. A baseline audiogram (14 hours after exposure to noise during work) is obtained for all the employees within six months. The audiograms are compared against subsequent audiograms and assessed each year. If any changes in the thresholds of greater than 10 dB (standard threshold shift) are noticed, appropriate noise control measures must be implemented immediately.

14.4.5 Education, Motivation, and Training

The effectiveness of the HPDs depends only if the employee wears it correctly and uses it when necessary. However, the education regarding the same is less know. This is true of HCEPs in general. Hence, an annual training program must be provided to each employee included in the HCEP. Both employers and workers must be educated about the importance of good hearing and avoiding hearing loss due to noise exposure. The training program includes maintaining noise control; effects of noise on hearing and other aspects; the

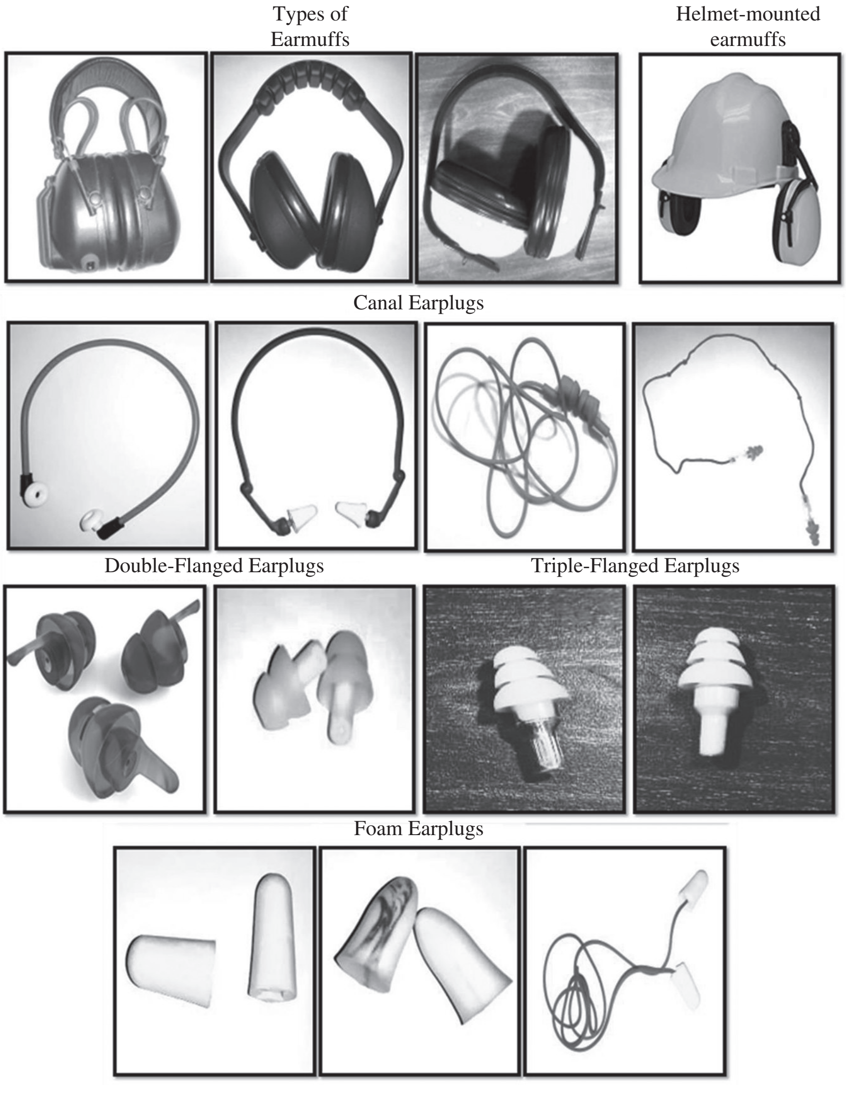

Figure 14.2 Different types of hearing protective devices.

purpose of hearing protectors; selection, fitting, use, and care of ear protective devices; and the purpose of audiometric testing. Providing workers with this input increases their involvement with the program and enhances the likelihood of securing their participation

14.4.6 Record Keeping

The employer is responsible for maintaining the documents and records related to hearing tests, noisy surveys, employee exposure measurements, noise control measures, and use of appropriate ear protective devices. The employer must also frequently evaluate and maintain records on the HCEP along with appropriate supporting documents.

14.5 Conclusion

Understanding the importance of implementing effective health and safety methods provides an opportunity for intervention and the potential for reducing the number of occupational medical conditions. The HCEP is viable. However, to work, it must be vigorously supported by the management and couched in a holistic framework that includes enforcement, education, motivation, and the availability of comfortable, effective HPDs. To conclude, hearing loss due to noise exposure is painless, permanent, and progressive, but it is highly preventable. Hence, a Hearing Conservation Program can be established as a national program.

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15

INDUSTRIAL SETTINGS – UNORGANIZED SECTOR

Sreeraj Konadath

15.1 Introduction

This chapter focuses on preventing the harmful effects of noise on health in individuals working in the unorganized industrial sector. Implementing a hearing conservation program (HCP) in these categories of workers is an enormous challenge as monitoring the HCP is going to be more tedious and less effective as opposed to implementation in the organized industrial sector. How hearing loss due to hazardous noise can be prevented in construction workers, laborers employed in the small-scale industry, handloom or power loom workers are discussed in this chapter. After understanding the contents of this chapter, the readers should be able to plan effective options to prevent the development of noise-induced hearing loss (NIHL) in industrial workers in the unorganized sector.

Learning Objectives

- To understand the scenario of developing occupational hearing loss in the unorganized industrial sector.
- To understand how hearing loss due to hazardous noise can be prevented in construction workers, laborers employed in the small-scale industry, handloom or power loom workers, etc.
- To be able to plan effective options to prevent the development of NIHL in industrial workers in the unorganized sector.

15.2 The Unorganized Industrial Sector and Hearing Loss

Individuals working in the unorganized industrial sector/informal sector often face challenges in multiple forms. This sector is not as well-structured as the organized one. The unorganized sector is not strictly bound by rules as it is primarily not overseen by the government. The employees are often not given the benefits and privileges; unlike what they receive in the formal sector. Hearing loss is one common concern in individuals working in the industrial sector. The problem is much more prominent as there is a lack of proper governance in the informal industrial sector. Hearing loss in the industrial sector is usually the end result of exposure to continuous or intermittent noise at work. The workers are often exposed to hazardous noise levels and are not aware or informed of the ill-effects of loud noise exposure. Usually, the risk is higher in the unorganized sector due to their long and unmonitored work schedules. The workers' categories include laborers of small-scale industry, construction workers, power loom workers, workers in tanneries, some workers in the shopping complex, etc.

The industries that contribute to noise at the workplace in the unorganized sector, including printing, sawmill, textile, and mining[1], are at risk of developing hearing loss due to noise exposure. The more the duration of noise exposure, the higher the risk of developing hearing-related problems[2]. Noise induced hearing loss is found to be the second most common form of the sensorineural type of hearing loss after presbycusis[3]. The hearing loss is often sensorineural in nature, wherein the damage occurs in the inner ear. Some individuals even experience acoustic blast injuries. The causative factor for the development of hearing loss is primarily lack of awareness about the hazardous effects of noise exposure. Exposure to noise leads to the death of sensory cells in the cochlea, along with causing damage to the vestibulo-cochlear nerve fibers. The sensory cells gradually die off due to apoptosis (dissolution of cochlear hair cells) or necrosis (rupture of the cochlear hair cells), when exposed to prolonged or high levels of noise[4]. Hearing loss due to noise exposure is often accompanied by tinnitus perception. Tinnitus is the perception of ringing or buzzing sound in the ear, in most cases due to some amount of cellular loss of the inner ear. Tinnitus is considered to be one of the classical clinical presentation after getting exposed to loud noises, typically due to cell injury or damage to the nerves associated with hearing. The degree of hearing loss can vary from minimal to moderately severe, and most of them do not show hearing loss beyond moderate degree. A classical 4 kHz notch[5] (Boiler's notch) in the audiogram is seen in most cases, especially in the initial stages of noise-induced hearing loss development. Gradually the loss extends to other neighboring frequencies as well; however maximum threshold shift in the audiogram is centered around 3 kHz to 6 kHz region.

15.3 Approach to Hearing Conservation in Unorganized Sector

Hearing conservation focuses on preventing the incidence of hearing loss or preventing the progression of loss in case the hearing loss has already occurred and in providing workers with the knowledge of protective devices to safeguard their hearing. Hearing conservation as a means to avoid the harmful effects of noise is challenging as the unorganized industrial sector is profit-oriented and not well-governed by government policies. However, the detrimental effects of noise on health need to be prevented as having hearing loss has a damaging effect on the quality of life. Hearing conservation in such a group of workers is planned with the notion that continued exposure to large noise levels over time causes permanent damage to hearing-related structures in the inner ear and the auditory nerve. Workers exposed to high levels of noise may be at risk of other harmful health effects as well.

The hearing conservation program should have the following steps for effective planning and administration. The measures should include:

a) Noise Surveys/Monitoring
b) Audiometric Testing
c) Hearing Protection Devices
d) Employee Education and Training and
e) Record Keeping.

Surveying the noise in the environment of concern/interest serves as the primary step in the hearing conservation protocol. The amount of noise prevalent in the workplace needs to be identified to know whether it is in the harmful range to cause noise-induced hearing loss. Mapping noise in the workplace serves as an ideal means to label or designate the work areas as hazardous zones if the amount of noise exceeds 85 dBA. These measurements are to be done using a well-calibrated sound level meter (SLM) set in the fast mode and A weighing network. The SLM microphone should be protected using a windshield and a distance of 1 or 1.5 m has to be maintained from the primary source of noise under consideration. Noise mapping will give accurate information about the amount of noise in the area under review. It will help in deciding whether there is a need for the workers to enroll in a hearing conservation program. The following noise measurements could be computed, namely LAeq (level equivalent), LAF_{max}, $LAF_{min,}$ and exceedance level (at L90) for the measurements while doing noise mapping. LAeq provides information on the average noise level over a measured period (to be defined while doing the measurement, ideally done for the entire working duration, typically 8 hours). The value at L90 indicates that the noise levels are higher than the obtained L90 value for 90% of the time (e.g. beyond 85 dB); LAF_{min} and LAF_{max} gives information about the minimum and maximum noise levels recorded during the measurement period. By determining these characteristics of the measured noise, a clear idea about the noise levels at the place of work in the unorganized sector is made available, which enables the competent authorities to decide on further strategies for hearing conservation programs. The suitability of land use (location of the place) for a specific purpose compared to prescribed standards given by the noise pollution (regulation and control) rules (2000)[6] can also be done based on the results of noise mapping. The areas can be classified into respective categories (Residential, Commercial, Industrial, Sensitive, and Mixed commercial residential) based on the noise measured.

In industries like handloom, specific noise measurements enabling labelling noise levels in each target area within the workspace need to be done to get a clearer picture of the hazardous noise levels. The noise levels need to be measured for shedding, picking, beating up and taking up stages, and the average noise levels (LAeq) during the job needs to be calculated to know the noise levels to which the worker is exposed. If the noise levels exceed 85 dBA, it is essential to include those workers in the hearing conservation program. One other way of measuring the amount of noise exposure of an employee is by using the noise dose meter. The amount of daily dose of noise exposure at the end of 8-hours-work shift, provides the best understanding about an employee's noise exposure. A reading of 100 dose indicates that the employee is at risk of developing noise induced hearing loss. The value of 100 dose indicates that the employee is exposed to a minimum intensity of 90 dB for a period of 8 hours. Those workers need to be equipped with adequate hearing protective device during work to prevent development and/or progression of hearing loss. Survey/mapping results indicate whether engineering controls (e.g. greasing of equipment ball bearing, repair or replacement of spares that would help in noise reduction) or administrative controls (scheduling break time to increase the effective quiet periods) or a combination (both engineering and administrative controls) can help these workers safeguard their ears from developing hearing loss. Previous research carried out in India indicates the noise exposure in workplace to be 80.44 dB in bus drivers and 77.82 dB SPL in auto-rickshaw drivers; in traffic police it is 75.33 dB SPL, and in street vendors it accounted to 74.42 dB SPL[7]. Talukdar (2001)[8] reported noise levels of 94 to 99 dB in the loom shed in a textile industry, which is high enough to cause significant hearing loss. As per the Damage Risk Criterion (DRC), exposure beyond 85 dB can cause considerable hearing loss if exposed for longer durations.

Noise level exposure can be considerably high in fabrication workers and other construction workers. A hand drill can generate noise levels beyond 90 dB and cause considerable temporary threshold shift (TTS) in hearing. If the exposure continues, even though intermittent, it can lead to a significant permanent threshold shift (PTS) in those workers who are exposed to noise. Identifying these individuals is quite a challenge as there is no clear evidence of short duration (other than loud impulse noises) noise exposure causing hearing loss when exposed over larger intervals. In such cases, it is always advisable to provide hearing protectors to the workers even when they are not exposed to noise, as detailed in the DRC. Intermittent noise exposures can also lead to hearing loss in the longer run.

Regular audiometric evaluation for those workers who are exposed to occupational noise in the unorganized industrial sector is also recommended. Suppose an individual is finding it difficult to follow conversation at a distance of one meter in the presence of noise at the place of work, this gives a clear indication that the amount of noise in the vicinity is beyond 80 dB SPL. An assessment of hearing is recommended for such individuals who are working in such noisy areas. Three forms of audiogram are recommended for industrial workers: pre-placement audiogram, monitoring audiogram, and terminal audiogram. The pre-placement audiogram is recommended for all the workers who are appointed to work in noisy areas. This needs to be done by a qualified Audiologist using a calibrated audiometer in a properly sound-treated room/booth before the individual starts working in the sector (ideally) or at least within six months of appointment. This serves as the baseline audiogram, and the record is to be preserved. A proper baseline audiogram record will also help to avoid unnecessary compensatory claims in the future. The second type of audiogram is called the monitoring audiogram. The monitoring audiogram is to be administered annually to see any standard threshold shift (STS). A STS is the hearing threshold shift from baseline. According to OSHA[9], an individual is reported to have an STS once there is a threshold shift of 10 decibels (dB) or more at 2000, 3000, and 4000 hertz (Hz) in one or both ears and record of it needs to be maintained. Monitoring audiograms will help the audiologists to know whether the ears are getting affected due to noise exposure. If there is a shift in hearing threshold observed, hearing protection is recommended, if not used already. Additionally, a measurement of noise where the person is working is to be done. This will further clarify whether engineering or administrative controls are required to preserve hearing further. This is one of the most recommended ways to control the deleterious effects of noise on workers—frequent monitoring and providing feedback. A structured plan on when the hearing assessment is to be scheduled needs to be chalked out in any work industry where noise is present. Following these schedules and getting a hearing evaluation done on time will help prevent hearing loss and prevent further progression of loss, if any. The final category of an audiogram that needs to be administrated on workers exposed to noise at work is a terminal audiogram/exit audiogram. Terminal audiogram type is administered once the worker leaves the job or changes role. Preserving the terminal audiogram records will help prevent false claims/disputes that may arise in the future.

The use of appropriate hearing protectors in noisy workplace provides the workers with the advantage of not developing hearing loss. Various types of hearing protectors are available in the market. The most common types of available protectors include earplugs, earmuffs, and helmets. Employers owning any form of the industry having a noisy workplace (having noise beyond 85 dB or more) should make the workers use ear protective devices (EPD) without fail. The cost of the EPD's are to be borne by the employer . The EPD chosen should have a good noise reduction rating (NRR) to be efficient in cutting down noise before it reaches the inner ear. The amount of attenuation provided by EPDs in real life is not precisely the dB value mentioned as NRR. The NRR is measured using C weighing network, and the ears' responses to sound is more likely to match with the A weighing network scale. In reality, the actual reduction provided by EPD is calculated by taking the NRR number (in dB), subtracting seven, and dividing by two[10] (e.g., if the NRR of the EPD is 40 dB, in real life, the amount of protection that an EPD will provide is 40-7/2=16.5 dB). In other words, the amount of hearing protection to a person working in 100 dB noise wearing an EPD with NRR of 40 dB will be 16.5 dB and they are exposed to noise of 83.5 dB after wearing the ear protector, which is well within the DRC for hearing loss. EPDs available in the market are technically adequate to prevent the noise damages that is caused due to a noise level of around 100 dB. If the noise levels exceed 100 dB, a combination of 2 EPDs, namely earplug and earmuff or earplug and helmet, is recommended. Any workplace with continuous noise of 110 dB is not suitable for working even with regular EPDs. Working in such places requires proper administrative controls. Individuals should be provided work shifts and breaks to ensure that they do not develop hearing loss as outlined in the DRC. Adequate quiet periods wherein the noise levels are much lower than 85 dB in-between work, in high noisy areas, need to be provided to the workers to safeguard their ears from hearing loss.

The selection of ear protective devices shall be from a set of EPD with good NRR, and the employee shall be given the opportunity to select the one which seems most comfortable to them. The employer should ensure proper monitoring of the use of EPD. The employee needs to be provided education and training to use the EPDs effectively and shall be provided with the replacement when the EPD is worn out. It is also necessary to maintain proper ear hygiene while using these ear protective devices. The employer shall designate personnel to monitor the effective use of ear protective devices, and essential actions need to be taken if the EPDs are not used appropriately by the employees.

The employer is responsible for keeping a record of all the activities carried out under the HCP, starting from the baseline audiogram. The date of the evaluation and the tester name and calibration status of the equipment needs to be documented appropriately. The follow-up audiograms, namely the monitoring audiograms, need to be administered at regular intervals and should be saved in the client records. Records need to be protected for the entire duration of employees' employment at a workplace. This documentation serves as the article that helps fight court cases/disputes that may arise during or post the employment tenure.

Noise control at the place of work is accomplished at two levels, 1) making the workplace safer and 2) making the worker safe from noise exposure. To make the workplace safer, all the machinery used in the industries needs to be silenced by means of engineering controls. Elimination of existing noisy machinery and replacing them with quieter ones meeting the industry standards also help make the workplace safer for workers. Workers are made safer to work in noisy areas by scheduling work shifts and ensuring that the individuals are not exposed to higher levels of noise over prolonged work schedules. Personal protective equipment must be provided to all the workers exposed to noise levels above 85 dB. Suitable noise protectors help prevent hearing loss and safeguard the ears of workers exposed to loud noises.

15.4 Conclusions

The following conclusions can be drawn from this chapter:

- A good hearing conservation program is to be planned and executed to prevent the harmful effects of noise in employees working in unorganized sector.
- Using an appropriate hearing protector with good NRR will help reduce the impact of noise on hearing structures.
- If the noise levels are higher than 100 dB, a combination of hearing protectors and sufficient quiet-time breaks is necessary to prevent hearing loss.
- The principles of hearing conservation applied in the organized sector are to be enforced in the unorganized sector also, so that the employees are benefitted and safeguarded from developing hearing loss.
- Proper employee training is also essential to educate them regarding the usage of ear protective devices.
- These employees should also be made aware of their work place rights with respect to aspects of hearing and hearing loss.

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16

HEALTHCARE SETTING

Atul Mohan Kochhar and Ravi Meher

16.1 Introduction

Noise is defined as unwanted, unpleasant, uncontrollable and unpredictable sound. The noise does not always mean a high-pressure sound, for example the continuous dripping taps may be of a low-pressure sound level, yet it can be considered very noisy especially in silent zones like hospitals. This can be very irritating to a patient in a hospital, especially when there is no back ground noise.

The effects of noise can be auditory or non-auditory. The auditory effects can be acute, which includes acoustic trauma. The acoustic trauma is due to sudden exposure to a very high intensity of noise and can result in immediate hearing loss, while chronic exposure to noise leads to noise induced hearing loss. Non-auditory health effects for noise exposure are perceived disturbance and annoyance, cognitive impairment, sleep disturbance and hypertension. Noise affects the mind and changes the emotions and behaviour in many ways. It interferes with communication and disturbs sleep. The high ambient noise levels, as well as peak noise levels in hospitals, have serious impacts on patient and healthcare staff. It results in sleep loss to elevated blood pressure among patients to emotional exhaustion and burnout among staff.

Learning Objectives

In this chapter we aim to:

1) List the factors to consider when measuring environmental noise in hospital settings
2) Equipment and approaches used to objectively measured noise in hospitals
3) Identify methods to limit the noise
4) The available guidelines as far as noise in hospital settings is concerned as prescribed by Indian standards and WHO

16.2 Sources of Noise in Hospital Settings

There are many sources of noise in hospital settings. Most of the large public hospitals are generally situated in very crowded place, near main roads with heavy traffic load. The hospitals are often surrounded by a large number of vendors and streets hawkers too. In these situations, the hospital settings can become very noisy. Thus, the noise audible inside hospitals may actually originate outdoors, e.g., vehicle traffic. Another important and main cause of indoor noise is conversations among employees and with patients and their relatives. Other common source of noise in healthcare settings are:

1. **ICU Settings**–
   In ICU there are three major sound categories:
   (a) sound related to humans
   (b) sound emitted by medical or technical equipment
   (c) sound entering the room from outside

   When the ICU is full, noise levels can increase significantly. Noise levels are often excessive, exceeding international guidelines in ICU. Staff conversation is responsible for most of the noise produced; medical equipment, telephones, doorbell and the alarm bells are responsible for causing high levels of noise.

2. **Operation Theatre Settings**–
   Noise is due to various equipments, suction machines, ventilators, drills and powered instruments, autoclave machines and human noise[1]. Noise pollution in the operating room can reach in excess 120 dBA. If we consider that recommended noise levels within hospitals should be at 45 dBA or less, there is a considerable gap. The average noise levels are between 51 and 75 dBA, and the maximum noise levels were between 80 and 119 dB(A)[2,3]. In several studies the highest noise levels were found in the orthopaedic operation theatres. It has been reported that noise in the operating room could cause permanent psychological stress within the staff[4]. Distractions lead to negative impact in communications amongst the operating room nurses/teams. It is noteworthy that studies have identified miscommunication as one of the leading root causes of error and poor patient outcomes.
   Less noise means:
   - More concentration
   - Easier communication
   - Less errors/complications

3. **Inpatient and Outpatient Department–**
   The OPD areas are generally very crowded during day time with very large group of people speaking and chatting in the registration areas and waiting areas. Alarms, televisions, trolleys and phones, as well as staff, visitor and patient conversations are reported as common sources of noise. Patients, visitors, coffee shops/restaurants in OPD area, rolling equipments like patient trolleys, equipment carts, elevators etc. are other sources of noise in hospital OPD areas. HVAC (Heating ventilation and air-conditioning) system which produce continuous low frequency sound. The generators, ambulance and sirens can also be sources of noise in hospital premises. The hospital paging system for healthcare workers and patients is another source of noise. Similarly, the MRI machines can be very noisy and can become uncomfortable for patients. In one of the studies hospital cleaning equipment was the second most important source of noise in hospital settings after generator. It is not necessary that the noise has to be a high intensity sound. For example, a dripping tap may be a low intensity sound level yet it is very annoying and disturbing.

16.3 Measuring the Noise Levels

Noise level measurements must be collected for at least one week from Monday through Sunday and in all shifts (morning, afternoon and night) in different hospital areas. Six random measurements must be taken at a time per shift in hospital areas. These areas must include OT, wards, Neonatal Intensive Care Unit (NICU), OPD and Emergency Room. In order to analyse hospital environment noise, a noise decibel meter is required. The noise levels vary with time and there is need to know the overall noise level over a period of time. Hence, Leq is measured. Leq is the Equivalent Continuous Sound Level and represents sound exposure over an elapsed period of time. But getting to this value requires multiple steps and the use of what is known as an Integrating Sound Level Meter. These meters normally do average of all the readings to give a Leq reading.

16.4 Standards

According to the Noise Pollution (Regulation and Control) Rules (2000) in India, silence zones like hospitals are supposed to have noise level of only 50 dB(A) Leq during day time and 40 dB(A) Leq at night time. An area comprising not less than 100 metres around hospitals, educational institutions and courts may be declared (by the State Government) as silence area/zone for the purpose of these rules[5]. According to WHO the standards are 40 dB(A) Leq during day time and 30 dB(A) Leq at night time[6].

