Faridpur Med. Coll. J. 2025;20(1):51-59 DOI: https://doi.org/10.3329/fmcj.v20i1.80716

Reveiw Article

Causes and Mechanisms of Tinnitus: a Systematic Review

NN Biswas[1], SMF Zishan[2], ATMSU Rahman[3], RK Rudra[4], D Roy[5], MRH Bulbul[6], S Hasan[7], MJ Uddin[8], BML Rahman[9], MH Ali[10]

Abstract:

Tinnitus, a common yet debilitating condition, is linked to factors like hearing loss, ototoxic drugs, head injuries, and depression. The mechanisms behind tinnitus remain unclear, though inner ear pathology, auditory nerve issues, and central nervous system abnormalities are involved. A review of 15 studies identified noise exposure, age, and hearing loss as common causes. Diagnostic tests, including pure tone audiometry, OAE=Otoacoustic Emissions, ABR=Auditory Brainstem Responses, and imaging (fMRI, MRI, PET) are useful but show significant variability. Standardized diagnostic methods are needed to better understand and treat tinnitus.

Key words: Tinnitus, Causes, Mechanisms.

Introduction:

Tinnitus is the perception of a continuous or intermittent sound in the absence of external acoustic stimulation. Often described as a "phantom" auditory sensation, it can manifest as a continuous or intermittent sound, which may vary from person to person. Tinnitus presents with a variety of sounds, including tonal humming, high-pitched ringing, hissing, whistling, or noises resembling crickets. It affects 10-15% of the population, with around 20% of individuals finding the condition bothersome enough to disrupt daily life. These patients may struggle with concentration, sleep, and everyday activities, often seeking help from healthcare providers, audiologists, or hearing specialists. For many, tinnitus is mild and does not interfere significantly with

1. Prof. Dr. Nripendra Nath Biswas, MBBS, DLO, FCPS (ENT), Professor & Head, Department of ENT & Head-Neck Surgery, Faridpur Medical College, Faridpur.
2. Dr. S.M. Faisal Zishan, MBBS, FCPS (ENT), Assistant Professor, Department of ENT & Head-Neck Surgery, Faridpur Medical College, Faridpur.
3. Dr. ATM Sumaief Ur Rahman, MBBS, DLO, Junior Consultant, Department of ENT & Head-Neck Surgery, Faridpur Medical College Hospital, Faridpur.
4. Dr. Ranjit Kumar Rudra, MBBS, FCPS (ENT), Junior Consultant (ENT), Bhanga Upazilla Health Complex, Bhanga, Faridpur.
5. Dr. Debabrota Roy, MBBS, FCPS (ENT), Junior Consultant (ENT), Sadarpur Upazilla Health Complex, Sadarpur, Faridpur.
6. Dr. Muhammad Rasedul Hasan Bulbul, MBBS, MS (ENT), Indoor Medical Officer, Department of ENT & Head-Neck Surgery, Faridpur Medical College