16.5 Effects of Noise

16.5.1 Impact of Noise

Excessive noise in hospitals reduces the intelligibility of speech and impairs communication, causing annoyance, irritation and fatigue and reducing the quality and safety of healthcare. It has been implicated in the development of intensive care psychosis, hospitalisation induced stress, increased pain sensitivity, high blood pressure and poor mental health.

Hospital noise disrupts sleep of the patients. The machine sounds in particular have a greater negative effect on arousal than human voices. Sound sleep is a highly important restorative process and noise disturbs it. According to the findings of several studies, noise mostly disturbs the sleep of the sick and the elderly. While both quality and quantity of sleep reduce because of noise, it also weakens the immune system and impedes the ability of the human body to generate new cells. Increasing number of medical studies point out that noise causes problems even during the day. According to a study by Vaidyanathan et al, noise can lengthen hospital stays by slowing the recovery rate, as the growing evidence of side effects from noise leads researchers to conclude increased metabolism, quickened heart rate and elevated blood pressure[7]. Of course, patients are not the only ones to be affected. The caregiver's concentration can suffer because of noise, increasing their stress levels and fatigue.

Post-hospitalisation recovery is also compromised. In one study from Sweden, coronary care patients treated during noisy periods had a significantly higher incidence of re-hospitalisation than those treated during quieter periods. Noise can have a cumulative effect. When hospitalised for several nights, patients can feel trapped in a stress inducing soundscape, leading to requests for pre-mature discharge and heightened risk of poor recovery and re-admission.

For hospital staff, high noise levels can impact negatively on communication, performance, wellbeing and caring behaviour and can contribute to burnout[8]. It has been reported that noise in the operating room could cause permanent psychological stress within the staff. It can also be a cause of miscommunication amongst the operating room staffs and can lead to errors in patient management. An astonishing 83% of healthcare staff asked in a survey, published in 2016, thought that noise in the operating room contributed to human error.

Poorly designed environments can result in private conversations between patients and staff or between staff members being overheard by unintended listeners, resulting in unacceptable breaches of confidentiality. At the same time, a poor acoustical environment impedes effective communication by rendering speech and auditory signals less intelligible. This has serious implications for patient safety.

Literature reveals that these noise levels cross the standard limits in most of the hospitals and have auditory as well as non-auditory effects in patients and the hospital staff.

16.6 Remedial Measures

A lot can be done to reduce noise and its effects on patients and staff.

16.6.1 Personal Protective Devices

These include earplugs and ear muffs. These can be used by the health workers working in noisy environment. These are not of much use in hospital settings because the health care workers need to listen to patients' conversation and queries and putting ear muffs will impede such interaction.

16.6.2 Engineering and Design Changes

The walls and roofs of the OPD may be made up of sound absorbing panels. Engineering and design modifications of the machine and equipment including the barrier creation will reduce noise. Reducing the amount of noise entering into hospitals and building is possible by simply closing the windows. It keeps away annoying sound. It can be the best measure for hospitals situated near main roads. Insulation of acoustic sound panels are some of the primary and most practical ways to reduce noise pollution. Soundproofing can help in blocking the sound vibrations and noise. This is done by improving insulation by installing sound proofing materials on the walls, ceiling and even on the floor. Using double-pane windows can significantly reduce noise inside the building. If some pieces of machinery are creating noise due to vibrations, you can check the noise by applying some noise absorbents to reduce noise. Proper lubrication and better maintenance of machines like suction machines in OT and ICU are beneficial practices to reduce noise pollution and improve efficiency. As lubrication reduces friction between movable parts, it helps to reduce noise.

The key design considerations that must be given attention while designing the patient care areas are

- Providing single-patient rooms as compared to multi-bedrooms are less noisy. The patients and healthcare workers are more comfortable as there the conversation is more private, more effective and confidential. There is no interference by other patients and relatives speaking at the same time.
- Installing high-performance sound-absorbing acoustical ceiling and wall tiles results in shorter reverberation times, reduced sound propagation and improved speech intelligibility. Also, this design measure increases speech privacy as less sound travels into adjoining spaces.
- Removing or reducing loud noise sources on hospital units and educating staff about the impact of noise on patients as well as themselves is effective in reducing noise levels.
- Providing patient examination rooms and treatment areas with walls that extend fully to the support ceiling will prevent voice and noise carrying through ceilings.
- The medical equipments (ventilators, connections for compressed air, oxygen and vacuum, syringe infusion pumps, suction pumps etc.) in ICU can be placed in a sound protective wooden section behind the wall of patient bed. In case of two patients in one room, noise-shielding sideboard between both patients can be installed.
- To reduce human and working related noise, as well as alarms at the bedside, closed working space may be created in between the ICU rooms with glass windows which provides unobstructed patient view with patient monitors and sitting area for health care workers.
- Even simple low-cost measures like fitting of all furniture legs with rubber shoes, replacing metal folders with plastic ones, lubricating the wheels of movable equipment can go a long way in reducing ICU noise[9].

16.6.3 Sound Masking

It is the addition of background broadband sound (such as white noise) which can be optimised for particular environments to mask and reduce noise induced disturbance. This has been shown in a non-randomised trial to significantly improve sleep of patients in hospitals. Similarly soothing music helps to reduce anxiety and distress among patients. Not all loud sounds are perceived as noise by patients. Some find the sound of the tea trolley pleasing, and some ICU patients welcome ringing telephones as a sign that they are not alone.

An environment devoid of appropriate sounds of hospitals involved in caring for patients is not the optimal outcome. In fact, a completely silent environment will backfire and the patients will feel lonely and depressed. Every single word, buzz or bell will be loud and clear as there will be nothing to stop the sounds from reaching the wrong ears of patients. According to Mazer, the challenge is to design a sound environment in hospital which is not disturbing or invasive. We need to improve the patient and visitor experience by not merely masking noise and other sounds but by adding positive and therapeutic sounds. For example, a water fountain or appropriate soothing music may be played in the background[10]. This is especially true at night because the environment at that time is really quiet.

Research shows that certain types of music induce relaxation and positive responses, which reduce activity in the neuroendocrine and sympathetic nervous systems, resulting in decreased anxiety, heart rate, respiratory rate and increased temperature. Music is defined as a complex of expressively organized sounds composed of some key elements: rhythm, pitch, harmony and melody. Music therapy or the therapeutic use of music to promote health and well-being in patients has been used in different settings including oncology, maternity, postoperative, intensive care, coronary care and paediatric.

Patients and families need clear information about likely noise levels during admissions so they are better prepared and can consider simple solutions such as headphones with their own choice of audio content. User friendly guides on the potential sources of noise in wards can also help. Education for staff is also needed, to encourage a culture that considers noise reduction an integral part of safe high-quality healthcare. A study by Ramesh et al suggests behavior modifications of the ICU staff for control of noise. This included speaking in low tones, avoiding shouts across the room except during an emergency, holding discussions in a separate room, handling trays and metallic objects gently, putting off the FM radio system, keeping volume of phone at minimum, and tuning alarm volumes using a sound pressure level meter to emit a maximum of 55 dB[11, 12].

Sound impacts patients and staff in many different ways. Unwanted sound or noise is a major problem in hospitals the world over. High noise levels negatively impact patient and staff health and well-being and may slow the process of healing among patients.

Niklas suggests 10 steps that hospitals can take up to effectively reduce noise[13]

1. **Form a special committee to study and address noise.** Members should educate staff (not only doctors and nurses, but those involved in ancillary departments, like transport), patients and visitors in order to raise awareness of noise and its effects on healing. The committee should also develop and enforce policies related to noise reduction. The program should be evaluated on an on-going basis (e.g., through patient satisfaction surveys) so that measures can be tweaked and added, as needed.

2. **Post signs reminding staff, patients and visitors to consider their voice level.** They should use hushed rather than normal speaking tones whenever possible and talk only in close proximity to the listener, not from a distance. This strategy can also help to improve speech privacy, which is key in healthcare settings. Some hospitals have topped anti-noise posters with clever acronyms like 'SHHH' (Silent Hospitals Help Healing) and 'HUSH' (Help Us Support Healing).
3. **Provide training on handling loud/disruptive vocalisation** by patients and, when applicable, reduce common triggers, such as understimulation, overstimulation, immobility, pain or discomfort.
4. **Purchase quieter equipment**, such as hand towel dispensers and door hardware. Also fix or replace any faulty equipment, such as squeaky carts and creaking doors.
5. **Reduce noise from electronic devices:** Lower the ringer volume on telephones and set cell phones to vibrate. Also ask patients to use headsets with televisions and all personal electronic devices. Turn off unwatched television sets.
6. **Designate 'quiet time'** during which no routine checks are made unless medically necessary.
7. **Restock supplies during the evening rather than at night** when patients are trying to sleep.
8. **Dim the lights in the evening** to encourage quiet and help patients prepare for sleep.
9. **Limit or eliminate overhead paging** by equipping staff with personal devices.
10. **Analyse the use of medical device alarms and reduce their occurrence.** Currently, alarms pose one of the biggest obstacles to noise reduction strategies.

Other measures which can be done and do not involve much financial burden on the hospital and can go a long run in decreasing adverse effects of noise are by changing the behaviour of staff and patients[14]. These include encouraging patients and staff to respect others by turning down the volume on cell phones rings, televisions, radio and other devices. Minimizing cell phone conversations in hospital waiting areas and encouraging others to do the same. Also, unnecessary entry of visitors into patient rooms during quiet hours must be restricted. Reminding staff to be quiet in the patient care setting and wearing soft sole shoes to minimize corridor noise. To make everyone aware testing sound level meters with display of sound levels can be installed that indicate sound levels in the area rooms. This will encourage everyone to be quiet.

16.7 Conclusion

Sound control is critically important in healthcare settings as it is known to have deleterious effects on the health of the patients and also interfere with the communication, performance, wellbeing and caring behaviour of the health care workers. There is now enough evidence that improving the acoustical environment in hospitals by careful designing can go a long way toward reducing noise and improving speech intelligibility and effective verbal communication among patients and health workers. Less noise means more concentration, easier communication and less errors/complications by healthcare staff.

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17

COMMUNITY AND SOCIAL SETTINGS

Margaret Lavina Fernandes

17.1 Introduction

This chapter will describe various scenarios in the community setting where noise can have an adverse effect on health. Community noise (environmental noise/residential noise/domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. (1) Various strategies for limiting noise in these settings will be suggested. The information and strategies may be utilized by healthcare professionals and personnel working in allied sectors for establishing and implementing noise reduction strategies to limit community noise.

Based on ethnographic observations during a community-based survey we have identified scenarios in urban settings where noise levels are above the acceptable level of 55 dB(A). (2) These are traffic noise due to vehicles, trains and take off/landing of aircrafts, power looms inside the house, public address systems, firecrackers, toy weapons, road construction activity, festive and other celebrations, election rallies, leisure events like pubs, clubs, rock music events, sports event, use of ear phones to listen music, television and audio systems at homes, video game consoles, audio systems in vehicles, construction activity in residential areas including bore well creation, air conditioning and ventilation systems and animal created noise like barking dogs.

In the rural setting various scenarios where noise is harmful are agricultural activity, festive and other celebrations, election rallies, power looms inside house, traffic noise due to vehicles, trains and take off/landing of aircrafts, cottage industry near and inside homes, use of ear phones to listen music, television and audio systems at homes and animal created noise like barking dogs.

In community-based settings noise rarely causes hearing loss but has a potential to damage hearing if the exposure is repeated or prolonged. In situations where the power loom is located inside the house and loud impulsive noises due to firecrackers, noise induced hearing loss can occur. In rest of the situations community-based noise is responsible for annoyance, irritation, cardiovascular effects, performance reduction, sleep disturbances and effects on social behavior like its impact on speech intelligibility and communication.

The peculiar characteristics of noise in each of these settings will be described. The maximum recommended noise levels to prevent any health hazard are summarized in a single section. This will assist in choosing the most appropriate method to quantify noise exposure described in Chapter 6, 'Measuring Sound'. The readers may utilize the information from Chapter 7, 'Principles of Quantifying Impact of Noise on Health' to measure the deleterious effects of noise in these settings.

Learning Objectives

1. List various urban and rural settings where noise levels are above the minimum acceptable levels.
2. Understand the concept of guideline value for various community settings.
3. Principles of noise reduction in community and social settings.

17.2 Community Noise in Urban Areas

17.2.1 Traffic Noise

Traffic noise affects people traveling long distance on daily basis, residing in homes in the vicinity of roads, railway tracks and airports. At its source, a two wheeler motor cycle, three wheeler auto rickshaw, cars and trucks emit 82, 87, 85 and 92 dB(A) respectively. (3)

Vehicles on the road cause continuous low frequency noise from the engines. The air horns of the vehicles generate impulsive high and low frequency noise. Garbage collection trucks generate extremely loud sounds during loading and unloading when their carriages are detached and fall on the road.

Urban communities located in the vicinity of railway tracks are exposed to intermittent high noise level. Motion of a train creates vibration and low frequency noise. The horns of trains can generate levels above 100 dB (A). Community-based studies in the city of Kolkata has documented high noise levels due to road traffic. (4) A comprehensive review of literature on the effects of road traffic noise on health in the Indian context revealed annoyance as an important effect. (5) High noise levels due to traffic noise has potential health hazards in children. (6)

Take off and landing of aircrafts generates significant noise for those residing in the takeoff and landing trajectory. In certain cities, air force bases are located in the outskirts. Passenger aircrafts create low frequency noise whereas jet fighters can create additional high frequency noise due to their supersonic speeds.

17.2.2 Power Looms inside the House

Many urban households run weaving activities using power looms inside their homes. If the loom is weaving a design pattern then the loom has to operate without a break till the entire weaving process is complete. For this reason, the loom is run for long hours even at nighttime. It creates predominantly low frequency noise with intermittent high frequency levels. Fig 17.1 shows the power loom being operated inside a urban household.

17.2.3 Public Address Systems and Firecrackers

Public address systems are commonly used in places of worship, festivities and election rallies. Depending on the nature of music or type of information being broadcast the noise levels may be high or low frequency. These noises are usually intermittent in nature. Also, firecrackers are used to celebrate festivities. They generate very high noise levels which is painful for the human ear. Two Indian studies have documented the high noise levels of toy weapons and firecrackers. (7, 8)

17.2.4 Leisure Events

Pubs, discothèques, clubs and rock music events generate extremely loud noises. Many of these activities are held in the late evening time. For residents of houses in the vicinity of these events, considerable degree of annoyance is experienced. Workers and customers in these settings are exposed to extremely loud noise especially low frequency sounds. Music and dance classes are held in households. In urban areas where houses have a partition, sounds get transmitted across the partitions to neighbours which cause significant annoyance.

17.2.5 Sports Events

Sports activities like cricket matches held near or in grounds located in residential areas create a lot of noise generated by the crowds cheering the teams. This is compounded by horns and noise making devices like vuvuzela, which create very high pitch sounds.

Figure 17.1 Power loom being operated inside an urban household in Bengaluru.

17.2.6 Use of Personal Audio Systems at Home

Personal audio systems like home theatre consoles are an important health hazard if played in loud volumes. Use of ear phones especially ear bud type of headphones could be a cause for concern. In some households, television is continuously played. This could be a cause of annoyance for the neighbours.

17.2.7 Video Game Consoles and Toys

Technology and animation has created video games that are a source of entertainment for children as well as adults. Many of the video games consoles are linked to home theatre audio systems to provide a special experience. Families invest in these devices for entertainment at home. Toy weapons like guns that emit noise create a high pitched shrill noise. The noise generated by these devices can be potentially harmful for the users especially children. (7)

17.2.8 Audio Systems in Vehicles

High noise generated by audio systems in cars and sports utility vehicles is detrimental for the passengers. The high bass is a source of low frequency noise.

17.2.9 Construction Activity in Residential Areas

Construction activities generate considerable noise levels that can affect the lives of people living in homes near these activities. In urban areas, metro rail construction is an important source of annoying noise especially during night when considerable amount of activities are performed.

17.2.10 Air Conditioning and Ventilation Systems

There are two types of air conditioning and ventilation systems: systems where compressors and ducts are in close proximity and those in which the compressors are located at a distance from the ducts that deliver treated air. In the first type of system, low frequency noise is generated by both the compressors and exit ports of the vents, whereas in the second type of systems the exits of the vents solely contribute to the noise. Compressor noise is mainly low frequency noise.

17.2.11 Noise Created by Animals

Noise due to animals is an important source of annoyance in residential areas. It may be pet or stray animals like dogs.

17.3 Community Noise in Rural Areas

17.3.1 Agricultural Activity

In rural areas, agricultural activities take place in the fields located near the homes of people. Machines used for processing the raw agricultural produce like threshers can generate significant level of noise in the houses in their vicinity.

17.3.2 Public Address Systems and Firecrackers

During festivals, other celebrations like social gatherings and election campaigns loud speakers are often used to play music and messages delivered by the campaigners. The blaring sounds of these audio systems create high decibel noise in residential areas. Firecrackers generate extremely loud noise which is painful to the ear. Some firecrackers like rockets create a shrill high pitched noise during launching.

17.3.3 Power Looms inside House

As in urban areas, power looms are located inside rural households. It is a good source of income generation. For completion of a design pattern on the fabric, the loom has to be continuously operated during day and night. This may be harmful for the residents and an irritant for the neighbours.

17.3.4 Traffic Noise

In rural areas some localities are beside the highway and railway tracks. Vehicular movement on the roads and rail tracks generate noise that can affect the persons living in these houses, especially at night time.

17.3.5 Take Off/Landing of Aircrafts

Conventionally airports were located at the fringes of cities. With an enormous increase in air traffic, the airports have been relocated to outskirts of cities. Many of the outskirts are rural areas. So the households located in these areas are exposed to loud noise of aircraft take off and landing.

17.3.6 Cottage Industry near and inside Homes

For income generation, many rural households have various categories of cottage industry located inside their households. Many of these activities involve machinery which generates intermittent or continuous noise inside the house. Some common activities are pickle making and grinding masala powder.

17.3.7 Use of Ear Phones and Audio Systems

With globalization, urban lifestyle and its amenities have pervaded into rural communities. Along with the benefits of modern amenities, it has also made people use personal hearing gadgets like ear phones. Long term use of these gadgets may be harmful to the listeners. Television with loud audio systems is also a cause for concern in rural households.

17.3.8 Noise Generated by Animals

Most of the rural households have pet dogs. These dogs are usually let loose in the night to guard the house and fields. The noise due to barking by these dogs is a source of annoyance for the neighbourhood.

17.4 Guideline Values for Community Noise in Specific Environments

Guideline value is the maximum permissible sound for a given environment in the community setting. (8) The night time levels should be at least 5 dB(A) below the guideline value. The guideline values for various settings are as follows:

Outdoor living area: The guideline value is 55 dB(A). Levels above this cause serious annoyance for the residents.

Indoor dwellings and inside bedrooms: Levels should not exceed 35 dB(A) as it leads to moderate annoyance, affects speech intelligibility and sleep.

Outside bedrooms: The maximum permissible level is 45 dB(A). Levels above this measure causes sleep disturbances.

School classrooms and pre-school indoors: Levels above 35 dB(A) affects speech intelligibility, disturbance of information extraction and message communication.

Pre-school sleep areas indoors (for children): The maximum permissible level is 30 dB(A) and noise higher that 30 dB(A) causes sleep disturbance among children.

Outdoor playground in schools: Levels above 55 dB(A) causes annoyance among children in these settings.

Indoors of hospitals: The maximum permissible level in these settings is 30 dB(A) above which sleep disturbances occur.

Hospital treatment rooms: In these settings the noise levels should be as low as possible much below the 30 dB(A).

Indoors and outdoors of shopping areas and traffic: Levels above 70 dB(A) causes hearing impairment as a long-term effect.

Ceremonies, festivals and entertainment events: In these settings the levels should not exceed 100 dB(A). These levels may cause hearing impairment if exposed for long hours.

Public address systems indoors and outdoors: 85 dB(A) is the guideline value for public address systems. Prolonged exposure to levels above this may cause hearing impairment.

Music and other sounds through headphones and earphones: The free field values for these systems should be within 85 dB(A) to prevent hearing impairment.

Impulse sounds from toys, fireworks and firearms: These settings are characterized by sudden impulse sounds which are harmful for hearing. The maximum permissible value is 120 dB(A).

Outdoors in parklands and conservation areas: Here there should not be any external sounds so as to preserve the tranquillity. The effects of mining noise on biodiversity has been documented in an Indian study. (9)

17.5 Strategies to Limit the Effects of Noise in Community Settings

Implementing noise reduction strategies in community settings is a challenging task. This section will describe the possible methods that may be employed. People and organizations working for noise reduction in communities have to adapt and adopt these based on the specific context.

The broad principles of any noise reduction strategy are noise measurements, reducing noise at the source, limiting reverberations in the closed space, blocking sound at the receiver level and measuring/monitoring harmful effects of high noise levels. The readers may utilize the information from Chapter 7, 'Principles of Quantifying Impact of Noise on Health' in Part II to measure the deleterious effects of noise in these settings and also measure sounds. The main factor that determines quantification of sound is the nature of the noise. Noise can be continuous, impulsive and continuous with interspersed impulses (mixed type). Based on this the noise quantification strategy is planned. .

For reducing community noise levels involving people in the community is crucial. Imposing laws framed by the pollution control board has a temporary effect. Many a time people follow the rules till a person from the enforcing authority is present. For consistency in following the rules, the community has to take accountability for enforcing these regulations. The first step is to create awareness among the community leaders who influence opinion. They can be made aware of the harmful effects of noise. Scientific information has to be explained in a simple and easily understood language. Role plays, street plays, demonstrations and storytelling methods may be employed. An ethnographic observation of various settings in the community where noise is potentially harmful is a useful resource on which these sessions may be planned. The opinion leaders must be given charge of implementing noise reduction programmes in the community. These leaders have to organize a group of community based volunteers predominantly youth who can conduct a noise survey in the community. A simple sound level meter costing Indian national rupees five thousand may be employed to perform the noise survey. A training session has to be organized covering the following aspects explained in an easily understood language: importance of conducting the noise survey, sound and its properties and technique of using the sound level meter. Scientific jargon should be avoided. Physical demonstrations using sound generating equipments like drums, whistles, rattles, bells, motors and vehicle horns should be used to explain various types of noise. In controlled situations, the sound level meter should be used to demonstrate the techniques of using it. Figure 17.2 shows a basic sound level meter. The main steps to use the meter are as follows: switching on the power button, ensure the setting is in dB (A), wait for the reading to stabilize it by holding it stationery for a while and noting down the reading. Using cycle mounted sound level meters has been recommended by an Indian study as a bicycle can be easily taken through all the narrow lanes in the community. (10)

After completing the noise survey the volunteers have to create a noise map of the urban or rural community. The map should clearly indicate residential areas where noise levels exceed the recommended 55 dB(A). There should be a description of the characteristics of the noise. Is it continuous, impulsive or mixed type? Based on the opinion of expert, potentially harmful effects of noise should be understood by the volunteers. These volunteers should organize small community-based educational sessions for all the people exposed to high noise levels. It should include both people responsible for generating the noise and those affected by noise pollution.

In these community-based sessions, people should be involved in a brainstorming session to examine possible methods to reduce noise which is harmful to all those exposed to it. Surprisingly the people who create noise may get aware that they are also affected by the noise that they create and it may have significant consequences. The volunteers can facilitate the session by giving some technical inputs like methods to limit noise like planting trees and shrubs along roadsides, introduction of silent zones around schools and

Figure 17.2 Sound level meter to measure noise levels.

hospitals, ban on air horns, enforcement of noise control regulations, use of silencers in auto rickshaws, bypass roads for heavy vehicles, restricting movement of heavy vehicles at night through residential areas, installing sound proof windows, thick cotton curtains, proper planning of residential areas and lubricating moving parts of machines on a regular basis. Demonstration of various types of ear protection devices and technique of using them should be performed. This is very relevant to those who have cottage industries and power looms inside the house.

Compliance with noise reduction strategies is a challenging domain. It involves shifting the behaviour of people. Behaviour change occurs by creating a culture of silence. Culture is defined as a set of practices followed in the community. The people in the community are primarily accountable for creating this culture. The volunteers have to use examples to highlight this powerful concept using examples. One example is culture of cleanliness, which ensures that people do not litter garbage. Similarly, when a culture of silence gets created, the new people who walk into this culture get conditioned to reduce noise.

After the set of strategies have been selected, the volunteers have to ensure that the community starts acting on them. Innovative methods should be employed to create a momentum for enforcing these strategies. There can be a competition organized for the most silent street or ward. Social media may be utilized to announce the areas that have ensured that noise levels remained within acceptable limits. The residents can share the experience of having a quiet environment in terms of sleep quality, performance improvement and ease of communication.

The groups of volunteers have to monitor consistency of compliance with these strategies on a regular basis. Ensuring that community noise remains within the recommended levels is an on-going process.

17.6 Conclusion and Key Messages

- The recommended noise levels in residential settings is 55 dB(A)
- Community noise (environmental noise/residential noise/domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace
- Guideline values are prescribed for various community settings and noise reduction strategies should target these values
- Various sources of community noise in urban settings are traffic noise due to vehicles, trains and take off/landing of aircrafts, power looms inside the house, public address systems, firecrackers, toy weapons, road construction activity, festive and other celebrations, election rallies, leisure events

like pubs, clubs, rock music events, sports event, use of ear phones to listen music, television and audio systems at homes, video game consoles, audio systems in vehicles, construction activity in residential areas including bore well creation, air conditioning and ventilation systems and animal created noise like barking dogs

- Various sources of community noise in rural setting where noise it is harmful are agricultural activity, festive and other celebrations, election rallies, power looms inside house, traffic noise due to vehicles, trains and take off/landing of aircrafts, cottage industry near and inside homes, use of ear phones to listen music, television and audio systems at homes and animal created noise like barking dogs
- Community involvement and participation is critical to ensure compliance with noise reduction measures.

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Part V

APPLICATIONS OF SOUND

18

THE INDUSTRIAL APPLICATIONS OF SOUND

*Prasanta Kumar Ghosh**

18.1 Introduction

Sound is a vibration which is created when an object pulsates in a medium such as air or water. This vibration travels through the medium as a wave. Sound cannot occur in a vacuum. For example, if a brick falls from a building, it hits the ground. The air pressure around the brick changes when it hits the ground. Due to the collision, it vibrates and produces sound. Sound waves have physical properties, namely, amplitude and frequency. Amplitude is associated with the loudness of sound. Low amplitude refers to a quieter sound and high amplitude refers to a louder sound. The number of repeated sound waves per second is called frequency. Lower and higher frequency sounds are often referred to as low and high pitch, respectively.

Sound has a wide variety of applications in industries such as medicine, dairy and food processing as also in defence and underwater. The objective of this chapter is to provide an overview of all these applications of sound.

Learning Objectives

- Understand sound therapy and its applications
- Study the use of ultrasound in medicine and medical applications
- Learn how the sound is used in the applications of dairy and food processing industries, underwater, microelectronic manufacturing, emulsion and remote turbulence detection
- Understand how architectural acoustics work in designing theatres, sound studios and so on
- Find how sound is used for navigation and animal echolocation
- Study recent applications of sound for animals like dogs, mosquitoes and as a pest repellent

18.2 Applications of Sound

18.2.1 Sound Therapy

Sound therapy is a treatment which uses sound to treat mental and physical stress. The technique involves sending sound waves and harmonic vibrations to the body through the use of instruments and the human voice. Sound waves help to facilitate a shift in brainwave conditions by entrainment. Entrainment matches the oscillating brainwaves by providing a stable frequency which they can attune to. It is possible to stimulate the brainwaves by using frequency and rhythm, which makes it possible to downshift normal waking consciousness/state (beta state) to relaxed consciousness/state (alpha state), then to meditative state (theta state) and to sleep state, where internal healing can occur (delta state).[1]

One of the most common sources of sound therapy is the "Tibetan singing bowl" (Figure 18.1). The bowl produces vibrations in deep tones which allows

Figure 18.1 Tibetan singing bowl.[2]

relaxation of both sides of the brain and helps in muscle regeneration. The vibrations also improve circulation, release tensions or blockages, relieve depression and mood-related concerns, as well as cure anxiety. It treats children with hyperactive disorders too by stimulating the immune system. The bowl is made up of five to seven types of metals which are connected to celestial bodies: mercury (Mercury), copper (Venus), iron (Mars), tin (Jupiter), lead (Saturn), gold (Sun), and silver (Moon).[2]

18.2.2 Clinical and Pharmaceutical Applications

The use of sound in clinical assessment has a long history. Stethoscopes are used by doctors to hear the internal sounds of the human body such as of the heart, lungs, blood flow, and so on. Nowadays, scientists are carrying out research and development for advanced applications of sound in clinical applications. Acoustical energy is used, for instance, for imaging and for different ways to cure diseases like cancer, stroke, and Parkinson's disease.[3]

Ultrasound technology has proved useful in the pharmaceutical field because of the ease with which the amplitude and frequency of ultrasonic waves can be tuned. It also offers flexibility in controlling the particle size, production of nano and micromaterials, crystallization control, and augmenting the solubility of weak soluble drugs. Ultrasound technology is used in preparing and processing fine biomolecules like nucleic acid and proteins since it verifies the structural integrity of the molecules. Based on the dimension and physical properties of particles, ultrasound is used for separation processes and effluent treatment.[4]

18.2.3 Sound in Dairy Products

In 2008, in China, the dairy industry had a big setback as more than 290,000 people, most of them infants, were affected due to the melamine (rich in nitrogen) content in milk.[5] Basically, raw milk contains pathogenic organisms like *Bacillus cereus*, Salmonella spp, and *Listeria monocytogenes*, which promote growth of microbes and so on. Hence, various techniques are involved in different industries for good post production microbiological control of the milk packages. This is where ultrasound is useful. Both high intensity and low intensity ultrasound are used for this purpose. During the storage or processing of dairy products, monitoring and quality control can be achieved by low intensity ultrasound based on the physicochemical variations. For homogenization, fermentation, extraction, and pasteurization, high intensity ultrasound (HIU) is employed.[6] During the production of cheese HIU enhances the gelation and syneresis, and decreases the fermentation time. HIU applications are used in ultrasonication for modifying the colour of dairy products. However, it has been reported that the application of HIU in milk is dangerous because it limits the lightness, chroma, and denaturation of proteins in pasteurized milk.

18.2.4 Sound in Food Processing Industry

Food safety is important. Significant research has been done on the development and expansion of fast and reliable food quality control systems. Extraction of intracellular material and cell destruction are the most common applications of sound in the food processing industry. The use of ultrasound in food processing helps develop novel techniques for preservation, activation or deactivation of enzymes; emulsification, stabilization, tenderization of meat, mixing and homogenization; dispersion, oxidation, and ageing; hydrogenation; ripening; dissolution; and crystallization. It also assists in solid–liquid separation, atomization, and degassing of food preparations.[7] Ultrasound is used as an alternate method for thermal treatments in food preservation for the removal of microorganisms and enzymes without annihilating the nutrients in foods.

Chemical reactions of proteins can be achieved by ultrasound which modifies the physical and chemical or functional attributes such as emulsification, solubility, foamability, and gelation. Ultrasound irradiation is used for mixing in oil technology. For example, the conversion of soyabean oil to biodiesel can be optimally achieved by using an oil to methanol ratio of 9:1. Ultrasound wave propagation evaluates the type of protein, size, and aggregation state to differentiate between original honey and adulterated honey. On the commercial side, industrialists need to think of minimizing the use of ultrasound in the food industry for achieving maximum results because it causes changes in materials based on the characteristics of the medium.

18.2.5 Sound in Underwater Applications

Sound travels at 1500 m/sec underwater. As the sound wave moves through seawater, the underwater objects vibrate and produce pressure waves that compress and decompress water molecules. Sound waves radiate in all directions from the source. Although identification and classification of underwater acoustic signals is difficult due to low signal-to-noise ratio, it is well known that animals use sound for communication. For example, dolphins use ultrasound for navigation and catching their prey. Dolphins hunt in the dark and have unique signature whistles to identify themselves. Sound propagation in air is complex due to reflection, scattering because of particle size, bubbles, and so on. Similarly, fluctuation in sound propagation in water happens due to a variety of reasons. Water has higher viscosity, heat capacity and conductivity compared to air. So, the speed of sound underwater is more affected by temperature, hydrostatic pressure, dissolved impurities and mass density.[8]

In 1906, naval architect Lewis Nixon invented sound navigation and ranging, or sonar in short. It was designed and developed to detect icebergs. Later, a large body of research on sonar was carried out during World War I.[9] From these and further research, different technologies have been developed in various fields including military and civilian applications. Sound propagation is used by sonar systems for navigation, to find the distance from an object and for obstacle identification, an illustration of which is shown in Figure 18.2. There are two types of sonar system—active and passive. Active sonar systems generate a sound pulse by using an acoustic projector and wait for the pulse to reflect from the target. Passive sonar systems receive the noise radiated by the object, that is, a submarine or a ship. By analyzing the sound waves, one can recognize the object type and find its speed, direction, and distance. In defence applications, sonar is used for tracking, detecting, and localizing enemy targets, such as surface ships or submarines, and acoustic sensors are used for firing of weapons. Radar or optical devices are dedicated for attenuation of electromagnetic waves in seawater compared to that of sound in air.[8] The comparison of active and passive sonar systems is shown in Figure 18.2.

Further, as sound waves can propagate underwater, they are used in the application of underwater communication systems. Such a system transmits and receives the vocal sound of humans through audio amplifiers and hydrophones. An acoustic modem is used to convert digital data into sound signals underwater which is also used for communication of higher quality digital data such as pictures and words.[8]

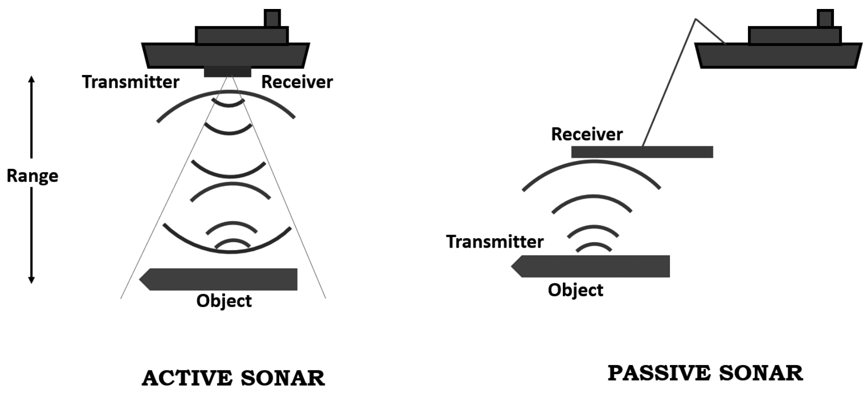

Figure 18.2 Comparison of active and passive sonar systems.[10]

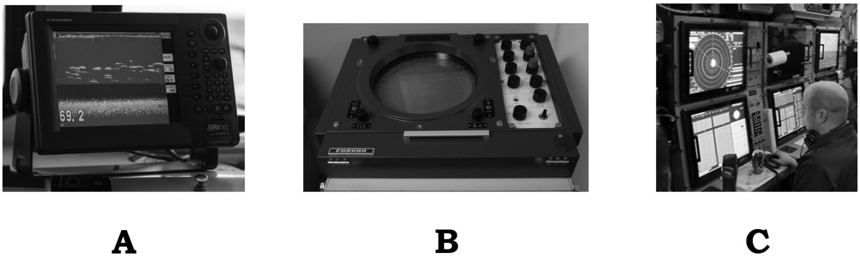

Figure 18.3 Different types of sonar devices: A. Fish finder[11] B. Sonar device for underwater acoustics[12] C. Sonar device.[13]

Underwater acoustics have played an important role in various applications over the last century. Nowadays, underwater acoustics is used widely in defence and also in civilian life, for example, fish finders, a picture of which is shown in Figure 18.3(A). Other sonar devices shown in Figure 18.3(B) and Figure 18.3(C) are used for object detection. Further, a variety of research is carried out for advancement in seismography, tomography, biology, topography, and weather patterns, which allows researchers to acquire deeper knowledge about the planet.[8]

18.2.6 Architectural Acoustics

Architectural acoustics are mainly used in designing theatres, hospitals, schools, colleges, malls, and other big buildings for controlling noise in music acoustics, speech intelligibility, theatre acoustics, or environments designed and developed for pleasant ambient sounds. Architectural acoustics are also used for controlling sound characteristics within designed spaces. In hospitals, sound from beeping equipment and alarms drastically increases because of the reflection of sound by the hard floors and ceilings which leads to increased noise levels. This problem can be avoided by replacing hard tiles with sound-absorbing tiles. In 2004, it was reported that patients in hospitals slept more comfortably after the ceiling tiles were replaced.[14] In schools, ambient noise can be controlled by placing acoustic absorbers in classrooms. While designing a theatre, attention is given to two issues: (1) creating sound effects, textures, and subtextual themes, and (2) planning the placement of the microphone and speakers such that the audience has the best feasible sonic experience. Architectural acoustics involves the use of acoustic metamaterials that enable low frequency sound mitigation and manipulation. Most of the materials which absorb sound are nonlinear and they don't absorb the same fraction of acoustic waves at all frequencies.

Acoustic construction materials reflect desired frequencies and absorb undesirable frequencies, that is, noise from machinery in factories and industries which is known to affect workers.[15]

While designing big buildings, attention is typically paid to the following constraints from the point of view of acoustics.

- **Building envelope:** A building envelope mainly refers to the outer layer of the structure that envelops or shields the building from outside environments such as heat, wind, water, and noise. It reflects and absorbs sound to reduce noise.
- **Interior structure:** Structured room, doors, windows, walls, floors, and ducts create a good acoustic environment or reduce noise level. For example, the shape of a theatre allows sound to flow unobstructed from the stage to all the seats and prevents sound from echoing.
- **Materials:** The selection of building materials is important because sound has properties such as reflection, refraction, absorption, diffraction, diffusion, and transmission. For example, a party wall between two apartments should contain layers of sound insulation to absorb noise.
- **Equipment:** The selection of equipment like escalators plays an important role in the acoustics of a building. Mechanical equipment that lack beeps and other noisy features are preferred.
- **Sound masking-** This is achieved by ambient sound that includes noise such as water fountains or electronic noise control that generates noise-cancelling waveforms in real time in response to undesirable noise . Sound masking is also done by using highly dense material which causes less sound to travel through it although it increases the weight of the floor and wall. Decoupling is yet another way of controlling sound.[16]

18.2.7 Emulsion

Emulsion is a mixture of two liquids which typically do not blend well (e.g., oil and water). Ultrasonication is a low-cost method for emulsion development with an important effect on the emulsion structure and size of droplets. It is known that ultrasonication produces emulsions with higher kinetic stability (i.e., stable for a longer duration of time) than other means of developing emulsions, for example, mechanical agitation. By applying low intensity, resonant ultrasonic fields to the emulsion, separation and recovery of the oil phase from oil-in-water emulsion can be done. Ultrasonication is used in various fields such as cosmetics, paints, food, pharmaceuticals, and agrochemical industries.[17] The drops shift towards the pressure antinodes of the standing wave under the influence of the acoustic force. The relative motion of drops is very sensitive to their initial configuration and physical properties, relative size of interacting drops and parameters of acoustic field. Around 80 per cent efficiency of oil retention can be observed in laboratory scale devices.[18]

18.2.8 Microelectronic Manufacturing

Acoustic imaging or microscopy is used for characterization of the quality and detection of problems in manufacturing objects on a microscopic scale. Acoustic microimaging or scanning acoustic microscopy is a nondestructive method that finds problems in biological, elastic samples and electronic circuits. This technique works efficiently to detect physical defects such as voids, delamination, and cracks with high sensitivity by observing the internal features of a sample in 3-D integration.[19] There are other techniques such as ultrasound impedance microscopy, which is a two-dimensional acoustic impedance imaging technique for characterization of biological tissue with microscale resolution.[20] Similarly, ultrasound scanning acoustic gigahertz microscopy and speed microscopy are used to examine the quality of wafer-bonded interfaces in three-dimensional integration.[21]

18.2.9 Forest Monitoring and Animal Echolocation

Loss of forest areas due to wildfires, floods or even illegal deforestation is a threat to the planet. Acoustic monitoring is the best solution for such a problem that involves observing and surveying of wildlife and environments remotely. A forest monitoring system consists of sound recorders which collect the data (sound) that is processed to extract useful data such as species occupancy detection, population density, abundance, community composition, monitoring temporal and spatial trends in animals behavior, and calculating acoustic proxies for metrics of biodiversity.[22] There has been research and development of devices for monitoring possible hazards, in particular loss of wood due to deforestation. Such a device continuously records the noise level in the forest area. Based on an algorithm in the system, the device has the capability to isolate the audio signal corresponding to the cutting of wood, for example, with a saw. Finally, it produces an alarm at timed intervals when the target event is identified.[23]

Similar to dolphins using sounds in underwater communication, animals and birds use echoes produced by the sounds they emit to find their path through leaf litter or in caves/tunnels under snow.[24] For example, bats use high-pitched sound for echolocation. Birds such as swiftlets and shrews use echolocation for navigation in the dark and for locating insects and other prey, respectively.

18.2.10 Remote Turbulence Detection

Atmospheric turbulence is known to pose danger to aircraft and can cause injuries to crew and passengers. For the safety and efficiency of aircraft transportation, in-flight detection, mitigation, identification, and avoidance of turbulent gusts are very important. Avoidance or mitigation of flying through turbulent air pockets decreases fuel consumption and increases ride comfort.[25] Acoustic waves are used to measure the propagation of turbulence which are diffracted by temperature and humidity fluctuations in the index of refraction.[26] Technology has helped develop 2D imaging acoustic sensors for detection of Close-In Air Turbulence. These sensors produce high resolution "images" of the air in front of Unmanned Aerial Vehicles.[27]

18.2.11 Dog, Mosquito, and Pest Repellent

Sound, mainly ultrasound, has been used to develop android applications that repel animals like dogs, mosquitoes and other pests. Dogs stop barking when they are afraid of something and get disturbed when they hear loud sounds. Ultrasonic dog repellent sounds provide a number of sounds with different frequencies to stop the animal from barking. In such an application, users need to set a frequency and duration. Mosquitoes are disturbed by high-pitched ultrasound. A few such applications are listed in Table 18.1.

18.3 Discussion

The graph in Figure 18.4 summarizes different industrial applications of sound, that is,, architectural acoustics, food processing industries, underwater

Table 18.1 Ultrasound applications for repellents

Application name	Usage	Date of Publishing
Ultrasound barrier app	This app is used to get rid of rats, dogs, mosquitoes and other insects.	14-07-2021
Ultrasonic Sounds Prank	Used for pranks against annoying people and also for mosquitoes, rodents, rats and other unwanted pests.	20-09-2018
UltraSound Detector	It detects ultrasound (ultrasonic) acoustic signals above the user-defined frequency (above 18 kHz by default). It is used in finding the leakage in air-conditioning and refrigeration systems	06-05-2018

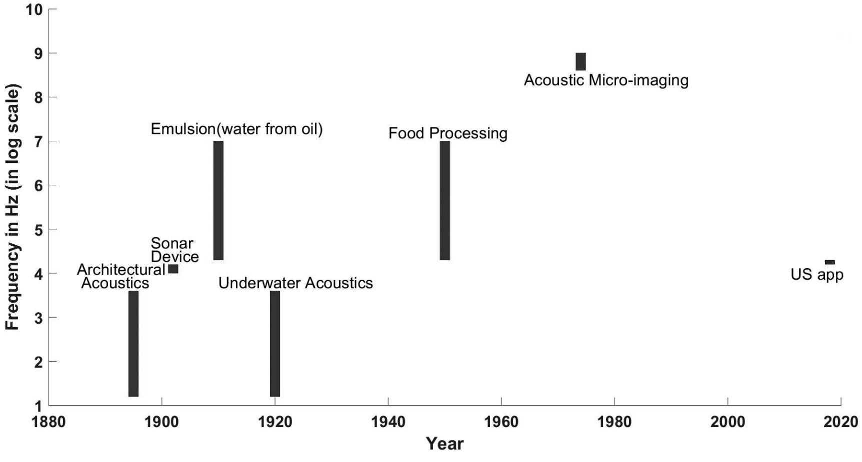

Figure 18.4 Graph of various applications of sounds showing the frequency range of sounds used and the year of invention (USG: Ultrasonography, US: Ultrasound).

acoustics, acoustic microimaging, and so on which cover a wide range of frequencies over 10Hz–-1GHz (including both audible and inaudible sounds). Architectural acoustics use a sound in the frequency range of 16Hz–4kHz for absorbing unwanted sound, blocking outside noise, and improving the sound quality in a location. It creates spaces that enhance the audibility or clarity of speech or music and the qualities of performances in concert halls. Sonar devices utilize a frequency range of 10Hz–1GHz for locating objects, measuring their distance, direction, and speed, and producing images of target objects. They use higher frequencies to provide more accurate location data. However, propagation losses increase with frequency. Lower frequencies are therefore used for long range detection (up to 10 miles) at the cost of location accuracy. As emulsion is often thermodynamically unstable, ultrasound with frequency from 25–45kHz is used to deliver high energy to separate water from oil emulsion, to extract phosvitin from egg yolk, and to separate butter from cream. Underwater acoustics use sound for communication in the ocean. Sound with frequency below 10Hz is not useful as it fails to propagate without penetrating deep into the seabed. On the other hand, sounds with frequency above 1MHz are rarely used for underwater communication as they are absorbed very quickly. Underwater acoustics applications include water exploration (finding the depth) and drilling (oil well). Food processing has a wide range of applications of sound in the dairy and meat industries, which include homogenization, mixing, extraction, filtration, and fermentation. It typically uses a frequency range of 20kHz–10MHz to deactivate the enzymes.

Acoustic microimaging is a powerful, nondestructive technique that can detect hidden defects in elastic and biological samples as well as in nontransparent hard materials and monitor physical defects such as cracks and voids. It uses a frequency range of 400MHz–1GHz which allows for a penetration depth of up to several millimeters. Nowadays, android ultrasound applications have also been developed as repellents for animals like dogs, mosquitoes and other pests which use a frequency range of 15kHz–20kHz, where users can set the frequency as required. Ultrasonic sounds create stress and jams the nervous system. This immobilizes the insects and they escape from the source of the ultrasound.

It is clear from the graph that the use of sounds in various applications is gradually increasing year by year. With more research and development, we expect to see more useful applications of sound by exploiting the characteristics of sound in different frequency ranges.

18.4 Conclusion

Sound has a large number of applications in various domains. Different frequency ranges of sound are exploited for different purposes. This chapter covers a large number of these applications.

While some of these applications are matured and available for commercial use in clinical and defence scenarios, many of the applications are in the development stage. On the other hand, research is on to develop many new applications of sound. Hence, in the years to come, we expect to see more applications of sound being available for the benefit of human beings.

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19

MEDICAL APPLICATIONS

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19.1 Introduction

Sound is a type of energy and propagates through vibrations in a medium. Thus, it requires a medium for propagation. Air is a good transmission medium for sound. Other mediums through which sound travels are solids, liquids and gases but not vacuum (space). Among various mediums, sound travels the slowest through gases, relatively faster through liquids and the fastest through solids.

Sound is classified into three types according to its frequency. Humans can detect the sounds in a frequency range of 20 Hz to 20 kHz, called audible sound. Sound below 20Hz is called infrasound. Sound ranging from 2 MHz to 18MHz is called ultrasound. Audible sound in a nursing home or hospital can bring positive vibes or feelings not only in patients but also among nurses and doctors. As sound can bring changes in the brain waves, several activities that are controlled by the autonomic nervous system can be altered by music. These include breathing, heart rate and activation of the relaxation response. Ultrasound, on the other hand, is used in various fields, especially in the medical field, because of some of its special properties. It is widely used in imaging techniques, therapies, surgeries and so on. This chapter presents the applications of sound in healthcare including different applications of ultrasound in detail.

Learning Objectives

- Understand different types of sound present in nature, that is, infrasound, audible sound and ultrasound
- Learn about the application of sound in healthcare, that is, in diagnosis, therapy and wearable devices
- Learn about ultrasound, its generation, detection, and its parts and modes
- Examine the purpose of a few ultrasound machines with illustrations

19.2 Different Types of Sound

There are different types of sound in the world around us. They have a wide variety of applications as well. However, only some sounds are used in medical applications. They are discussed below.

Sound is classified into three types according to its frequency range as follows.

1. Infrasound
2. Audible sound
3. Ultrasound

1. Infrasound: These sounds have low a frequency and are inaudible to humans. Typically sounds lower than 20Hz are categorized as infrasound. Infrasound is generated by weather patterns, seasonal winds, volcanoes, storms and some types of earthquakes. Infrasound is also used by animals such as elephants, whales, hippopotamuses, rhinoceroses, giraffes and okapis to communicate over long distances and repel foes.[1] The extremely low frequency infrasonic hydrophone is used to locate undersea oil deposits.[2] Infrasound is also used in non-contact healing for joints, muscles and so on.[3]

2. Audible sound: The human ear can detect sound in the frequency range of 20Hz to 20,000Hz, called audible sound. The sounds that humans can hear include speech, music, instruments and crackers.[4]

3. Ultrasound: Sounds with frequency above 20,000Hz are categorized as ultrasound. The medical field uses ultrasound up to a maximum of 18MHz. Ultrasound is used for a wide variety of industrial applications including packing and separation, and extraction of fats in dairy products. In the medical field, ultrasound is used for medical imaging, therapies, cleaning of surgical equipment and so on.

19.3 Use of Sound in Healthcare Applications

All three types of sound, infrasound, audible sound and ultrasound, are used in different medical applications. A summary of the broad categories of applications is shown in Figure 19.1 and discussed below.

19.3.1 Diagnosis/Assessment

Diagnosis is the examination of a person for identification of illness or symptoms of illness and other problems. It is undertaken using medical equipment with the help of healthcare providers. On the other hand,

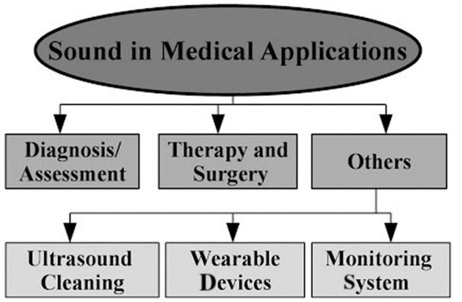


Figure 19.1 Classification of sound in medical applications.

assessment is an evaluation made by a doctor to make an informed decision on whether or not to provide treatment, and if yes, what approach to take. Such assessment devices include stethoscopes and audiometers.

19.3.1.1 Diagnosis

Ultrasound has a large number of applications in healthcare mainly in diagnosis. Diagnostic ultrasound, sonography or ultrasonography is a non-invasive method to view the internal organs of the body. It includes imaging of internal organs like the heart, blood vessels, liver and thyroid to diagnose, evaluate and identify their condition; clots; source of pain, swelling and infections; and so on.

Some ultrasound procedures are invasive. For example, a transvaginal ultrasound, used to scan the female reproductive organs, consists of a transducer called a probe, which is inserted into the vagina to scan and produce a detailed image of the organs in the pelvic region.

a. History of Ultrasound

The use of ultrasound in the medical field began during World War II in different parts of the world. In 1942, in Austria, Dr. Karl Theodore Dussik published the first work on medical ultrasonics in imaging which investigated the transmission of ultrasound in the brain.

The development of commercially available systems from the mid-1960s onwards allowed an extensive dissemination of the ultrasound-based techniques. Further rapid growth in technological advances in piezoelectric materials and electronics provided enhancement from bistable to grayscale images and from still images to real-time moving images. The technological advancements led to a quick growth in ultrasound applications. In parallel with the development of imaging technologies, there had been progress in the development of the Doppler ultrasound. The fusion of the two technologies resulted in Duplex scanning. Colour Doppler imaging developed subsequently. These provided more scope for the investigation of blood circulation in and blood supply to organs. In the 1970s, the development of the microchip and increase in processing power allowed faster and more powerful systems including enhancement of signals, digital beamforming, interpreting and displaying data, that is, 3D imaging and power Doppler.[5]

b. General Working Principle of Ultrasound

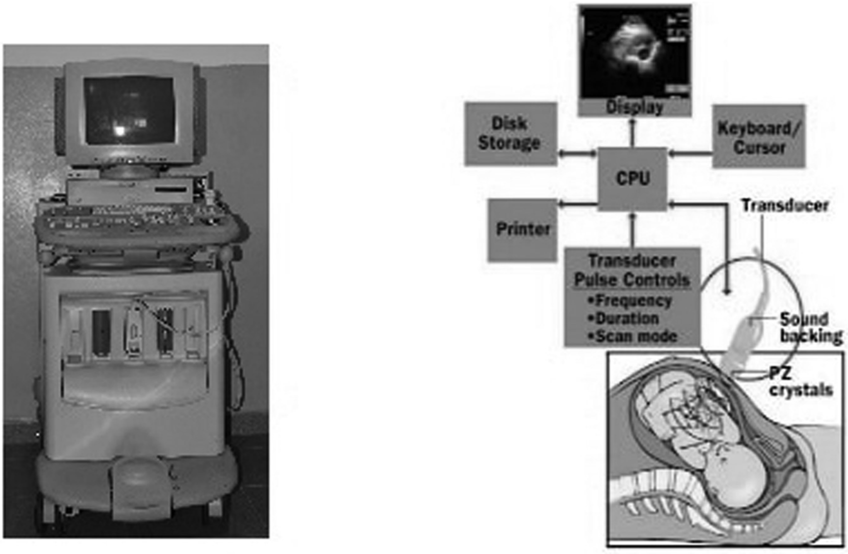
Two basic principles need to be understood to know about the working of ultrasound.

1. How ultrasound is generated
2. How the image is formed

1. Ultrasound generation: Ultrasound is generated by a piezoelectric transducer consisting of ceramic crystals, which converts electric current to pulses of sound waves. An electric current is passed through a cable to the crystals, resulting in their deformation and vibration. This vibration produces the ultrasound beam. The frequency of the ultrasound waves created is predetermined by the crystals in the transducer.

2. Image formation: Ultrasound uses the pulse-echo principle to generate an image. Ultrasound waves are produced in the form of pulses but not continuously because the same crystals are used to generate and receive sound waves, and they cannot do both at the same time. In the time between the pulses, the ultrasound beam enters the patient and is reflected back to the transducer. The reflected acoustic waves cause the crystals in the transducer to deform again and generate an electric signal, which is converted into an image and displayed on the monitor. A transducer generally emits ultrasound only 1% of the time; the rest of the time is taken up in receiving the returning echoes.

Depending on the type of the scan, different dimensional images – two-dimensional (2D), three-dimensional (3D), four-dimensional (4D) and five-dimensional (5D) or even higher dimensional (HD) – can be obtained. A black and white picture is obtained in 2D ultrasound images. This flat image helps in showing the skeletal structure and making the internal organs visible. A 3D image of an organ can be created in 3D ultrasound. For example, it allows a pregnant woman to see her baby's face, rather than just the outline of the face. In 4D ultrasound, a live video is created where a sequence of 3D images are obtained. In such a moving video, the smile or yawn of the baby in the womb



A B

Figure 19.2 A: Ultrasound machine; B: Different parts of an ultrasound machine.[6]

can be seen. HD ultrasound images are even clearer and sharper with better resolution as a result of the advancement in ultrasound technology.[45]

Diagnostic ultrasound is mainly used to view the internal organs like liver, kidneys, uterus and ovaries during pregnancy and monitor the developing baby's health, diagnose gall bladder disease, examine a breast lump, check thyroid gland, detect genital and prostate problems, evaluate blood flow and metabolic bone disease, and so on. An ultrasound device consists of probes, keyboard, CPU, display, printer and disk storage. Figure 19.2 shows the various parts of a typical ultrasound machine. The parts are briefly described below.

Central Processing Unit (CPU): The CPU is the brain of the ultrasound machine. It is part of a computer and consists of amplifiers, microprocessor, probes and power supply as peripheral parts. The CPU transmits electrical current to the transducer to emit acoustic waves and receives pulses from the transducer which were obtained from the returning echoes. It processes the received pulse data and forms the image to be shown on the monitor. Later it stores the processed data or images on the disk.

Transducer Pulse Controls: This unit is typically meant for an operator of the ultrasound machine, known as the ultrasonographer. With the help of this unit, the ultrasonographer can set the frequency and time period of the ultrasound pulses and also the scan mode of the machine. The commands are received from the operator and translated into changing electric currents, which are applied to the crystals in the probes.

Display: The computer monitor is a display that shows an image or processed data from the CPU. Depending upon the model of the ultrasound machine, the image may be coloured or black and white.

Keyboard and Cursor: Every ultrasound machine has a keyboard and a cursor with an in-built trackball. It allows the operators to add notes and take measurements from the data.

Disk Storage: The disk stores the processed image or data. The disk can be a floppy disk, hard disk, compact discs (CDs) or digital video discs (DVDs). Generally, the scanned image or data are stored on CDs along with the patient's medical records.

Printers: These are used to take hard copies of an image. Typically, ultrasound has thermal printers which print copies of images from the monitor display.[6]

An ultrasound that scans internal images or other structures, for example, abdominal ultrasound, transvaginal ultrasound, is usually referred to as anatomical ultrasound. The same anatomical ultrasound which combines the applications of Doppler and colour Doppler effect for measuring and visualizing the blood flow in vessels within the body or in the heart is called a functional ultrasound. It can also measure the speed and direction of the blood flow. Examples include elastography, Doppler ultrasound, ultrafast Doppler (neuro-functional ultrasound), breast ultrasound.[7]

Every ultrasound consists of probes. The first step before using ultrasound for examination is selecting an appropriate probe, which depends on the patient's problem, scan depth, exam type and anatomical or functional structure. Probes are nothing but transducers developed on the basis of different criteria such as clinical applications, patient characteristics, examination type etc. Probes are categorized into two types based on the arrangement of crystals. (1) Conventional probes are the main probes used for most applications. Linear, phased and convex probes are conventional probes. (2) Speciality probes are dedicated to specific clinical applications. Endocavitary probes and transesophageal probes are speciality probes.

1. **Linear Probe:** This probe has crystals arranged in a linear fashion and measures the linear displacement along a single axis in any direction; hence, the name linear probe. An image and functionalities of a linear

Table 19.1 Various probes and their examinations and frequencies[9]

Probe Type	Examinations or functions	Frequencies
Linear Probe	2D imaging – thyroid, tendon, vascular examination, blood vessel, breast visualization 3D imaging – breast, thyroid, arteria carotis of vascular application	2D: 2.5MHz–12MHz 3D: 7.5MHz–11MHz
Convex Probe	2D imaging – musculoskeletal, abdominal, vascular, nerves Diagnosis of organs, neonatal and paediatric applications 3D imaging – abdominal examinations	2D: 2.5MHz–7.5MHz 3D: 3.5MHz–6.5MHz.
Phased Array/ Cardiac Probe	Cardiac, abdominal, brain and transesophageal examinations	2MHz–7.5MHz
Endocavitary Probe	These probes provide internal examinations of the patient – examination of the rectal or vaginal area which includes females' ovaries, uterus, cervix and pelvic area	3.5MHz–11.5MHz
Transesophageal (TEE) Probe/ Pencil Probe	Usually this is used for invasive techniques of viewing internal organs of the cardiac regions	3MHz–10MHz

probe are shown in Table 19.1. A linear probe uses a frequency range of 7.5MHz–11MHz for 3D image formation while a lower frequency range is used for 2D image formation,. It creates high-resolution images near the surface of the body. The 9L-D and the 12L-RS are the bestselling linear probes from General Electric.

2. **Curvilinear/Convex Probe:** This probe has a curved array which allows it to view a wider field/area shown in the picture in Table 19.1. It uses a frequency range of 2.5MHz–7.5MHz for 3D image formation and a lower frequency range for 2D images. Typically, abdominal scans use this probe due to their wider field of view and deeper penetration. The V6-2 and the C5-1 are the bestselling curvilinear probes from Philips.
3. **Phased Array Probe:** This probe has a smaller handle with a square-shaped array. It uses a frequency range of 2MHz–7.5MHz as a central frequency. Generally, it scans the image of the heart. Phased array probes have greater depth in order to reach the heart and produce an image.
4. **Endocavitary Probe:** This probe has a U-shaped array with a much longer handle. It uses a frequency range of 3.5MHz–11.5MHz as a central frequency. These probes are used to scan inside the rectum or the vagina.

Endocavitary probes do not have a great range of depth because of the shape but they allow a wider field scan than convex probes. The Mindray SD8-1E and the GE RIC5-9A-RS are the bestselling endocavitary probes.

5. **Transesophageal (TEE) Probe:** This probe, also known as a pencil probe, is generally used for invasive scanning. It is inserted into the esophagus or the patient's stomach to provide images to show obstructions in the heart. Its controls are located in the handle and the probe can move in all four directions. It uses a frequency range of 3MHz–10MHz as a central frequency.[9]

Each probe exhibits different modes which perform a particular function to operate. Ultrasound has four modes, namely, A-mode, B-mode, M-mode and Doppler mode, explained in detail below. Each mode has a specific function whereby the doctor can choose the probe based on the patient's condition, scan depth, type of images and so on.

- **A-mode:** It is a simple mode of an ultrasound. Generally it scans a line through the body with the echoes plotted on the screen as a function of depth. It represents one-dimensional images. A-mode focuses on a particular point of the destructive wave energy.
- **B-mode:** In this mode, a linear array of transducers parallely scans a plane through the body that can be viewed as a 2D image on the display.
- **M-mode:** M stands for motion. In M-mode a high-speed pattern of B-mode scans, whose images follow each other in sequence on screen, enables doctors to view and measure a range of motion as the organ boundaries that produce reflections move relative to the transducer.
- **Doppler mode:** This mode uses the Doppler effect to measure and visualize the blood flow in various organs. Doppler sonography plays a vital role in medicine.[10]

Different probes are used for various examinations. A quick overview of the different ultrasound transducer/probe types and their applications is provided in Table 19.2.

Ultrasound diagnosis includes both invasive and non-invasive techniques. Invasive diagnosis includes the transvaginal ultrasound, which is used to examine and scan the internal organs of the female reproductive system. Transvaginal ultrasound scanning involves insertion of a small ultrasound probe called a transducer into the pelvic area or vagina to obtain detailed scans of the organs in the pelvic region. It evaluates the uterus, ovaries, vagina, fallopian tubes, cervix, gall bladder and so on.[11] Some of the invasive ultrasound examinations are presented in Table 19.3. Non-invasive diagnosis includes cardiac regions like the heart and blood vessels, abdominal aorta and its

Table 19.2 Types of probes and their applications[9]

	Linear	Convex	Endocavitary	Phased Array	Pencil
General imaging	Yes (small parts, breast, etc.)	Yes (abdominal)	Yes	Yes (abdominal)	No
Cardiac	No	No	Yes	Yes	Yes
Vascular	Yes	Yes	No	No	Yes
Obstetrics and gynaecology	No	Yes	Yes (endovaginal)	No	No

Table 19.3 Different types of invasive ultrasound devices and their purposes

Ultrasound Devices (Year of invention)	Purpose
A. Transvaginal ultrasound (late 1985)	It is used to examine the female reproductive organs such as ovaries, uterus, fallopian tubes, vagina and cervix. The examination is conducted by inserting the probe inside the body. It is also called endovaginal ultrasound.[12]
B. Endoscopic ultrasound (EUS) (1980)	It is used to assess digestive (gastrointestinal) and lung diseases. It helps gastroenterologists examine the stomach and other organs like the bile duct, pancreas, gall bladder and liver. This ultrasound can help identify tumours and surrounding lymph nodes in stomach cancer patients.[13]
C. Ultrasound-guided needle biopsy (1972)	The needle biopsy is used as a safe and effective procedure for collecting tissue specimens from different intrathoracic lesions. Percutaneous biopsy facilitates the differentiation of primary lung cancer from metastases or inflammatory lesions by obtaining tissue samples for diagnosis and staging.[14]
D. Cavitron ultrasonic surgical aspirator (CUSA) (1979)	Hepatobiliary surgery, neurosurgery, urology, gynaecology and gastrointestinal surgery are various multiple surgical subspecialties which use the cavitron ultrasonic surgical aspirator. CUSA is good for ultrasonic surgical aspirator where fragmentation, suction and irrigation occur together.[15]

major branches, liver, spleen, gall bladder, pancreas, kidneys, bladder, uterus, ovaries and unborn child (fetus) in pregnant patients, scrotum (testicles), thyroid and parathyroid glands and so on. Some of the non-invasive ultrasound examinations are shown in Table 19.4.

Table 19.4 Different types of non-invasive ultrasound device applications and their purposes

Ultrasound Devices (Year of invention)	**Purpose**
A. Ultrasonography (1928)	Medical ultrasonography was developed during World War II. In medical ultrasound imaging, ultrasound energy is created which propagates through the tissues of the body in the form of travelling pressure waves.. A frequency of 3MHz to 10MHz is required for imaging. Piezoelectric materials help in ultrasound beam production and detection. These materials vibrate and produce ultrasound when placed in a varying electric field. The signal in the ultrasound scanner is detected by the electric field produced when there is ultrasound reflection.[16]
B. Urodynamic Measurement device (1987)	The urodynamic device measures the amount of urine left in the bladder after urination. Urodynamic evaluations are carried out on patients with hypersensitivity symptoms to assess features such as volume at first sensation of bladder filling, maximum cystometric capacity, increased bladder sensation, the absence or presence of detrusor overactivity and reproduction of bladder pain.[17]
C. Elastography (1991)	Elastography is a non-invasive technology to assess the mechanical properties of tissues. It measures the elasticity or stiffness of a tissue and determines fat in the liver. It is inexpensive, portable and provides good diagnostic accuracy.[18]
D. Ultrasound - foetal heart rate monitor ultrasound machines (Cardiotocography) (1968)	Monitoring the foetal heart rate (fHR) is a common assessment of foetal well- being. Doppler ultrasound is the de facto standard technology for fHR monitoring. For continuous monitoring of fHR during and before labour, the ultrasound transducer is fixed on the maternal abdomen.[19]
E. Musculoskeletal ultrasound (1958)	Ultrasound imaging uses sound waves to produce pictures of muscles, tendons, ligaments, nerves and joints throughout the body. It is used to help diagnose sprains, strains, tears, trapped nerves, arthritis and other musculoskeletal conditions.[20]

Table 19.4 (*continued*)

Ultrasound Devices (Year of invention)	**Purpose**
F. Abdominal ultrasound (1948)	It is used to examine abdominal regions including the liver, pancreas and gall bladder.[21]
G. Obstetric ultrasound (1958)	It is used to examine pregnant women to view the baby's growth in the embryo and foetus stage as well as the uterus and ovaries of women.[22]
H. Ultrasound Echography (1953)	Extracorporeal shock waves therapy (ECWT) and high-intensity focused ultrasound (HIFU) are two therapeutic ultrasound modalities for treating ischemic heart disease and cardiac arrhythmias.[23]
I. Three-dimensional ultrasonography (3D USG) (1970)	It is used for diagnosing congenital uterine anomalies and determining lung volume. Real-time 3D ultrasound has gained more attention in medical field because of the following reasons: 1. It gives interactive feedback for a physician to acquire good quality images. 2. It provides timely spatial information of the scanned area. Therefore an intraoperative ultrasound examination is important.[24]
J. Ultrasound biomicroscopy (UBM) (1990)	It is a non-invasive in vivo imaging and high-resolution ultrasound technique. It gives detailed evaluation of anterior segment structures and anterior ocular segment at near light microscopic resolution.[25]
K. Cerebrovascular ultrasonography (1982)	Cerebrovascular ultrasonography is used to detect cerebrovascular disorders, with extremely high temporal resolution and excellent spatial display of brain structures, cerebral vessels and extracranial arteries.[26]
L. Dermoscopy (1992)	It is a device used for evaluation, treatment and diagnosis of dermatological disorders including melanoma and nonmelanoma skin cancer, benign tumours, inflammatory diseases and lipoablation.[27]

19.3.1.2 Assessment

Assessment refers to an evaluation of a patient's condition physically using devices like a stethoscope, audiometer and so on. Following the assessment, a doctor gives suggestions for the next examination or treatment. Some of the assessment devices are listed below.

A. **Stethoscope:** The stethoscope (Figure 19.3) is a low-cost medical device for listening to the internal sounds of the human body. It is a sound-based

Figure 19.3 Stethoscope.

(acoustic) device having a small circular resonator connected to two tubes with earpieces. The resonator is held to the chest of the subject and the earpieces are inserted in the ears of the clinical staff. This enables the clinical staff to listen to subjects' heart or breathing action. Although a stethoscope is a basic device used by all clinicians, the environment background should be quiet to listen to the sound. It also takes effort and time to interpret the sound captured by a stethoscope. Due to these limitations, diagnosis is done based on not only a stethoscope but also other medical devices. Currently digital stethoscopes driven by artificial intelligence (AI) are available in the market. These devices are based on digital sensing technology having AI combined with active noise cancellation.[28]

B. **Audiometer:** An audiometer is typically used by audiologists and trained professionals who give advice to patients on the right selection of hearing aids. The audiometer is a medical device, as shown in Figure 19.4, using which a subject is tested on his/her hearing loss in a soundproof room. In this test, the subject wears earphones to hear sounds and words. The same tone is repeated at faint levels to find the quietest sound a person can hear. This helps generate an audiogram. One of the solutions derived from an audiogram is to suggest a hearing aid for the subject. The amplification of soft sounds is needed for subjects facing trouble in hearing.[29]

Figure 19.4 Audiometer.

19.3.2 Therapy and Surgery

Therapy is a treatment intended to relieve or heal a pain/disorder. This is sometimes done through ultrasound, audible sound and infrasound.

19.3.2.1 Types of Therapy

A. Ultrasound Therapy: It is a type of therapy which uses ultrasound to relieve pain. It is performed by a therapist using an ultrasound therapeutic device. The therapist chooses a small surface area where a gel is applied either to the patient's skin or to the head of the transducer, which helps the sound waves to uniformly penetrate the skin. This is carried out for 5 to 10 minutes. While ultrasound therapy is not effective for all chronic pains, it may help reduce the pain of any of the following: carpal tunnel syndrome, osteoarthritis, phantom limb pain, myofascial pain syndrome, bursitis, pain caused by scar tissue, sprains and strains. Table 19.5 summarizes various ultrasound therapies.

There are two types of ultrasound therapies based on the rate at which the sound waves penetrate the tissues: (1) Thermal ultrasound therapy and (2) Mechanical ultrasound therapy.

1. **Thermal Ultrasound Therapy:** This therapy transmits a continuous ultrasound wave. The deep tissue molecules undergo microscopic vibrations caused by the sound waves resulting in heat and friction. Increase in the metabolism action and heating or warming effect at the cellular level encourages the healing in soft tissues.

Table 19.5 Various ultrasound therapies[31]

• Physiotherapy • Sonophoresis • Sonoporation • Uterine fibroid ablation • Phacoemulsification (cataract removal)	• Surgical cutting of tissue and homeostasis • Transdermal drug delivery • Promotion of bone fracture healing • Targeted gene therapy	• Bacterial control • Dental hygiene • Detection of pelvic abnormalities • Lithotripsy, fragmentation of calculi • Thrombolysis

2. **Mechanical Ultrasound Therapy:** This therapy uses the pulses of ultrasound waves to penetrate into the tissues. While this has a minor warming effect, it also causes expansion and contraction in tiny gas bubbles in soft tissues. This decreases the inflammatory response, which reduces swelling and decreases pain.[30]

B. Infrasound Therapy: It is a type of therapy which uses infrasound to relieve pain, increase bone health by stimulating the healing of fractures, and decrease symptoms of dysponea (an obstructive pulmonary disease) and other lung diseases.[32] Infrasound was found to promote proliferation and inhibit apoptosis in bone marrow mesenchymal stem cells (BMSCs). The results indicated that 60 minutes was the most suitable period for applying infrasound treatment to BMSCs.[33]

C. Sound Therapy (Audible Sound): Sound therapy, in which auditory and vibratory inputs are used to influence a person's physiological and/or psychological state, includes sound healing, vibroacoustic sound therapy, music and music therapy. Practitioners of sound healing may use chimes, chanting or drumming to create particular sound frequencies at specific intervals in an effort to promote health and healing of the mind and body. Vibroacoustic sound therapy is a sound technology that uses audible sound vibrations to decrease stress, promote relaxation and improve health.

In contrast to sound therapy, research has been conducted to investigate the possible effects of music and music therapy. Several researchers have found that listening to specific types of music can lower blood pressure and heart rate, reduce pain, decrease anxiety and improve sleep.[34]

19.3.2.2 Ultrasound Surgery

Ultrasound surgery is used for destroying uterine fibroids, kidney stones, tumours and so on. High-frequency, high-energy ultrasound waves are used to target and destroy uterine fibroids. For example, in uterine surgery the procedure is carried out while the patient is inside an MRI scanner. The machine allows the doctor to visualize the patient's uterus, locate any fibroids and destroy the fibroid tissue without making any incisions. For example, Magnetic Resonance-guided Focused Ultrasound (MRgFUS) is a non-invasive ablation method and uses ultrasonic pulses to heat up and destroy fibroid tumours – abnormal benign growths in a woman's uterus. Focused ultrasound surgery uses MR guidance to accurately target the fibroids and spare the healthy tissue.[35]

19.3.3 Others

Apart from the diagnosis/assessment and therapy/surgery, ultrasound is used in the medical field in hospitals for monitoring systems, cleaning of surgical instruments and surgical clothes, and so on, and wearable devices such as hearing aids.

19.3.3.1 Nurse Calling and Monitoring System

Such a system in hospitals uses audible sound making it beneficial for patient care service provided by nurses. The monitoring/calling system is installed in wards and rooms, monitored and actioned by nursing staff at nursing stations. The nurse call button is placed near every patient's bed so that he or she can easily reach the nurse in case of any urgent need. The audible and visual alert reaches the nurse both on the control station located at the nursing station as well as near the door of the patient's room. The nurse identifies the right patient based on the location address displayed and acknowledges the call by pressing the acknowledgment button and attends to the patient's needs. Similar nurse call buttons are installed in patient restrooms, common public restrooms in outpatient areas so that patient care is not compromised in terms of response to a distress call.[36]

Another advantage of the nurse call system is activation of Code Blue, that is, patients needing pulmonary resuscitation wherein a nurse needs the support of a rapid response team. There are many additional features of nurse call systems such as wireless remote to patient, monitoring of turnaround time of nurse, intercom/cell phone alerts and so on. The nurse call system technology is being integrated with hospitals' digital blankets and it is a way forward to improve the overall care of patients. A similar audiovisual application of the token system is used in outpatient pharmacy and other diagnostic areas like radiology to improve patient flow. The outpatient queuing management system is yet another audiovisual application to identify and provide patient direction to the desired doctor for consultation.

19.3.3.2 Ultrasound Cleaning

The discovery of ultrasonic cleaning and use of cleaners as shown in Figure 19.5 has a significant effect on the healthcare industry. Ultrasound is used to clean and sterilize materials and instruments such as surgical instruments, implants, dental instruments and other delicate medical tools and devices. It is also useful for removing bloodstains from clothes, delicate instruments and surgical tools like scissors, forceps and so on. Ultrasound finds use in hospitals, dental care units and clinics. As surgical instruments have to be completely cleaned and sterilized for use, this cleaning method has been perfect for the healthcare industry. The ultrasonic process of cleaning medical equipment is fast and efficient. It makes sure that devices/instruments are cleaned properly and are safe to use.[37]

19.3.3.3 Wearable Devices

Wearable devices play a very prominent role in healthcare because of usage comfort, size, reliability and so on. They serve as a real monitoring system and evidence for future assessment and treatment. Some wearable devices are listed below.

Figure 19.5 Ultrasound cleaner.

A. **Hearing Aids:** These aids (Figure 19.6) increase the audible sound entering the ears of hearing-impaired people to help them listen to clearly and loudly. The small earpiece hearing aid has a microphone to receive sound signals. These sound signals are converted to a digital form to get amplified within the amplifier inside the ear piece. The speaker of the amplifier provides the final input to the subject's ears for smooth hearing. There are various types of hearing aids available in the market such as completely-in-the-canal hearing aid, in-the-ear, behind-the-ear, receiver- in-canal or in-the-ear or visible-open-fit. Battery life, microscope quality and noise reduction technique are a few points to be considered besides the weight while procuring a hearing aid.[38]

B. Wearable Ultrasound Patch Monitors Blood Pressure Deep Inside Body: This is a non-invasive wearable device which uses ultrasound to monitor blood pressure in arteries deep beneath the skin that helps people in determining their cardiovascular condition with greater precision. It is also used for clinical applications for testing blood pressure. It is used in real-time applications such as continuous monitoring of blood pressure changes in patients with lung and heart disease and also for patients who are critically ill or undergoing surgery. Since it uses ultrasound, it has the potential of tracking other physiological signals and vital signs from places deep inside the body.[39]

Figure 19.6 Hearing aids.

C. Wearable Ultrasound Sensors for Lung Monitoring: This is a wearable device consisting of a sensor that uses ultrasound to monitor the patient's lungs. These examinations can also be done at patients' homes, which avoids hospital visits. The sensor consists of a thin film and uses ultrasound technology. The device has the potential to monitor patients' lung conditions remotely. It shares the results with hospitals and clinics and avoids face-to-face contact, reducing the use of more expensive hospital-based imaging facilities.[40] This helps during pandemics such as COVID-19.

19.4 Discussion

Sound, particularly ultrasound, has a wide variety of applications in the medical field. One of the optimistic applications in imaging techniques is ultrasound imaging, which consists of flexible devices such as probes (also known as ultrasound transducers). In most of the cases, ultrasound is typically painless, non-invasive and does not require needles or injections; in a few cases, however, ultrasound can become painful and invasive when it requires the insertion of probes inside the body. Patients aren't exposed to ionizing radiation, making the procedure safer than diagnostic techniques such as X-rays and CT scans. In fact, it captures images of soft tissues that do not show up well on X-rays. There are not many side effects or harmful effects of ultrasound. It is very accessible, affordable and low cost when compared to X-rays, and CT and PET scans. Studies have shown that ultrasound is generally safe because it does not use radiation.[41] Ultrasound has a few drawbacks. It has low penetration through bones or air. For example, it has limited penetration in obese patients. The quality of ultrasonography depends on the equipment and the skills of the operator. On the other hand, MRI, CT and PET scanning have relatively higher cost, they take more time to give a scanned image and require experienced operators or radiologists. Image resolution is less in ultrasound when compared to CT scans and MRIs.[42]

19.5 Conclusion

Sound plays a vital role in healthcare, especially in ultrasound applications like imaging, therapies, surgery, wearable devices and so on. From World War II, imaging has been continuously evolving. Miniaturized and flexible devices, inspired by the advances in technologies, electronics materials, fabrication, digital and wireless communication, have emerged as the next-generation smart devices in health and medicine. Technologies are developing day by day in diagnosis, therapy and wearable devices to make life more comfortable and easy. Researchers have developed a wearable ultrasound scanner which is cost effective, portable and can be powered by a smartphone. Transducer crystals are being replaced by piezoelectric crystals with vibrating drums which are made of polymer resin; such a transducer is called a polymer capacitive micromachined ultrasound transducer. These are low cost and cheaper to manufacture.[43] Wearable ultrasound therapy devices have even been developed to treat joint pain.[44] All types of sounds, that is, infrasound, audible sound and ultrasound, are used for therapy for different health conditions. With more technological developments in the years to come, more applications of sound in medical applications will be seen.

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20

MUSIC-BASED INTERVENTIONS

A Paradigm Shift from a Socio-Cultural to a Neuroscientific Perspective

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20.1 Introduction

Music is a collection of well-organized, coordinated sounds, vibrations, and silent moments. It is an auditory stimulus that includes organized elements such as melody, form, style, rhythm, harmony, and timbre (1). Music has been produced and enjoyed across all cultures and throughout history and has been observed as behavior in humans from time immemorial. Music, which is a biological phenomenon, is generally considered a cultural creation (2). It is one of the human cultural universal activities with the power to evoke a broad range of emotions from exhilaration to relaxation, happiness to sadness, and fear to comfort in the listeners or performers (3). It is a universal language that influences human existence by being a medium for communication, which is said to have pleasant and healing experiences. The healing powers of music are now studied by modern science and medicine to understand how and why different approaches and methods work in specific clinical conditions. Music and its healing powers have been acknowledged in all cultures and for time immemorial. Various methods and techniques have been followed for using music in healing. They are being used to target symptoms of several diseases/disorders in a range of clinical conditions such as physical medicine, oncology, paediatrics, neurology, psychiatry, and rehabilitation (4).

Learning Objectives

- Understanding music as a socio-cultural and biological phenomenon
- Brief history of music therapy and Indian music therapy
- Music and the brain
- Shift in music therapy from a socio-cultural to a neuroscientific perspective
- Need for systematic research in the area of music therapy.

20.2 Music Therapy: A Brief Historical Perspective

Music can have a positive influence on health and well-being in different ways and in a varied scope of contexts. Musical activities have the potential to be therapeutic and educational and have an enriching experience (5). Musical behaviour is universal in nature and observed in humans across their life spans. It is powerful in modulating emotional experience, and over the last three decades, there is a significant body of literature proving the psychological and physiological benefits of engaging with music both actively and passively. Music has been acknowledged to have a deeper role to play in humans' life, and it is surely beyond mere entertainment. Music therapy and music-based interventions are therefore gaining a strong scientific base to explain how and why music therapy works and how it impacts the human brain and how specific methods of music interventions are useful in chosen clinical conditions.

The concept of music therapy goes back thousands of years. According to Rolando Benenzon, during 1500 BCE, the use of music to influence the human body was first mentioned in writing in Egyptian medical papyri. Greco-Roman, Arabian, Indian, and Chinese traditional medicines include various concepts of music used in a therapeutic way. Mythological and biblical sources also give proof of this through stories and quotes. The history of modern music therapy starts in the eighteenth century. Music therapy continues to grow and develop internationally.

In 1942, in the United States, a Music Advisory Council of the Joint Army and the Navy was formed by the Secretaries of War and the Navy that involved famous personalities in the world of music. In 1943, music became an integral part of the reconditioning program of the army, in accordance with the advice of Surgeon General Norman T. Kirk. It was then considered as a recreation for the soldiers rather than music therapy. As the military officials observed that music aided the soldiers to keep their morale high, the Army Service Forces (ASF) developed a program called "Music in Reconditioning in ASF Convalescent and General Hospitals". With the help of this program, injured soldiers were entertained by women's military bands. These women further contributed to the medical world by continuing to practice music therapy.

In India, evidence of *Gandharva tattva*, the science of music, can be traced back to the fourth century B.C. The therapeutic effects of musical melodies are explained in "*Raga Chikitsa*." Music was used in treating illness by a sixteenth-century classical musician, Swami Haridas, and a few others. During the seventeenth century, Nayaka King Raghunatha Nayak and his minister Govinda Dikshitar presented the effects of music on emotion in their work "*Sangita Sudha.*" Remedial use of music in psychological ailments has been recorded in palm leaf manuscripts that are being preserved in the

Thanjavur Saraswati Mahal Library. *Nada Yoga and Raga Chikitsa* are the main pillars of the ancient system of Indian music therapy and stem from a deeper understanding of the healing properties of sound, various pitches, and music. The system of *Nada Yoga* claims that the universe has evolved from a sound projection. Sound is inherently linked to consciousness according to Indian philosophical practices. The term "*Nada*" can refer to "flow of consciousness." Developing an unconstrained relation between sound and consciousness was the concern of this system. *Raga chikitsa* dealt with the therapeutic effects of ragas. *Raga* is a sequential set of chosen notes (*swaras*). There is no equivalent feature of music in the Western Classical music tradition. The emotional effects of a given raga can be diverse. Raga can impact a wide range of emotions such as happiness or sorrow, peace or anger, calmness, and so forth, depending on their nature, and it is this quality of music that makes it therapeutic. This shows that emotional healing in conditions such as anxiety and stress can be made possible with Indian ragas. In fact, the feature of the raga and phase of raga elaboration is known to have a strong impact on the emotional experience of the listener. Emotional experience is known to vary within the different phases of raga elaboration (like alap to jor jhala) (6). Only a handful of systematic studies have been carried out examining the role of Indian traditional/classical music as a method of treatment (7, 8). A study on one-time listening to Indian classical music excerpts in chronic schizophrenia patients has shown promising results in improving attention as measured by brain electrical activities (electroencephalography – EEG and event-related potential – ERP) (9).

Various schools of thought similar to the ones observed in the field of psychology such as the humanistic school of thought, psychodynamic approach, behavioural approach, and neuroscientific approach provide explanations as to how and why music therapy works. The behavioural approach in music therapy centres around adaptive learning experiences and behaviours. It includes behavioural adaptation, active involvement, and so forth and is generally a problem-oriented approach. It calls for a sound knowledge of the principles of behaviour and capacity to represent the sessions accordingly. The humanistic approach in music therapy is schooled by the theoretical principles of humanistic psychology. This approach is controlled by a holistic and person-centred approach. It focuses on features such as natural creativity, privilege of self-expression and so forth of the client. The recent one that is also considered as a newer frontier in the field of music therapy is the neuroscience-based music therapy approach. With the accumulation of evidence contributing to a deeper understanding of the effect of music on the brain and how various techniques employed in music therapy impact various functioning of the human brain, the neuroscience-based approach is enabling music therapy in general to gain a stronger scientific basis and acceptance as an evidence-based therapy.

20.3 Music Therapy versus Music-Based Intervention

Music therapy, music-based intervention, music medicine, and so forth are used interchangeably in scientific literature. However, they carry different meanings. Music therapy is considered as an established integrated health profession that makes use of music to facilitate therapeutic activities. Music therapy may be carried out in one-on-one sessions or as group sessions. Depending on the needs of the client, the session can take around 30 to 50 minutes. Music therapy is delivered via two main intervention methods, namely, active and passive/receptive techniques. Active techniques involve a person making music, by composing, singing, playing instruments, improvising music, moving, or discussing their musical experience. Passive or receptive techniques comprise listening to and responding to music. Both techniques are usually combined during treatment and are used as an initiation for the discussion of feelings, goals, and so forth (10).

Clinicians who have undergone specific and systematic training in a given form or method of music therapy are called certified music therapists. They work in a different setting as part of the healthcare team. Music therapists will decide the effective intervention to be used depending on the needs of the client. There are four methods used by a therapist (11). First is being receptive, where the client is supposed to respond verbally, silently, or using another modality after they listen to music which may be live or a recording. Some may include music-assisted relaxation and the use of music and visuals. This approach is suitable when the client is nonverbal or prefers a passive approach through listening. The second type is re-creation, a music-centred method where the client is motivated to play or sing along a pre-composed music piece. This type of intervention will be applicable for a diverse set of populations, from children with delay in development to those with brain injury, or elderly population suffering from dementia. The third type of approach involves improvization which consists of impetuous music making using one's voice, simple instruments, and body percussion. In this type of intervention, the therapist is required to hear and interpret, and eventually respond to the client's performance. A population who are non-verbal or are uncomfortable to express directly make the appropriate set for this type of intervention approach. The fourth type of music intervention approach is composition or song writing, where the client is encouraged by the therapist to create their own music or lyrics, which then can be recorded or performed subsequently (12).

Five factors contribute to the effects of music in a therapeutic scenario. They are power of music in modulation of attention, modulation of emotion, modulation of cognition, modulation of behaviour, and modulation of communication (13). The first factor is the modulation of attention. Music grabs our attention and distracts us from other negative experiences (worry, anxiety etc.). This also explains the effects of listening to music during medical procedures for anxiety and pain reduction. The second aspect is the modulation of emotion. Activity of brain regions that are involved in the initiation, generation, maintenance, termination, and modulation of emotions can be regulated using music. Music also modulates cognition; the third factor that contributes to the effect of music therapy is modulation of cognition. Music is related to memory processes (including the encoding, storage, and decoding of musical information and events related to musical experiences). It is also involved in the analysis of musical syntax and musical meaning. The fourth factor that contributes to the effect of music therapy is modulation of behaviour. Behaviours such as the movement patterns involved in walking, speaking, and grasping can be evoked and conditioned with the help of music. The fifth factor is modulation of communication. Music is a means of communication and can also affect communication. Hence, music can play a major role in promotion of social bonding, improving language functions, and improving social relationships (13).

Music therapy makes use of the dynamic capabilities of music to the betterment of one's well-being. A person's relatedness and responses to music to uplift positive changes in mood and overall mental health is used by music therapists. The therapy incorporates creating music with different types of instruments or listening to music. Therapies like cognitive behavioural therapy (CBT) and counselling involve talking, and thus it makes them not suitable for people who face problems with verbal communication. This is where music therapy can be advantageous. As the therapy does not depend on verbal communication, it can be helpful for those who have difficulty in conveying verbally. So, it can be considered as an alternative to therapies such as (CBT), counselling therapy, and so forth.

The experimental process or protocols which use music in its different forms and study its therapeutic effects are referred to as music-based interventions (14). Music interventions can be considered as musical exercises or methods which are primarily composed of music listening, music-making, or singing (15). Listening to music based on the music medicine approach, relational music therapy, general music-based approaches, rehabilitative music therapy, individualized music listening are some of the types of intervention with music in clinical settings. Music therapy should not be confused with music medicine which is a music-based intervention which is done by healthcare professionals.

It is important to know how our body responds to music during different music-based activities. Measuring the electrodermal activity and heart rate gives an idea about the effects of music perception on the activity of the autonomic nervous system. The number and intensity of outlines, shivers, and chills are also investigated which supports this understanding. Music listening has an evident effect on motor functions of a person. Movement initiation by music perception in the way of dancing, tapping, swaying, singing, hopping, head-nodding, and so forth along with music is a very common experience (16).

Different features of music such as melody, pitch, tempo, and so forth are processed by different areas of the brain. Rhythm is processed by the cerebellum, a small portion of the right temporal lobe aids understanding of pitch, and the emotional signals generated by the music are decoded by the frontal lobes. When one hears powerful music, the nucleus accumbens, the reward centre of the brain, can even induce physical signs of pleasure, such as goosebumps. These profound physical responses of the body to music can be used by music therapy to support people with mental health conditions.

Music therapy offers extra benefits to listening or creating music than what other forms of therapies offer. For example, learning and practicing a music excerpt can improve reading, comprehension ability, memory, coordination, and so forth. Participants enjoy a sense of accomplishment by creating a music excerpt, which in turn boosts their self-esteem and mood. Music therapy taps into the creative side of an individual, which turns out to be a better way of introspecting difficult emotions or even suppressed emotions. Both evaluation and enhancement of cognitive, social, emotional, and motor functioning is often possible using music therapy.

Other documented benefits of music therapy include attentiveness, concentration, communication skills, confidence, increased motivation, self-awareness and mindfulness of others, improved self-esteem, emotional release, increased verbalization, beneficial effects on the psychological and physiological health, improved quality of sleep; alleviation of stress, anxiety, substance dependency, autism, personality issues; improved overall quality of life and so forth.

The International Association for Music and Medicine established in 2009 at the University of Limerick, Ireland, aims to explore music therapy, music and medicine, and music-based interventions in healthcare contexts. The American Musical Therapy Association has about 2500 and more members working for hospitals, schools, clinics, rehabilitation centres and private practice settings (1).

20.4 Music and Brain

Some of the extensive and diverse networks of the brain are said to be activated by music. It activates the auditory cortex, memory regions, and regions of the brain related to motor movements. Emotional music, in addition to activation of the region of emotion, also synchronizes it. As music can activate almost all brain networks, it can keep a number of brain pathways strong. These pathways involve the cognitive function, learning, happiness, well-being, and so forth. Along with psychological effects, music is said to have influence on physiological well-being too. Music boosts one's immunity, helps to reduce the levels of stress and anxiety, and can also ease depression. Studies show that for patients undergoing surgery results of music listening were far more effective than the prescribed drugs. Listening and playing music is said to have a connection to lower levels of cortisol, the stress hormone.

The pituitary gland, secretions of which affect the nervous system and the flow of blood, is stimulated during music listening. Music listening creates a vibration in the cells of the listener. These vibrations are necessary to change the consciousness of the patients, which in turn can help promote their health. One of the major uses of music listening is that it helps one relax and feel refreshed. Listening to some light music during work can improve one's efficiency. Negative emotions such as worry, bias, anger, and so forth can be controlled by listening to music. It also helps in improving neurocognitive functions such as attention and memory. In addition, it can also help in addressing stress, pain, blood pressure; help patients recover post-surgery; help growth in premature babies, and so forth.

20.5 Music Therapy – from Social Science to Neuroscience Perspective

With time, music which was considered as a socio-cultural activity is now seen in the light of neuro-based practice. Here we can see a paradigm shift, that is, a transition of music-based interventions from a socio-cultural to neuroscientific perspective. Evidence for one such paradigm shift is the emergence of neurologic music therapy (NMT). It is defined as "the therapeutic application of music to cognitive, sensory, and motor dysfunctions due to neurologic disease of the human nervous system" (17). NMT differs from general music therapy in the mode of delivery. General music therapy involves treating different scopes of patients' needs such as physical, mental, and so forth by adopting the ways such as music listening, playing, or music writing. NMT is an evidence-based practice which focuses mainly on neuroscience of music (18). It is a methodical treatment approach to improve sensorimotor, language, and cognitive functioning through music (17).

It also takes into account the elements of music that cause changes in the brain and its connection, also known as neuropathways. These are done using NMT interventions which is a specific neuroscience research-based technique. This intervention is applied in a manner according to the therapeutic needs of the client.

Music must be viewed as something that can stimulate our brain. It is a non-invasive technique, which has attracted much interest. The therapeutic value of music can be in part explained by its cultural role in facilitating social learning and emotional well-being. However, a number of studies have shown that rhythmic entrainment of motor function can actively facilitate the recovery of movement in patients with stroke, Parkinson's disease, cerebral palsy, and traumatic brain injury (19). Studies of people with memory disorders, such as Alzheimer's disease, suggest that neuronal memory traces built through music are deeply ingrained and more resilient to neurodegenerative influences. Findings from individual randomized trials suggest that music therapy is accepted by people with depression and is associated with improvements in mood disorders (20).

Various studies have been conducted to learn the effects of music on the human brain at a neural level. Neuroimaging studies are the major ones that have contributed to understanding the neural underpinning of music-based activities. These studies have recognized different brain regions that are activated by music listening or recall (21). Comprehending how our brain analyses, stores, and retrieves music is one of the most demanding issues in the field of neuroscience. Direct neural recordings acquired from the human brain indicate distributed and overlapping brain regions correlated with music listening and recall (21).

Over the last 30 years, various studies have been conducted to explore the neural underpinnings of music listening. Using imaging techniques such as functional MRI (*f*MRI) and PET, studies demonstrate the association of music listening with hemodynamic feedbacks in a distributed network which involve the auditory cortex, brain areas associated with motor control, and different other cognitive functions such as memory (e.g., hippocampus, temporal cortex), working memory (e.g., frontal cortex), control of attention and emotion. Various electroencephalography (EEG) researches also have augmented these findings (22).

Neuromusicology looks into the fundamentals of human musical information processing such as neural encoding, localization of functions, and dynamic principles. There is a divergence between sensory and cognitive neuromusicology. Understanding the operation of musical signal processing with respect to functional, physiological, and biochemical undertaking of the auditory system involves sensory neuromusicology. Cognitive neuromusicology focuses on studying the association of different brain regions in cognition in view of music. Both the sensory and the cognitive approaches can be considered as a part of a single research strategy with an objective to explore the neural mechanisms underlying sensory, perceptual, and cognitive information processing (23).

Evidence shows that a group of brain structures involved in various functions like cognitive, sensorimotor, and emotional processing are activated on listening to music or making music. Investigations on the favourable effects of music on psychological and physiological health can be achieved using the existing knowledge on neural correlates of music-evoked emotions and their health-related autonomic, endocrinological, and immunological effects (24). Emotions evoked by music can bring about autonomic and endocrine responses and also facial expression which is a motoric expression of emotion. Studies demonstrate that music enhances individuals' health and well-being through involvement of neurochemical systems. These are with regard to different aspects such as (i) reward, motivation, and pleasure; (ii) immunity; (iii) social connection; (iv) stress and arousal and so forth (3). These observations provide a basis for using music as a therapeutic technique (24).

Music therapy can assist the brain in re-organizing and creating new neural pathways. This ability of the brain to change and grow following different experiences is considered as neural plasticity (25). Studies in neural plasticity show that music not only has an effect on brain development but can also shape the adult brain. Researches have proved that the plasticity induced by music training is not restricted to developing the brain; it can also improve the functional and structural aspects of different brain regions (25). This functional and structural plasticity can be induced in the anterior and middle part of the hippocampus by music practice, and these changes are followed by increased expertise in musical tasks, working or short-time memory, and fluid intelligence (26). Musical training aids in improving cognitive and perceptual motor function eliciting changes in structure and functions of the brain. In older adults, learning a new skill engages neural plasticity more strongly (26).

Developments in neuroimaging techniques such as *f*MRI, PET, and EEG make the research on effects of music on neural plasticity more efficient. The studies conducted show that cognitive fall-off and dementia can be put off by recent and past musical activities. Neuroplasticity of the human brain is used to associate musical ideas with motor skills. Music therapy is manifested in rebuilding the motor skills in the elderly whose motor function declined following a stroke (26).

The brain has a neurotransmitter called dopamine that is involved in motivation and reward-seeking behaviour (27), working memory (28), and reinforcement learning (29). According to studies, response of dopamine neurons is translated to stimuli during learning (30). Stegemollar identified three main principles of neural plasticity that demonstrate the effectiveness of music therapy in uplifting behavioural changes (25). The first principle is that music triggers the release of neurotransmitters such as dopamine and serotonin which are associated with the reward system in the brain and are responsible for feelings of happiness. Dopamine plays a major role in neural plasticity as the stimulation of dopaminergic neurons is said to cause cortical remapping. The second principle is the Hebbian theory which states that "neurons which fire together wire together," meaning that neurons which fire together within tens of milliseconds tend to form a new connection together or strengthen the existing one. This theory is used by therapists to pair music with movement, breathing, vocalization, and so forth to induce simultaneous firing of neurons that control the behaviours described. According to the third principle, plasticity of the brain will be negatively affected by listening to noise, and this results in increased stress which in turn affects the cognition and memory (25).

It is known that music is efficient in inducing strong positive emotions and also in uplifting the mood of a being (31). These qualities of music can certainly be used in clinical arrangements where negative emotions such as pain and anxiety affect one's well-being, and this will create a need for employment of anaesthetic and analgesic drugs. According to studies, music is considered to lessen the stress during pre- and post-medical procedures including surgery, angiography, colonoscopy, and so forth.

A study was conducted to establish these findings where patients were grouped randomly either to a music group who listened to instrumental music or to a control group which was made to listen to a non-musical placebo stimulus. Both groups were asked to listen to the auditory stimulus about two hours before and in the intra-operative duration. Results demonstrated that, during surgery, compared to the control group, patients of the music group had a lower propofol consumption and lower cortisol levels. This provides evidence to the argument that listening to music reduces sedative requirements to reach light sedation. It also shows that during surgery music can exert a stress-reducing effect under local anaesthesia. These findings stipulate that music can be used as an effective treatment to bring down stress in clinical context (31).

Studies on animal models show that prolonged exposure to music can improve one's learning due to changes done in the hippocampus (25). This can be due to the fact that acoustic signals of music are more consonant than that of speech (30). Music therapists work with subjects with different kinds of neurologic and physiologic conditions and use the elements of music to make necessary changes in the brain. A Cochrane database systematic review published in 2017 carried reports that in people with depression, music therapy is said to have short-term beneficial effects. When compared to effects of treatments alone, music therapy along with the usual treatments help in reduction of depressive symptoms. The anxiety levels of depressed individuals were found to be reduced and they were found to have improved global functioning.

20.6 Conclusion

Music therapy has come a long way since the early twentieth century. Music plays an important role in individual and social development. Music therapy has a broad and extensive history. It has an active relationship with the brain, and it has distinctive advantages when compared to medications. Music is used in the form of therapy and intervention because of its positive effects on both physical and psychological ailments. These interventions have seen a transition from a socio-cultural to neuroscientific perspective. The science of music therapy is still being investigated through advanced methods and techniques. However, we still need to explore to gain full awareness of its potential. There is a significant need to carry out further randomized controlled trials.

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Part VI

NOISE CONTROL REGULATIONS AND IMPLEMENTATION

21

REGULATIONS AND IMPLEMENTATION

Debesh Panda and Sanjeevi Seshadri

21.1 Introduction

Learning Objectives

- Provide a highly summarised snapshot of how noise has been sought to be legally regulated.
- Demonstrate the benefits and pitfalls of the extant legal regime in place.
- Propose solutions for policymakers and legislators on how to make the regime more effective.

The chapter is organised in three parts. In the first part, the regime that existed before the year 2000 is discussed, which can be described as a patchwork quilt of measures peppered by laws and judicial interventions in equal measure, both of which are characterised by their *ad hoc* approach to solving a problem that required solutions that were holistic and institutional in nature.

The second part describes the legal regime subsequent to the enactment of the Noise Pollution (Regulation & Control) Rules, 2000 under the Environment (Protection) Act, 1986, and gives a bird's eye view of the performance of the legislative intervention in practice. The important takeaway from this period is that the Supreme Court of India itself found the regime to be deficient and found it expedient to issue directions in the exercise of Articles 141 and 142 of the Constitution of India, which would have the force of law, till appropriate legislation was enacted.

The third part of the chapter explores, keeping in mind the fact that no changes have been made in nearly 16 years since the directions issued by the Supreme Court of India, the nature of changes in the regime that ought to be carried out to offer realistic solutions to problems at hand. The chapter looks at noise regulation from other jurisdictions with the objective of identifying useful takeaways for a future regulatory regime in our country. The objective of the analysis is to be constructive, rather than critical, so as to not only capture the low-hanging fruit in the policy landscape but also the alternatives that are more complex from a policy perspective but which ought to engage the attention of lawmakers in the near future.

21.2 Part 1: Pre-2000 Regime

Before notification of the Noise Pollution (Regulation & Control) Rules, 2000, there was no specific legal measure to deal with the issue of noise pollution. In fact, prior to 1987, the only remedy a person aggrieved by noise pollution had was to either sue under the law of torts for damages/compensation in monetary terms or to file a criminal complaint alleging commission of offences under Chapter XIV of the Indian Penal Code, 1860 (*hereinafter* '**IPC**') which is titled "*Of Offences affecting the public health, safety, convenience, decency and morals.*" It is only subsequent to 1987 that changes were ushered in the legislative framework to address this aspect with more specificity.

In practice, the criminal law remedy was more efficacious and immediate. It is useful to thus begin our discussion with the measures under criminal law.

Chapter XIV of the IPC begins with Section 268 which defines a public nuisance and broadly provides that a person commits the offence of public nuisance where the act committed or omission done causes common injury, danger, or annoyance to the public or to the people in general who dwell or occupy property in the vicinity. This provision clearly covers noise pollution for the act of causing noise pollution leads to common injury, danger, or annoyance and it is expressly clarified therein that a common nuisance is not excused on the ground that it causes some convenience or advantage. The punishment that follows on a successful conviction is, however, a slap on the wrists, being the general punishment prescribed in Section 290, IPC, namely, a fine which may extend to two hundred rupees. Practically speaking, making an allegation of public nuisance to the police translates into securing the intervention of the police with the hope that the nuisance will stop, as opposed to securing a successful conviction after a full-blown trial.

It does not, however, mean that convictions have not been followed in practice. In *Kirori Mal Bishambar Dayal v. State* (1958 CriLJ 91), the Punjab and Haryana High Court was confronted with an interesting case, where a flour mill that had been in operation for many years was converted into a metal factory and, as a consequence, became a source of noise pollution for the neighbours and was thus alleged to be a public nuisance. Whilst upholding the conviction of the owner of the factory under Section 290, the Court had made some very significant observations in respect of the *"prescriptive rights"* that the mill owner claimed on account of having operated the facility for years altogether, without any complaint from the local residents. Of particular relevance is the observation that in the realm of criminal law, *"…no prescriptive right can be acquired to maintain and no length of time can legalise, a public nuisance…"* [1] This is useful, as in civil law it has been recognised that a "…*right to commit a private nuisance can, in certain circumstances, be acquired either by prescription or by the authority of a statute…"*[2]

It is well known that firecrackers and certain industrial machinery are huge contributors of noise pollution. Within Chapter IX, Section 285 creates an offence where combustible matter is used so rashly or negligently as to be likely to cause hurt or injury to any other person, whilst, Section 287 creates an identical provision in the context of machinery. These provisions could be invoked where the use of the firecracker or machinery, in the context of noise pollution, has resulted in hearing impairment or some other medical condition. However, criminal law operates in a different realm altogether, where the threshold to obtain success is very high as it would be very difficult to establish the existence of criminal intent in every single case of noise pollution.

This brings us to the other legal remedy that existed prior to 1987, that is, the remedy of filing a civil suit for compensation, alleging the commission of the tort of nuisance. This remedy is fairly well settled, from and by judgements abroad as well as in India. The Madhya Pradesh High Court in *Dhannalal & Anr. v. Thakur Chittarsingh Mehtap Singh* [2] summarised the principles governing the tort of nuisance and noted that *"Constant noise, if abnormal or unusual, can be an actionable nuisance, if it interferes with) one's physical comforts."*

In terms of these principles, people could institute civil suits before local courts, seeking a permanent injunction, that is, an order prohibiting the noise polluter from continuing his conduct, aside from seeking damages. Despite this, on account of the slow pace of resolving cases in the civil courts and its relative complexity, prior to 1987, it was more common to see the remedy under criminal law being availed of.

In 1987, the Air Prevention and Control of Pollution Act 1981 (*hereinafter* 'Air Act') was amended by the Parliament, and Section 2(a) which defined "air pollutant" was amended to include within its fold, noise, when present in the atmosphere in a concentration which may tend to be injurious to human beings. The debates in the Lok Sabha reflect the manner in which the perception as to the importance of noise regulation had changed with the passage of time:

> *"...Noise pollution is also a burning topic nowadays. In the big cities the noise pollution has reached up to 50 to 90 decibels due to which it is becoming difficult to live peacefully..."*[3]

The amendment was more of a shift in policy on paper, with the situation, in reality, being one that accorded a step-motherly treatment to the *"burning topic"* as was evident from the judicial and administrative infrastructure created to address the problem. As a consequence, the only notable interventions witnessed were by Constitutional Courts that issued directions on an *ad hoc* basis in Public Interest Litigations, in exercise of their overarching writ jurisdiction under Article 32 and 226 of the Constitution of India. The most notable intervention was of the Supreme Court of India in "*Noise Pollution, In re [Forum for prevention of Environmental & Sound Pollution] v. Union of India*" where the Court had heard the case in public interest, after being apprised of a shocking incident where, on account of the blaring music coming from loudspeakers in a particular neighbourhood, a 13-year-old girl ended up being subjected to rape as her cries of help went unheard. It was the supervision and scrutiny of the Supreme Court that resulted in the notification of rules under the Environment (Protection) Act, 1986 to tackle the increasing menace of noise pollution from various sources.[4]

21.3 Part 1: Post-2000 Regime

The need for an overhaul in the manner in which noise pollution has to be tackled had been acknowledged and dealt with by the Central Government by notifying the Noise Pollution (Regulation and Control) Rules, 2000 on 14th February 2000 ('Noise Rules'). This is evident from the preamble to the Noise Rules itself, which records as under:

> "...*Whereas the increasing ambient noise levels in public places from various sources, inter-alia, industrial activity, construction activity, firecrackers, sound-producing instruments, generator sets, loudspeakers, public address systems, music systems, vehicular horns and other mechanical devices have deleterious effects on human health and the psychological well-being of the people; it is considered necessary to regulate and control noise-producing and generating sources with the objective of maintaining the ambient air quality standards in respect of noise;*..."

These rules for the first time recognised the need for ambient air quality standards to be modulated on the basis of town planning and zoning regulations and contained provisions as to the legally acceptable levels of sound in four such kinds of zones, that is, industrial, commercial, residential area or silence zone. In other words, there was a shift from an approach that was legalistic to something that was more technically nuanced. For more details refer chapter 3. Physics of Sound, Hearing and Speech

Aside of requiring State Governments to notify zones on the basis of grounds realities, responsibility was also given to an officer specially appointed for the purpose by the State or Central Government in terms of Rule 2(c) of ensuring compliance with ambient air quality standards. In addition, regulation of noise emanating from the use of loudspeakers and use of horns, sound-emitting construction equipments, and bursting of firecrackers was also specifically provided for in terms of Regulations 5 and 5A of the Noise Rules respectively.

Firecrackers are one topic that has repeatedly engaged the attention of the Supreme Court of India. On 27th September 2001, the Court had issued various directions,[5] which it refused to modify even when an effort was made to persuade it by citing "customary" bursting of firecrackers on festivals and celebrations, as well as the hardship caused to the fireworks industry and the loss of jobs, on account of the restrictions imposed by its directions, as is evident from its subsequent order on 10th September 2003.[6]

The other mischief that the provisions enacted in the year 2000 addressed was the misuse of loudspeakers. It became mandatory in terms of Regulation 5(1) to obtain a formal written permission from the nominated State Government officer to use a loudspeaker or public address system. Moreover, in terms of Regulation 5(2), it was provided that even with such permission, a loudspeaker or a public address system or any sound-producing instrument or a musical instrument or a sound amplifier shall not be used at night time except in closed premises for communication within.

Subsequently, the rigours of this provision were mollified by the insertion of Rule 5(3) by way of the Noise Pollution (Regulation and Control) (Amendment) Rules, 2002, which created an exception to Rule 5(2) in terms of which the State Government could, at its discretion, permit the use of loudspeakers during night hours (between 10.00 p.m. and 12.00 midnight) on or during any cultural or religious festive occasion of a limited duration not exceeding fifteen days in all during a calendar year. A challenge had been raised to the validity of this amendment before the High Court of Kerala, which was rejected and then carried in appeal to the Supreme Court of India. The Supreme Court upheld the view taken by the High Court of Kerala. [7]

Later that year, in a seminal judgement, the Court comprehensively dealt with the issue of noise pollution where it not only exhaustively dealt with the sources of noise pollution but also examined the extant medical knowledge on the effects of noise pollution. [8] The Court engaged in a comparative analysis of jurisdictions across the world such as the United Kingdom's Noise Act, 1996 & Noise & Statutory Nuisance Act, 1993; the United States' Noise Pollution and Abatement Act, 1970, Japan's Noise Regulation Law, China's Prevention and Control of Pollution form Environmental Noise as well as the

Noise Control Act, 1975 in Australia. After an exhaustive survey of the judicial pronouncements which included its own decisions as well as that of the various other High Courts in the country, it concluded as under:

> *"...117. We have referred to a few, not all available judgments. Suffice it to observe that Indian judicial opinion has been uniform in recognising the right to live in freedom from noise pollution as a fundamental right protected by Article 21 of the Constitution, and noise pollution beyond permissible limits as an inroad into that right. We agree with and record our approval of the view taken and the opinion expressed by the several High Courts in the decisions referred to hereinabove..."*

On this footing, the Court issued numerous directions to foster an effective regime for preventing noise pollution.[8] While it is not necessary to reproduce each and every direction, it is important to note that the Court made it clear that the guidelines were in the nature of law issued under Articles 141 and 142 of the Constitution.

21.4 Lacunae and Suggestions

As far back as 2005, itself, the Supreme Court had made it clear that noise pollution regulation in India was weak and gave various reasons to support that conclusion. [8] Pursuant thereto, the National Green Tribunal (NGT), a specialised body created specifically by Parliament for the disposal of cases concerning environmental protection, had taken cognisance of the issue of statutory authorities in Delhi failing to control noise pollution as per the statutory mandate of the noise regulations. Amongst various issues concerning the lack of infrastructure that were raised in those proceedings, one of the aspects was concerning the paltry fines leviable for violation of the rules. Pursuant to the intervention of the NGT, there was a substantial increase in the fines leviable in Delhi for various infractions of the noise pollution regulations. [9] The NGT in its order dated 1st August 2019 noted the infeasibility of launching criminal prosecutions in the context of noise pollution.

> *"...The CPCB needs to devise the scale of compensation to be adopted as a measure to enforce the Rule 4(2) of the Noise Pollution (Regulation and Control) Rules, 2000 by the concerned authority on the basis of "Polluter Pays" principle. Though violation of the rules like the Noise Rules here is a criminal offence punishable under Section 15 of the Environment (Protection) Act, 1986 with imprisonment up to five years and fine up to Rs. 1 lakh, since prosecution of a non-cognizable offence may have its own limitations, civil liability on "Polluter Pays" principle can be invoked by the enforcement regulatory authority as per the guidelines which may be laid down by the CPCB.*

> *The scale of compensation may have reference to the extent and severity of default and whether the default is a repeated offence..."*[10]

Whilst the NGT did not spell out the reasons, there are inherent drawbacks to regulating noise pollution through the machinery of criminal law that are obvious on the face of it. The first hurdle in practice is the high standard of proof that needs to be met to achieve a successful prosecution in criminal law, which in turn, is inextricably intertwined with the inherent problem once faces while regulating noise pollution – collecting credible evidence that would withstand scrutiny of a court of law. Unlike air or water pollution, where even if the polluting event stops it is feasible to collect evidence of the same *post facto* and aftereffects are quite discernible, in noise pollution, once the polluting event is over, the aftereffects are psychological and it is not feasible to collect evidence thereof. In other words, unless evidence is contemporaneously collected in a scientific manner that can withstand scrutiny in a court of law, quite often it becomes very difficult to establish delinquent behaviour by an offender, especially if he takes steps to shut down the noise before it can be positively documented. Further, it is unlikely that one will have the equipment readily available by which noise pollution can be documented in a manner that would be legally admissible and capable of withstanding scrutiny before a Court of law. Even the police are unlikely to have such equipment in every police station across the country, leave aside common citizens.

In comparison, to fasten civil liability, the standard of proof is lower and easier to meet, that is, of a preponderance of probabilities. Further, given the nature of the offence, in the galaxy of criminal offences, noise pollution is regarded as a minor misdemeanour, usually punished with a fine or minor imprisonment. The offence, if any, is usually bailable. All that is thus achieved by criminalising noise pollution is that the dockets of courts get burdened with cases that ultimately even the victim of the offence loses interest in. The victim, more often than not, does not even get the fine, as it goes to the coffers of the state, and the amount is so very insignificant as to ensure any real interest of all the stakeholders concerned. Chronic delays that are part of the Indian criminal justice system serve to exacerbate the perception that criminal prosecutions are ineffective and not much of a disincentive.

Thus, evolving a summary proceeding before a specialised forum under which monetary compensation can be awarded to the victim creates greater incentive for detection of delinquent behaviour and expedites successful conclusion of legal proceedings with decisive outcomes for all the parties concerned ought to be explored by policymakers. In doing so, the basic legal principle around which the summary proceeding ought to be modelled is the concept of Polluter Pays, which would allow Courts to employ the concept of strict liability when it comes to dangerously noisy equipment, such as construction equipment or industrial machinery. Pithily put, strict liability envisages making an individual, who brings on to his property a dangerous item, responsible for all damages and consequences that arise from its use, regardless of fault or intent. This principle was originally articulated by the House of Lords, in *Rylands v. Fletcher.* [11]

The second broad aspect that ought to engage the attention of policymakers is the fact that standards for ambient noise across the globe are changing fast. As a country, we are not moving with the times, and this is because noise pollution is being looked at from a bureaucratic and legalistic perspective. It would be of considerable assistance if in the next generation of legal measures creation of a specialised body in the nature of a task force is envisaged which would be populated by subject experts such as doctors rather than legal minds and bureaucratic pundits alone. The recent experience of how the Supreme Court of India handled the oxygen crisis across the nation and also dealt with the issue of covid vaccinations by creating task forces confirms that such a course of action only serves to assist the Government in discharging its functions, and policymakers should not be antithetical to explore such measures.

There is a crying need for the Government to revisit the standards for ambient air quality in terms of the latest international practices, which, at present, is expressed in terms of zones. The WHO recommends permissible sound limits on the basis of the sources and keeping in mind the latest technologies available in that relation.[12] The United Kingdom is another country with numerous legislations and bodies that look into the issue of noise pollution and is in the process of streamlining and simplifying the overall process.[13] We should take inspiration from these changes and evolve our legislative mechanism accordingly.

The third broad suggestion is to introduce measures that would empower and equip the common man in assisting the Government in regulating noise pollution by formulating mechanisms that would enable them to collect evidence and simplify the means of making it legally admissible. Policymakers could take inspiration from measures introduced by other countries to introduce applications that can be installed on smartphones where the general public can provide relevant *"first information"* of delinquent behavior with information such as location and relevant time, as well as other relevant details[14] which could include recording of the delinquent behavior through cameras and smartphones [15] and try and strike a balance between lowering the threshold for evidence being introduced that would curb delinquent behaviour while also providing sufficient checks and balances to prevent misuse of the lowered thresholds in law. If necessary, measures could be evolved whereby upon such *"first information"* being supplied a duty is cast on the jurisdictional police or municipal authorities to document and record the noise using a specialised device like a decibel meter forthwith and upload it on a centralized database using blockchain-based technology so as to be minimise the scope for such evidence being impeached later as having been tampered. The complainant would then have the benefit of having unimpeachable evidence to successfully prosecute a case for compensation in civil law, before the specialised tribunal, under a summary procedure for this purpose. There is empirical evidence that suggests that the very fact of increased reporting and prosecution of delinquent behavior is likely to have a positive cascading effect on effective regulation of the legal mischief.

The fourth suggestion for policymakers would be to utilize existing infrastructure to better document noise levels, which would assist the Government in improving zoning standards and reducing ambient noise levels. Existing traffic signals and surveillance cameras/speed guns that are commonplace across cities could be upgraded to include mechanisms to record ambient noise levels.

This is important keeping in mind that noise regulation is dynamic and subject to the vagaries of urbanisation and change. While countries around the world, particularly those in Europe, being alive to this reality, have taken active steps to actively monitor noise levels and progressively lower permissible noise levels across urbanised zones by making distinctions between annual average noise levels at day, evening, and night periods, India's permissible limits have remained unchanged since 2000. Recording of ambient noise levels is thus necessary to achieve optimal regulation, spatially and temporally. If this is done and a specialised body in the nature of a task force populated by subject experts such as doctors rather than legal minds and bureaucratic pundits alone, as suggested earlier, is recommended, the changes that would be ushered would be more dynamic, scientific, and real world, as opposed to being bureaucratic and legalistic, which has been the traditional approach to dealing with noise regulation.

The other aspect that experts frequently point out but legal measures do not give due importance to is the need for regulatory measures to be alive to the fact that, aside of noise levels, noise frequency also plays a huge role and causes health issues such as vibroacoustic disease, sleeping disorders, and problems with concentration.[16] This is yet another aspect of noise regulation that has escaped consideration so far and merits due consideration.

The fifth suggestion for policymakers is that in addition to *"zoning"* as a yardstick on which measures for noise regulation are modulated, adoption of *"noise surveillance"* measures as per the fourth suggestion above should be calibrated with the identification of *"high risk"* areas where one may resort to stronger monitoring on a real-time basis as a licensing requirement itself instead of having to depend entirely on *"first information"* from victims of noise pollution. For instance, policymakers could make it imperative that when municipal authorities receive an application for grant of sanction for construction plans of new buildings, installation of a device that is permanently connected over the internet to a database on a central server is made compulsory, so that such sound from *"high risk"* areas is subjected to constant monitoring on a real-time basis. Similar requirements may also be put in place for industrial noise as a part and parcel of the licensing requirements for such facilities by classifying them under the *"high risk"* category. Therefore, modulation of the statutory framework so as to provide for such measures, as and when an area or an activity falls under a *"high risk"* category, would automatically go a long way while formulating the next generation of noise regulation measures in our country.

The sixth suggestion would be to better regulate manufacture and sale of high noise devices such as pressure horns, multi-tone horns, and sirens. In other words, one could consider imposing similar checks and balances as are imposed for sale of sirens that are used in ambulances and vehicles of dignitaries so as to create a disincentive for their sale and purchase. Such sirens are not available over the counter, and it would be convenient to subject pressure horns and multi-tone horns to similar restrictions. One may also consider imposing a requirement of obtaining prior permission as is presently in existence for loud speakers under Rule 5 of the Rules.

21.5 Conclusion

As a country, we have come a long way from the pre-1987 era, where noise regulation did not have dedicated legal framework and one had to resort to the general mechanism of civil or criminal law for redress, when wronged. It is outdated to however continue to associate noise pollution as an adjunct to air pollution, *inter alia,* as has been the approach since 1987. Instead of bringing about piecemeal changes through delegated legislation under the Environment (Protection) Act, 1986, it would be appropriate to completely overhaul the mechanisms in place for regulating noise and come up with a framework that is not bureaucratic and legalistic but is premised upon expert intervention and is swift and dynamic so as to cater to the challenges that we are going to face in the years ahead.

The orders of the Supreme Court of India should be hint enough for policymakers that the existing regime is not comprehensive, which has constrained the Court to resort to its plenary jurisdiction under Article 141 read with 142 of the Constitution of India to formulate a regime that will continue to remain in place till it is either modified by the Court or substituted by an appropriate legislation. Nearly 16 years have expired since the patchwork quilt of directions of the Hon'ble Court was put in place. It is about time policymakers wake up and formulate better measures for noise regulation that are comprehensive and realize that noise regulations only through the mechanism of criminal law is not efficacious.

Instead of subjecting it to regulation by existing mechanisms under the civil law, it would be appropriate to formulate a specialized mechanism that adopts a summary process to compensate victims of noise pollution, premised on the principles of polluter pays and strict liability. This would be consistent with the measures being taken internationally by several countries to deal with noise pollution.

Further, noise regulation should be dovetailed with existing municipal and other statutes, so that it is no longer treated like a pariah, but becomes a part and parcel of everyday discourse and is subjected to better implementation and monitoring in areas where it is needed the most.

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Part VII

FRAMEWORK FOR CONDUCTING RESEARCH ON IMPACT OF NOISE

22

FRAMEWORK FOR CONDUCTING RESEARCH ON THE IMPACT OF NOISE AND MUSIC ON HEALTH

Ramesh A.

22.1 Introduction

This chapter intends to familiarize the reader with the steps involved in conducting research in the area of noise and music and their impact on the health and well-being of human beings. Research primarily intends to create new knowledge to solve challenging healthcare situations. With this perspective, research and knowledge creation will be used as synonyms. The seven main steps in knowledge creation are depicted in the schematic diagram in Figure 22.1. The first step is identifying a challenging healthcare situation in the domain of deleterious health effects of noise and beneficial effects of music. The challenge is stated as a research question in nine primary domains (description in small groups, evaluating laboratory-based parameters, estimating prevalence/incidence in populations, evaluating therapies, measuring costs, developing tools to screen/predict/diagnose, measuring risk factors, predicting variables by estimating the strength of correlation and examining beliefs/perceptions/experiences). From the research question are derived the objectives. The second step is to develop a conceptual framework of variables around the objective. The third step is to review existing literature to examine if any researcher has already addressed the objective. The fourth step is to choose the most appropriate study design. The fifth step involves selecting the sampling strategy and calculating the sample size followed by data collection. The sixth step is summarizing data to arrive at results. The last and seventh step is to apply the tests of significance to examine the generalizability of the findings to the target population.[1] Internationally accepted standards for reporting research studies employing various study designs will be elaborated.

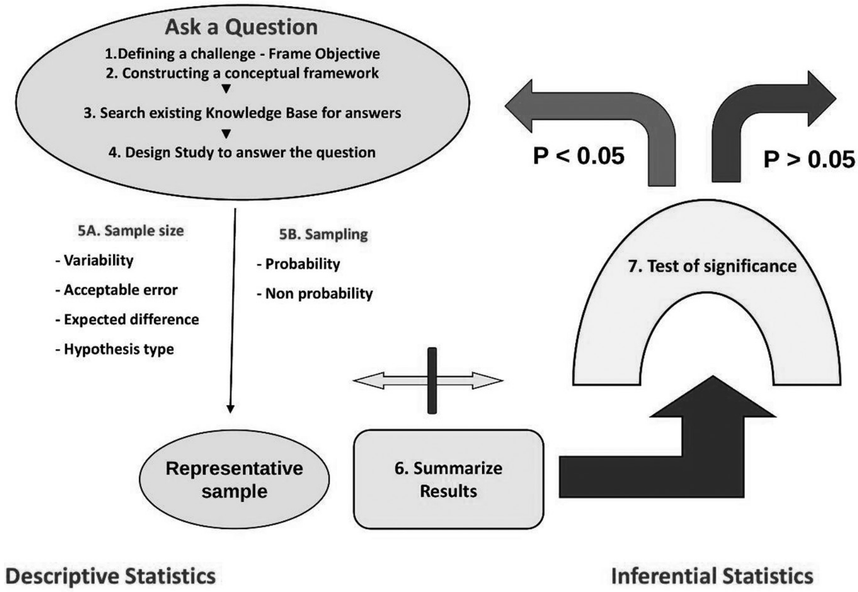

Figure 22.1 Seven steps of knowledge creation (research methodology).

Learning Objectives

- Understand the process of identifying a challenging healthcare situation in the domain of noise, health and music, and state it as a research objective.
- Construct a conceptual framework mapping all the variables.
- Review literature to search if an answer exists for the objective based on previous research.
- Design a study to answer the research objective.
- Choose a representative sample from the universe of the study.
- Collect and summarize the data.
- Perform appropriate tests of significance to generalize the findings for the universe of the study.

22.2 Step 1: Identifying Challenging Healthcare Situations and Framing Objectives

Clinical immersion to identify challenging healthcare situations requiring knowledge creation is the first step. Ethnographic observation over a period of three weeks should be conducted in a structured manner. To gain broad perspective stakeholders from allied branches should also be involved.

The team of observers depends on the context. For music-related situations the team can consist of musicians, sound engineers, psychologists, ear nose throat specialists and audiologists. For identifying challenges in organized and unorganized sectors of industries, the team may consist of human resource managers, workplace quality enforcers, health activists, lawyers, psychologists, ear nose throat specialists and audiologists. In healthcare settings medical personnel of the concerned specialty or hospital area, human resource managers, quality control department staff, psychologists, ear nose throat specialists and audiologists can be involved. Identifying challenges in community settings requires local opinion leaders, gram panchayat members (rural areas), ward councillors (urban areas), schoolteachers, professional social workers, psychologists, ear nose throat specialists and audiologists. After identifying the challenges, the team should have a focus group discussion with the people exposed to high noise levels in these settings. The list of challenges should be displayed; the exposed people should be requested to examine their relevance and indicate areas in which they feel research should be undertaken. The high-priority challenges identified by this technique should be chosen to create new knowledge. This is called researching with the people.

The next step after identifying the critical challenges is to frame a research question and identify the category to which it belongs. Readers may download a free education app named Research Genie from Google Play Store or App Store that describes questions in all the nine domains relevant to healthcare. A three-series article describes the app and method to utilize it to frame research questions in these domains. Other apps that may assist with research are Academia.edu, R Discovery, PubMed, PMC books, Research Notes (contains a large open access library for review of literature), ResearchGate (assists in connecting to peers with similar research interests), Endnote and Paperpile (assists in organizing research documents). The research question should consist of some or all of the following components: population that is being studied (P), interventions if they are being evaluated (I), comparator group if comparisons are being made (C), outcomes (O) and time period by which the study has to be completed.[2]

The first category of questions is description in small groups. It deals with the proportion of a particular event. For instance, what is the proportion of noise-induced hearing loss (outcome/event) in people working in a pub located in a particular area of city (population)? The answer to this question will give us estimates of the burden of noise-induced hearing loss in a particular pub identified by the researcher. Based on this, large-scale population-based studies on incidence (new cases) and prevalence (existing cases) can be conducted to estimate population-level disease burdens or event rates.

The second category of questions is about laboratory-based values. Its structure is similar to the first category. The difference is that the outcome here is a number. What is the range of noise levels (outcome/event) generated during granite polishing in a particular construction site located in Jaipur (population)? The answer to these questions assists in getting estimates of a numerical measure in a particular context. If the values are found to be clinically relevant, normative ranges can be evaluated by conducting studies in the concerned population.

Estimating the prevalence/incidence in a community is the third category. What is the prevalence of noise-induced hearing loss (outcome/event) in individuals in the urban wards of a district located near an airport (population)? This question deals with prevalence. What is the incidence of noise-induced hearing loss (outcome/event) in newly recruited health personnel working in the laundry section of hospitals (population) over a period of three years? Here the incidence of new cases is measured. The answer to this category of questions assists in policy and advocacy to take actions to prevent noise-induced hearing loss.

The fourth type of question compares two methods of interventions. In people exposed to high industrial noise (population), what is the comfort level (outcome/event) using an insert type of ear protection device (intervention 1) versus head worn ear protection device (intervention 2)? The answer to these questions aids in choosing the most appropriate intervention.

Measuring costs is the fifth category of questions. What is the cost effectiveness (outcome/event) of pre-employment screening for hearing impairment (intervention) in industries with high noise to prevent compensation claims? The estimation of costs assists in prioritizing resources for a particular activity over another.

Research questions based on developing tools to screen/predict/diagnose events is the sixth category. Can we use a smartphone-based decision-making application (new test/device/paradigm/position) to predict the probability of mobile phone users (population) developing noise-induced hearing loss (outcome/event) is an example of a question of this category. These questions are directed at creating innovations in the area of noise and health.

The seventh category of questions deals with measuring risk factors. Are smokers (at-risk group) more likely to have develop noise-induced hearing loss (outcome/event) compared to those who do not smoke (not-at-risk group)? Identifying and quantifying risk guides us to develop risk-reduction strategies.

Can we predict one number based on the other is the eighth type of question which is based on mathematical correlation. Is noise dosage (quantitative parameter 1) correlated to decibel dip on pure tone audiogram (quantitative parameter 2)? The answers to these questions will help arrive at the formula to predict one based on the other.

The last and ninth type of question deals with describing beliefs/perceptions/experiences. Why do people working in high-noise areas not wear ear- protection devices is a question that intends to explore beliefs, perceptions and experiences about wearing ear-protection devices. The answer to these questions uncovers the basis of health-related behaviour and thereby gives access for changing behaviour.

22.3 Step 2: Developing a Conceptual Framework of Variables and Defining the Variables

After framing the research question, a conceptual framework of all the known factors that influence the outcome should be mapped and defined. This will be explained using an example. Consider the research question that compares two types of interventions. In people exposed to high industrial noise (population) what is the comfort level (outcome/event) using an insert type of ear protection device (intervention 1) versus head worn ear protection device (intervention 2)?

Here the outcome is comfort level which is called the dependent variable as it is dependent on the interventions, namely, insert and head worn ear protection devices. The researcher should clearly define the dependent and independent variables. In certain situations where two groups are not compared, there will be only one variable which is the outcome. All the other variables influencing the results must be mapped around the dependent and independent variables. These variables are termed confounding factors, or confounders, and effect modifiers. Confounders influence both the dependent and independent variables, whereas effect modifiers influence only the dependent variable. For example, the age of the person will influence the comfort levels as well as utilization of the ear protection device. Pre-existing hearing loss will influence comfort levels due to a phenomenon called recruitment (sudden disproportionate increase in perception of loudness with small increments in noise levels). So age is a confounder and pre-existing hearing loss is an effect modifier. Both these variables can distort the results of the study. After mapping all the variables, each variable should be classified as numeric (numbers), nominal (categories) and ordinal (grades). The type of ear protection device is a nominal variable; comfort levels measured using a psychometrically validated scale is a numerical variable; and classifying the degrees of comfort as "no discomfort –- mild discomfort – moderate discomfort – severe discomfort – painful to wear" is an ordinal variable. After operationalizing the variables we can proceed to the next stage, that is, stating the hypothesis and defining the objectives.

Hypothesis is stating the research question for statistical testing. Statistical concepts will be elaborated in the section on "applying statistical tests of significance." An example will be used to illustrate templates that frame objectives from the research question. The readers may use these templates to define their objectives. Table 22.1 shows research questions in each healthcare domain related to noise and the objectives derived from these questions.

Table 22.1 Objectives based on population, intervention, comparator and outcome components

Research domain	Research question	Objective
Description	What is the proportion of noise-induced hearing loss (outcome/event) in people working in a pub located in a particular area of city (population)?	To estimate the proportion of noise-induced hearing loss (outcome/event) in people working in a pub located in a particular area of city (population)
Lab Range	What is the range of noise levels (outcome/event) generated during granite polishing in a particular construction site located in Jaipur (population)?	To estimate the range of noise levels (outcome/event) generated during granite polishing in a particular construction site located in Jaipur (population)
Incidence/ Prevalence	What is the prevalence of noise-induced hearing loss (outcome/event) in individuals in urban wards of a district located near an airport (population)? What is the incidence of noise-induced hearing loss (outcome/event) in newly recruited health personnel working in the laundry section of hospitals (population) over a period of three years?	To estimate the prevalence of noise-induced hearing loss (outcome/event) in individuals in urban wards of a district located near an airport (population) To estimate the incidence of noise-induced hearing loss (outcome/event) in newly recruited health personnel working in the laundry section of hospitals (population) over a period of three years
Therapy	In people exposed to high industrial noise (population) what is the comfort level (outcome/event) using insert type of ear protection device (intervention 1) versus head-worn ear protection device (intervention 2)?	To compare comfort level (outcome/event) in people exposed to high industrial noise (population) using insert type of ear protection device (intervention 1) versus head-worn ear protection device (intervention 2)

Table 22.1 (*continued*)

Research domain	**Research question**	**Objective**
Cost	What is the cost effectiveness (outcome/ event) of pre-employment screening for hearing impairment (intervention) in industries with high noise to prevent compensation claims?	To compare the cost effectiveness (outcome/event) of pre-employment screening for hearing impairment (intervention) in industries with high noise to prevent compensation claims
New Test	Can we use a smartphone-based decision-making application (new test/ device/paradigm/position) to predict the probability of developing noise-induced hearing loss (outcome/ event) among mobile phone users (population)?	To compare the accuracy of decision-making using a smartphone-based application (new test/device/ /paradigm/ position) to predict the probability of developing noise-induced hearing loss (outcome/ event) among mobile phone users (population)
Risk Measurement	Are smokers (at-risk group) more likely to have develop noise- induced hearing loss (outcome/event) in comparison to those who do not smoke (not-at-risk group)?	To estimate the risk of developing noise-induced hearing loss (outcome/event) in smokers (at-risk group) in comparison to those who do not smoke (not-at-risk group)
Correlation	Is noise dosage (quantitative parameter 1) correlated to decibel dip on pure tone audiogram (quantitative parameter 2)?	To estimate the strength of correlation (outcome/ event) between noise dosage (quantitative parameter 1) and decibel dip on pure tone audiogram (quantitative parameter 2)
Beliefs/ Perceptions/ Experiences	Why do people working in high-noise areas not wear ear protection devices is a question that intends to explore beliefs, perceptions and experiences about wearing ear protection devices	To describe the perceptions of people working in high-noise areas regarding use of ear protection devices

22.4 Step 3: Review of Literature to Examine If Any Researcher Has Already Addressed the Objective

A comprehensive review of literature is a critical step that must be completed before embarking on designing the study to answer the objective. A strategy should be employed to review existing knowledge base. The most commonly used database is PubMed. The database should be searched using medical subject headings (MeSH). Various methods of advanced search strategies are available to extract relevant citations from this database. Other commonly used databases are Cochrane Library, Google Scholar, Indian Medlars, Embase, NHS Evidence and CINAHL. A reference manager software like Refman, Endnote or Zotero should be utilized to store and cite the references. A researcher working in the domain of noise and health should constantly update the references on a quarterly basis to understand the latest developments.

22.5 Step 4: Choosing the Study Design

If literature review reveals that no prior work has been done to answer the research question, then the study can be designed to create new knowledge to address the issue. The study design is chosen on the basis of the type of research question and there are guidelines for each design.

Descriptive, lab range and incidence/prevalence questions: The study design best suited to answer these questions is a cross-sectional study (observational design). It can be prospective or retrospective. The quality of these types of studies is evaluated using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines available in the website of Equator Network.[3]

Therapy questions: This category of question is best answered by randomized controlled trials (RCT). The main intention of randomization is to eliminate selection bias and achieve balance of prognosis. Human beings by design are biased either intentionally or unintentionally. The Consolidated Standards of Reporting Trials (CONSORT) is the most appropriate guideline to ensure quality of randomized controlled trials.[4]

Cost questions: Measuring costs in healthcare is elaborated by the term 'health economics'. There are primarily three types of economic analysis, namely, cost effectiveness analysis, cost utility analysis and cost benefit analysis. Cost effectiveness analysis (CEA), measures cost incurred per unit change of a clinical parameter (e.g., rupees spent to reduce one decibel of noise). The results of the CEA guide the policy maker to choose the most effective intervention. Cost utility analysis estimates the cost to change health utility measures in a given context. Disability adjusted life years (DALYs) is an example of a utility measure. It is a measure of the individual burden of disability derived from large scale population studies. These measures are available from the Global Burden of Disease study. Many countries have developed national specific utility measures. Suboptimal management of noise-induced hearing loss can lead to hearing disability in the long term. So the cost to reduce one DALY by various interventions in high noise environments is an example of cost utility analysis. As utility measures are standardized across populations, a cost utility analysis can be used to compare various interventions across different contexts. These comparisons are tabulated as Stochastic League Tables. Cost benefit analysis measures the economic benefit that an individual gains through his earning in terms of cash income for the amount spent for the health condition. The Consolidated Health Economic Evaluation Reporting Standards (CHEERS) guideline is the most comprehensive method to ensure the quality of health economic studies.[5-7]

New test questions: Validations design is the most appropriate study design to answer this category of questions. Here various characteristics of the new tool are estimated based on the reference test. Different characteristics of the new test are described in terms of validity, reliability, sensitivity, specificity, positive predictive value, negative predictive value, accuracy, precision, efficiency and likelihood ratio.

Validity is a measure of whether the instrument measures what it is supposed to measure. Reliability is a measure of the consistency with which a research instrument yields results. Expressed in simple terms, a reliable instrument is one which yields the same results every time it is applied to the same subject by different testers (intertester consistency) or to different subjects by the same tester (intratester consistency). Sensitivity is a measure of how well the test detects a condition. Specificity measures how well the test excludes people without the disease. Positive predictive value is a measure of the probability of the disease being present if the test is positive. Negative predictive value is a measure of the probability of disease not being present if the test is negative. Accuracy and precision measure what proportion of tests will give the correct result. So it is a combination of sensitivity and specificity. The likelihood ratio of positive test is a measure of how much more likely the test will be positive in a person with disease compared to a person without the disease. We recommend you learn these concepts in detail if you plan to conduct validation studies. Once you understand the concepts, these values can be calculated using online calculators. The recommended guideline to ensure quality of validation studies is Standards for the Reporting of Diagnostic Accuracy studies (STARD).[8;9]

Risk measurement question: In this type of study two types of designs can be used. Case-control and matched cohort designs are the most appropriate study designs to answer these questions. In case-control design the event has occurred and for each case an age and gender matched control is chosen. In matched cohort designs, two cohorts, one with exposure and another without, are followed up to observe the occurrence of the event. Case-control and cohort designs are classified as observational analytical studies, so the quality of these type of studies are evaluated using the STROBE guidelines.

Correlation question: The data for correlated parameters are collected from observational studies. So the design in these type of objectives is observational analytical. It is analytical because the two variables are correlated. Here again STROBE guidelines are most appropriate to evaluate the quality.

Beliefs/Perception/Experience questions: These type of objectives explore an entirely different domain in comparison to all the previous objectives. In these situations, in-depth interviews, focus group discussions and ethnographic observations are employed to describe beliefs, perceptions and live experiences of people in various contexts. The interviews are recorded and transcribed. Themes are derived from the written transcripts. In another approach, theories grounded in the data can be conceptualized. All these designs are called qualitative study designs. Adequate training is required for conducting these types of studies. Though the data may appear abstract, specific guidelines have been developed to evaluate the quality of these study designs. The Standard for Reporting Qualitative Research (SRQR) is a comprehensive checklist for ensuring the quality of these types of designs.[10;11]

22.6 Step 5: Select Sampling Strategy and Sample Size Estimation

The main intention of sampling strategy and sample size calculation is to ensure that the selected sample is representative of the target population. Sampling strategy is based on inclusion and exclusion criteria. Inclusion criteria specify all the requirements to select the correct target population. Exclusion criteria specify those aspects which may confound the results hence cases with these factors should be excluded. Take the therapy type of research question: In people exposed to high industrial noise (population) what is the comfort level (outcome/event) using an insert type of ear protection device (intervention 1) versus head worn ear protection device (intervention 2)? Here the inclusion criteria would be people exposed to high industrial noise who wear ear protection devices. The exclusion criteria would be those with allergic otitis externa (allergy of the ear canal). These cases need to be excluded as the skin condition could cause discomfort which would confound the outcome. In other words, comfort levels with using the ear protection device could be influenced by the ear canal condition and give erroneous results. There are two types of sampling strategies, namely, probability sampling and non-probability sampling. In probability sampling every individual has an equal chance of getting selected. Non-probability sampling is mainly based on the convenience of the researcher.

Sample size is determined by the extent of variability in the population in the parameters being measured. If two parameters are being compared, the expected difference between these parameters influences the sample size. So in research objectives in which observational designs are employed, variability is determined by examining previous studies. When comparisons are being made, the researcher should have estimates of the expected difference based either on their experience or on a pilot study.[12] The reader is requested to use the Research Genie app to understand sample size calculation for each objective in the nine healthcare domains elaborated in the previous sections.

22.7 Step 6: Data Collection and Summarizing the Results

Data is collected according to an objective. There are primarily three main families of data, namely, numerical, categorical and qualitative. Numerical data is expressed as numbers on a scale with zero as reference. Sound pressure levels measured as pascals is a numerical measure. The common measure used to depict noise levels is decibels. Decibel is a logarithmic scale. For an arithmetic function with a decibel-based measurement, the latter has to be converted to sound pressure levels. This is an important concept for researchers in the domain of noise to understand. Categorical data can be classified as distinct groups. Insert type and head worn type of ear protection devices is an example of categorical data. Qualitative data is an entirely different family of data. Structured responses to questions are mistakenly considered as qualitative data. Qualitative data is written narratives, for example, the narrations of users of ear protection devices such as "It causes a feeling of discomfort around the ear", "Sometimes it pains" and "I do not like to wear it". So the data collection proforma should be designed according to the type of data, with appropriate codes for categorical data. The collected data has to be cleaned for any error before analysis.

The collected data is summarized to make it meaningful. A collection of numbers or scripts cannot be used to make decisions. For example, a long list of minute-by-minute noise samples over a 24-hour period has no meaning. The average value, the most common value or the centrally placed value assists in interpreting quantitative data (numerical or categorical). For qualitative data a thematic framework assists in understanding the transcripts. For each type of objective a specific method is employed to summarize data. Research Genie can assist in identifying the most appropriate summary measure for a given objective.

22.8 Step 7: Applying Statistical Tests of Significance

The findings of the study are based on the sample selected from the universe where the research question was asked. Sampling and sample size ensure representative sampling, which makes the findings generalizable to the universe. The application of the tests of significance derives a probability measure of this generalizability. A particular objective has a specific test of significance. A simple approach to choose the test of significance is to understand it in the context of each objective in the nine domains of healthcare. For the description and incidence/prevalence type of objective, the Z-test of proportions is the most appropriate test of significance. Here we will introduce the concept of assumptions before applying the test of significance. When we communicate to a person in Kannada, for example, and expect a response, we assume that the person understands Kannada. Likewise, data has to fulfill a certain set of assumptions before the Z-test of proportions can be applied. Random sampling and independence of measurement (measurement obtained in an individual should not be dependent on any other prior factor that can systematically bias the measurement) are two assumptions to be fulfilled before applying the Z-test of proportion. The assumptions ensure that data analyzed by the computer program is representative of the population/universe. Computers cannot ensure random sampling and independence of measurement; it has to be done by the researcher. The Z-test of means or student's t-test is the correct test of significance for the lab range based objective. To test statistical significance of two interventions or to compare costs, an independent sample t-test is employed if data is normally distributed and the Mann-Whitney U test or Wilcoxon signed-rank test if the data is skewed and assumptions violated. The tests employed when assumptions are violated are less powerful in assisting us to generalize the results to the universe. If three interventions are compared, analysis of variance (ANOVA) is used if data is normally distributed and the Kruskal Wallis test is used if assumptions are violated. For objectives that measure risk chi-square is employed if assumptions are fulfilled and Fisher's test if assumptions are violated. Pearson's correlation is used for normally distributed data and Spearman's for data that violate assumptions in the correlation category of questions. Objectives based on beliefs, perceptions and experiences are answered by qualitative methods that do not employ tests of significance.

A checklist to maintain quality in research studies on noise, music and health is placed below.

- Framing objectives: Does the objectives clearly define all the variables to enable measurement?
- Conceptual framework: Has a comprehensive framework of all variables influencing the outcomes been constructed?
- Review of literature: Is the search strategy robust enough to scan all existing knowledge bases?
- Study design: Has the most appropriate study design been chosen?
- Sampling: Have all the aspects of heterogeneity in the universe of interest been considered while sampling to ensure representativeness?
- Data collection and summarizing: Is the data collection platform accurate and of quality? Has the most appropriate summary measure been chosen?
- Applying tests of significance: Has the correct test of significance been employed to generalize the results to the universe of the study?

22.9 Conclusions

This chapter creates a robust framework for undertaking knowledge creation in the domain of health, noise and music. The main conclusions it draws are as follows.

- Knowledge creation by research is required to address the challenges in the domain of noise, music and health.
- There are seven steps in the process of knowledge creation, namely, identifying a challenging healthcare situation in the domain of deleterious health effects of noise and beneficial effects of music and deriving objectives, developing a conceptual framework of variables around the objective, reviewing existing literature to examine if any researcher has already addressed the objective, choosing the most appropriate study design, selecting the sampling strategy and calculating the sample size followed by data collection, summarizing data to arrive at results and applying the tests of significance to examine the generalizability of the findings to the target population.

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Part VIII

CHALLENGES AND FUTURE DIRECTIONS

23

CHALLENGES AND FUTURE DIRECTIONS

Sujith John Chandy and Sunil Philip Chandy

23.1 Introduction

When talking of sound, it is important to reflect on how we understand sound and how we as humans interact and engage with it. Sound is not merely physics, nor is hearing purely biology. Sound has social, political and religious roles to play in society. Therefore, to talk of challenges and future directions regarding sound and its interaction with health requires a holistic multi-disciplinary engagement. This is a large task not possible within the confines of this concluding piece. What we will explore therefore are some ways in which sound can be understood and present some possibilities of how we could interact with sound in ways that promote healthy living and healing. This will then help us to understand the challenge and future directions for the sound-health inter-phase.

Learning Objectives

- Recognising the historical importance of sound
- Realising the shift in the place of sound in human experience
- Understanding how sound affects us and our environment
- Knowing the importance of paying attention to sound
- Integrating the association between sound, music and health

23. 2 Terms

We will first clarify the terms we use to contextualise how we speak of sound, music and health.

23.2.1 Health

Health is often narrowly defined from a hospital culture, but the WHO defines it as: 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.'[1] This holistic understanding of health forms the backdrop of how we will talk of the impact, effect and influence of sound and music in our lives.

23.2.2 Sound

Sound is understood physically to be a vibration experienced through a medium that the majority of humans experience as an acoustic phenomenon. Vibrations outside the range of human hearing might be classified differently. Understanding sound as physical vibration is important to understand how we interact with sound, not just through our ears but also through our entire body.

23.2.3 Music

Music is primarily a form of sound making which is organised under the principles of the culture it arises from.[2] Music understood in this way highlights two inter-connected features of sound:

23.2.3.1 Sound Can Be Made

The making of sound is a relatively simple task, and most creatures make sound. In contrast, the making of light is biologically rare. Sound is therefore something human beings can produce and control.

23.2.3.2 Sound Can Be Organised

The ability to make sound and our ability to produce and control sound allows us to organise it in different ways. The primary ways humans have organised sound is through language and music. Both music and language are present in all cultures. While there are overlaps between the two, all cultures have a distinction between the sound of language and that of music.

Having identified our terms broadly, let us explore some interactions of sound.

23.3 Sound and Time

Sound is an experience of time. A simple contrast between our experience of sound and that of light is the speed with which they reach us. The flash of lightning alerts us to the coming sound of thunder. We wait for the sound of thunder. That is an experience of time. A painting can be experienced in an instant or reflectively over a period of time. The choice is ours. A piece of music however requires being experienced in the time with which the sounds unpack themselves. We cannot hurry our perception of it. We talk of the slowness of sound and as an experience of time, because it has implications in how we engage with it and in how we talk of our future engagement of sound.

23.3.1 The Past

Any talk of future directions needs to take account of the past. Our response to sound is a key part of our human evolution. Sound gave us information about our environment, especially that which we could not see. It alerted us to the presence of other creatures, the arrival of rain, and of others like ourselves. It provided modes of survival, one of which was social bonding.

23.3.1.1 Social

From the earliest time, humans used sound to form social groups. The voice was the way by which we communicated, and this became the basis of language. Language through sound provided increasingly complex communicative systems which then allowed us to form social systems for survival. Language until very recently was primarily oral and framed around the acoustic. Therefore, language in the oral sense can be understood as an organisation of sound. There is another arguably equally important organisation of sound, which also has been an important feature of human evolution: music. Some scientists like Steven Pinker considered music to be 'auditory cheesecake,'[3] in other words, sound that's aesthetically pleasing. However, research has shown that music is fundamentally connected to both our evolutionary past and our current existence.[4] Researchers have generally understood that language and music arose from similar neurobiological mechanisms and that possibly they were initially a singular form of acoustic communication.[4] Music forms several functions within societies, from the declaration of war, to healing and bringing together the community for celebration and lament. Sound through language and music was always a key area of human flourishing.

23.3.1.2 Personal

On an individual level, sound has a history as well. Our sense of sound forms in the womb, and our first impressions of the outside world come through sound. Touch is the first sense we develop, and it is important to note that sound is something we can sense through touch. The experience of deaf musicians (which we will expand later) is testament to how our interaction with sound isn't only through our hearing mechanisms. Retaking our theme of development in the womb, we first hear our mother's voice and then other distinguishable voices and sound which create our initial understanding of the world outside ourselves and the womb. The effect of music on the foetus is a rich vein of research that shows how in our personal histories we start to process and respond to sound.

Simply summarised sound historically was a key part of our health, whether it was personal, social or spiritual. Our interaction with sound was key in forming our identity as individuals and groups. We highlight the above 'historical' aspects of sound for an important point about sound: Sound is a crucial way of connecting and interacting with the world, others and the divine. This is a fact that we are less and less aware of today as our culture has become far more visual. It is worth discussing this shift away from sound by talking about some developments over the last few centuries to our current one.

23.3.2 The Present

Our relationship to sound in today's world is based on the different developments that have happened across the world culturally, socially and technologically. We're going to focus on the technological side, by exploring some important technological developments that have fundamentally changed our relationship to sound.

Historically sound was always ethereal. Sounds were without permanence; they arose, and they died, a sound happened and faded away. Unlike an image which remains in place, sound always peters to nothing. The only way sound remained was in human memory and imagination. As suggested before, sound was fundamental to how language functioned within society. Language was tied to the abilities of speaking and listening. It was core to how human beings connected with each other and organised themselves. A technological development started changing how we interacted with language. It is known as 'Writing'.

23.3.2.1 Writing and Printing

Writing and later printing changed the possibilities of interacting with language. Speech and what was heard could now be *recorded*. Writing becomes the first way of recording sound. The language of human beings could now be placed on a page for others to 'hear.' Writing was still connected to sound because the assumption of writing down was tied to the notion that it would be read out aloud (including private reading). Additionally, writing and reading were skills of the elite, while for most people oral acoustic interactions were still primary. This connection between writing and sound went through a fundamental change when the technology of printing spread widely in Europe and then the rest of the world. Now language could be industrially produced in the printing press, making it far more accessible to all people.

Walter Ong researched the appearance of printing in society, and proposed that it fundamentally changed human consciousness itself.[5] It is worth thinking of how it changed our relationship to sound as well. Previously our ears were far more attuned to remembering things that were said in our more oral societies. As education spread, we became less dependent on the oral. Today, there are groups of people especially within more technologically advanced societies who primarily communicate through written text (electronically) than by voice and sound. There are accounts of people who haven't heard a single human voice within earshot for days.

This 'silencing' of the human voice didn't make things quieter for humanity. Industrialisation brought new sounds in the environment that humans have struggled with in terms of health and wellbeing. Printing was the industrialisation of writing. Sound itself later became industrialised with the next development that significantly changed our relationship to sound: that of recording technology

23.3.2.2 Recording Technology

Previously, writing 'stored' sounds as a set of abstract symbols that then had to be deciphered by the reader. The development of sound recording technology provided the ability to 'imprint' the waveforms themselves that could then be activated at any time of choosing. If printing changed our relationship to language, then sound recording changed our relationship to the other important sound that was part of human existence: *music*. Sound recording meant that music didn't need to be only performed and heard in particular places and times, but could be heard anywhere and anytime. All it required was the technology to record and hear. Sound became something increasingly manipulated and manufactured. While sound was previously something that occurred within shared spaces, now sound was held in objects, heard at one's leisure. A further development in the form of headphones made transferability and experience of sound even more personal and flexible. Sound now didn't have to be spread in the spaces they were produced, they could be confined to mere proximity of one's ears.

These technologies come with a set of implications for our health. Beyond the obvious reality that loud sound damages our ears, it is worth asking what our present-day interaction with sound and music mean for us today, its effect on health, and the challenges it raises.

23.4 Links between Sound, Music and Health

Research shows the influence of music on physiological parameters such as the heart rate, blood pressure, respiration, body temperature, brain waves, skin response and even the systems of endocrine and immune function [6].Different types of music may affect these functions in various ways. For example, fast paced dance beats and rock music can increase the heart rate, while lullabies decrease the heart rate, sometimes inducing sleep. The pitch, rhythm, tone, tenor, type of instruments, chords and harmonies all have varied effects on the body. It is important that we recognise this as we listen and participate in different types of music.

In the mental dimension, parts of the brain recognise and interpret various properties of music. Different centres process rhythm, pitch, timbre and so on [7]. These processes are required not just for music but for speech as well. Aniruddh Patel's *Music, Language, and the Brain,*[8] is an excellent exploration into the overlaps and distinctions that occur in our perception of music and language, both within the realm of sound. Music also has well known effects on our emotions, based on cultural context and other factors, causing joy and celebration, while also evoking sadness and reflection. Music also has important connections to our memory, where songs evoke feelings from the past. This connection to memory might be an important part of the formation of our self-identity.

The social aspects of music are well known. Music creates a sense of togetherness, especially when those who like a particular type of music come together. Many of our get-togethers are for music performances, concerts and programmes. Music gives an opportunity for social recognition, leadership and teamwork. All in all, music gives a strong sense of social well-being, thereby contributing to health.

23.5 What Sound Does Today – Challenges

Previously we spoke of the fundamental shift in our interactions with sound that have brought us to the current state in today's world.

23.5.1 Prioritisation of the Visual

Our current understanding and perception of sound is formed by what we assume sound does and the importance it has for us today. When thinking about sound, we have to first contrast it to the visual for the simple reason that our culture today has become overwhelmingly visual. While there are large pockets globally where visual technology hasn't taken hold, it can be argued that much of the world now uses smart phone screens to interact. Our eyes are at the forefront of our experience.

The prioritisation of the visual today inevitably affects our understanding of sound. In Western societies, sound is something to be controlled and privatised. Public sound is considered a nuisance while music is relegated to the background when doing other tasks. This means that we don't give as much attention to how sound affects us and its importance to us.

The prioritisation of the *visual* means that we pay less attention to *sound* as a whole and its impact on our health. The emphasis on the instantaneous visual over the slower experience of sound creates individuals and societies ever more in a hurry. As said earlier, sound is an experience of time, and the far quicker visual is causing us to hanker for the immediate rather than resonate with the rhythms of sound, the ebb and flow of its waves. Another impact of the prioritisation of the visual could be the presence of far more technologies around eye-care compared to ear-care. The care of the ear is far less understood and developed in the mind of ordinary individual, compared to the eye. Other than hearing aids and earplugs what do most people understand about ear care?

The lack of understanding of sound shows itself in the world beyond health too. In any building, the infrastructure for sight is far more developed than for hearing. Buildings are budgeted and equipped with sufficient lighting and projection, but when it comes to sound, there is far less investment in budgeting, design and implementation. This presents a very basic challenge: the need to give sound its due importance by giving sound more attention in itself i.e. paying attention to the medium of sound rather than always giving 'focus' to its content. Giving sound due attention will provide better information to assess its impact on our health as individuals and society. This challenge could be met by a combination of educational and creative channels. Employing pedagogical methods that centre on sensory experience as a mode of learning would be an overall strategy in terms of education. Schools could be encouraged to engage with sound through curriculum, by incorporating experiential models of learning about sound as experience rather than the abstract physics model of teaching about sound.

Additionally, sound could become part of pedagogical practice through different practices of listening. A story of a teacher and her students illustrates this: A teacher was struggling to hold the attention of a disruptive class. She decided to play a game with them. They had to close their eyes and say out aloud what they could hear. Each child had to name a unique sound that they were experiencing. The usual suspects of traffic, wind and footsteps were mentioned. Finally, a child said, 'I can hear my breathing.' The teacher said, 'Good, now we can begin our class.' The act of listening provided a centring of the person and her attention. Attending to sound in the content and mode of the curriculum could be expanded in higher education especially amongst healthcare professionals.

Attending to sound in this way would improve understanding and practice of sound and its impact on our individual and societal health. It will also help those who suffer from sensory overload and conversely those who have impaired sensory functions.

23.5.2 Perception of Sound

The last few decades have produced considerable research into our perception of sound. Yet researchers accept that the understanding of neuro-biological mechanisms of hearing is still in its infancy.[9] Previously, it was considered that the ear merely transferred sound waves across its constituent parts to the nerve, from which it was translated and carried on to relevant neural networks of the brain. The reality as ever is far more complex. At each stage of the hearing mechanism there is a filtering of the sound. By the time it reaches the nerve, the sound has already changed in some form.[10] Additionally, the hearing mechanism isn't just a one-way system where sounds travel from outside ourselves, through our ears, to our brains. Rather, the neural networks actively impact the sensitivities of the ear, fashioning what we hear based on prior experience, expectation, emotional states and so on.[11] This has different implications in how we understand the treatment of hearing loss and other acoustic deficiencies. The top-down fashioning of our hearing means that it becomes highly contextual. Hearing tests that play individual sine tones (simple frequencies) might give an indication as to some features of our ability to hear. However, someone with a strong sense of context will be able to manage their hearing because of an ability to fill the gaps which are caused by deficiencies of their biological ear. Conversely, someone with a poor sense of context might have perfectly healthy ears but will be unable to hear what is happening. The psychological and neurological influences on hearing are a challenge for understanding our hearing health.

Our hearing health is also not merely connected to our ears. Earlier we said about how touch is a way to perceive sound. That is simply because sound is a vibration and therefore our sense of touch is also a way of 'hearing.' Sound as a vibration has an impact on our entire body. There is limited research on the impact of sound on our body as a whole. What are the impacts of living in close proximity to different loud sources, whether they are factories, machinery or domestic appliances? There are many frequencies that are beyond human hearing as well and the question arises about their impact.

These challenges need to be met by further research into the impact of different sound environments on the body. The human body today is experiencing a set of vibrations at several frequencies which it never did before. The impact of these vibrations needs to be assessed on short and long terms basis on both physical and emotional levels while also examining the relation between the physical and emotional impacts that sound can have. Music's variable impact upon us shows the complexity of these tasks as music has different effects upon body, mind and memory all of which constitute the core identity of a person.

23.5.3 Deafness

The talk of vibration and touch as a form of hearing leads us back to the experience of the deaf. Deaf communities are unique in that they developed languages which were devoid of sound. This doesn't mean that the deaf cannot engage with sound. It is just that deafness makes acoustic speech a deficient way of communicating. The deaf in fact experience sound and this experience is in stark contrast to the blind person's experience of light. The vibration of sound means that it is accessible for those whose hearing mechanisms are deficient. There are cases of several deaf musicians (such as Evelyn Glennie) who can perform to high levels of traditional musicianship. With the right infrastructure (like a resonant platform), they can experience the sound in a way that they too can play and sing along with other people.

The deaf experience of sound points towards the multi-layered nature of sound. Since sound is vibration, it can travel through air, water, solid and we can experience it through our bodies. The deaf experience also shows that the way society sets itself up can exclude or include people. In many cases the ability to listen might be tied closely to the way in which the sound is produced and/or the way it is being received. Deafness provides a challenge in how we understand sound and its impact on our bodies, while also asking questions on the inclusive ways of accessing sound.

The challenge of the hearing impaired on our societal norms is worth engaging with. Recently in the UK, British sign language (BSL) was accepted as an official language by the government. An official acknowledgment of the language means that it acquires funding and societal status that allows hearing impaired people more access to different areas of society. Sign language has shown wider application in helping those with developmental differences in the acquisition and use of language.

23.5.4 Environment and Climate Change

So far we have spoken in very anthropocentric terms. It is important to consider the environment that we are a part of. Our actions on the environment and the sound we make have significantly affected the sonic landscape of our environment. There is research showing how birds in urban areas have changed their song and the times at which they sound it. Birdsong is essential for species survival and the sonic disruption that human action has produced is disruptive to the survival of different creatures. David Haskell writes of the loss of sonic diversity in our world indicating the loss of biodiversity which is crucial for the well-being of our planet.[12] His books *The Songs of Trees*[13] and *Sounds Wild and Broken*[12] are a biologist's reflections on attending to the sounds of our environment and are worth reading.

23.5.5 Overall Challenges

These discussions on prioritisation of the visual to the environment bring us to the challenges that sound presents to us through the various chapters of this book. If one were to summarize the main challenges that the 'sound world' face today, one could think of it in various domains. One domain is research. Quantifying the effects of music on health, both quantitatively and qualitatively would be very important as we go into the future, from a risk and benefit point of view. In relation to this, there also needs to be more research on how confounders such as background noise, vibrations and effect modifiers affect health. It would be important to design and make available the right infrastructural and service tools to conduct such a research.

The other domain which remains a challenge in sound is in the domain of learning. One learns music, but not much about sound itself, except some aspects of the biology of hearing. We need to learn more about sound, not just from a science point of view, but also an art point of view, if we are truly to imbibe the values of sound and learn about its harmful and beneficial effects for health and life as a whole. It would be important therefore to create interactive and experiential educational modules to understand the physics, biology and art of sound, hearing and speech. These educational modules need to address the needs of not just professionals, but also the public at large, especially as the noise pollution in the world increases at a rapid scale.

The other domain is in the preventive strategies to mitigate the harmful effects of sound. One way is to promulgate laws and regulations. However, implementation in a uniform manner is always a problem and that too to sustain the implementation. That is why having an ethical attitude towards sound as an individual is important. Internal regulation through behaviour change and understanding, that sound needs to be respected as individuals and as a society, will help in the long term. Other preventive strategies also need to be thought about. However, for any strategy, evaluating the baseline problems and assessing the effect of a particular strategy is important. Unfortunately, many challenges exist, including the high cost of sound measuring equipment and resource personnel with sufficient expertise. Another challenge is in monitoring and maintaining any sound protocols once implemented.

All these challenges require a lot of thought, brainstorming, but above all, an understanding of the problems of sound, and a commitment to address the challenges posed through collective wisdom, research, learning and policy implementation.

23.6 Future Possibilities

What has been covered here in this short article on sound is merely a scratching of the surface. The possibilities of sound and its future potential are enormous for life's journey and our health and well-being. How we approach sound and how we deal with sound in the future, therefore, needs to be explored further, especially in the light of the challenges which have been described in the previous section.

23.6.1 Sound Studies

There needs to be a building of volume around the study of sound especially in the non-Western world. Over the last two decades, a multidisciplinary field of research into sound has grown which offers many interesting possibilities regarding our understanding, perception and use of sound in our lives. Broadly this research field has been called 'Sound Studies'.[14]

'Sound studies' is a set of research activities around sound. It crosses various established disciplines from astrophysics, sociology and law. In astrophysics, it could be understanding the different frequencies emitted across space, while in sociology it could be research into slang, and in law it might be analysis of witness testimony. Sound studies as a multi-disciplinary field reflects sound's own multi-layered nature as has been reflected above. If health is understood in terms of the whole person, then sound studies is something healthcare professionals should start to engage with. It opens up different methods and practices, and how various disciplines can interact for the flourishing of human beings. Furthermore, sound studies show the direct impact of sound on us at different levels, from the biological to the psychological, from the social to the communal. What sound studies does, and this is the future direction that is proposed, is that sound needs to be given closer and careful attention.

23.6.2 Possibilities of Sound

Giving sound closer attention will open and offer several possibilities for health. Here are a few of them:

1. **Sound gives us fluid ways of interacting with each other.**
   Sound is a transfer of energy, and unlike light is something which we have more control over, in terms of making sound or ignoring it. We can communicate not just through language, but also through different tones and rhythms by which we speak. Beyond language, sound can be used to interact through music and more basic sound making actions. Rudy David is a music practitioner who works with children with different abilities and development using sound.[9] He designed a drum that gives access to children of different abilities to communicate and express themselves through sound. David's engagement of children through sound shows the ways in which pedagogies can be developed to account for variable abilities of people in society.
2. **Sound can provide ways of achieving a healthy cohesion of self and society.**
   Meditation has been increasingly accepted as an important practice for health. In the different traditions of meditation there are different approaches to sound, from pure silence, to chanting, to music. These approaches are ways of attending to sound in order to enhance the cohesive possibilities that meditation offers.
3. **Many sounds can coexist together, and this could inspire how groups of people can coexist together without oppression or violence.**
   Multiple sounds occur concurrently and our perception processes filter out unwanted sounds while elevating others. This is illustrated in the 'cocktail party problem'[15] where our hearing is examined to understand how we are able to hear one voice speaking to us amongst several other simultaneous voices. In music however, we hear multiple sounds simultaneously, and all those sounds interact in our perception to create a 'harmonious' whole. We can hear percussion, different instruments and voices, and yet they all belong together contributing to each other. This perception of sound is something worth exploring in terms of how we understand social cohesion, where people belonging to different communities intermingle and work together.
4. **Attending to sound and hearing shows that there is much that exists in the 'background' which is worth exploring and experiencing.**
   Sounds are constant on a pure physical level. There is the story of the composer John Cage, being in an anechoic chamber, a specially constructed room where no external sound or vibration can enter. Cage

was surprised to hear a high sound and a low one. They turned out to be the sounds of his nervous system and circulatory system.[16] The stethoscope, the tool to hear the heart, is the iconic image for the medical profession. Sound as shown in multiple medical disciplines offers important information of what is happening within the body. Sounds from the body are often considered vulgar, but if we are willing to hear them for what they are, these sounds will provide important indicators of the state of our bodies and beings.

5. **Listening is an important skill to be developed.**
   Attending to sound is fundamentally connected to listening. We have seen how the perception of sound can often be fashioned by top-down processes. Quite often our attention to sound is modulated by our prior experience and bias. For the medical profession this is a key issue, as practitioners need to listen on different levels from patients' ailments to colleague's discussions and departmental conversations. A lack of careful listening has consequences which only need to be imagined. The ability to listen is something that can be developed, and is also worth speaking of the energy and the cost of listening. The appropriate amount and types of rest required will improve listening practices, which in turn will deliver better health outcomes.

23.7 Conclusion

The challenges and possibilities mentioned above are again a whisper, and sometimes a soft pouring of speculation. However, the act of attempting to listen to what we don't normally hear is an important part of our engagement with sound and health. The future directions of sound and health are fundamentally connected to the basic act of listening. The process of listening, the attention given to sound, is the kind of attention we should be giving to the nature of sound and our perception of it. For this to happen there needs to be a re-appraisal of how we are choosing to experience the world and stepping back from the bright lights of the visual world, with its demanding colours and requirements for immediate response. Instead, we need to step into the sound world where, as each sound wave rises and falls in crests and troughs, sounds will come to us and then die, slowing us to experience time as a gift, resonating with our body, echoing into our memory. We hope that through this reading, you will step into the world of sound and music, surmounting the challenges, and embracing its potential in the future for the well-being of you and the society.

23.8 Key Messages

- Across multiple spheres today, sound isn't getting the attention it deserves
- A deeper engagement of sound, especially through different practices of listening is required
- Sound and music are essential for the well-being of individual, society and the planet
- In order to preserve our well-being, we should rekindle our relationship with sound and music through learning, research, and application in our daily lives
- The challenges that are faced with sound today should be understood and researched, so that we can strategise towards a better relationship with sound for the future.

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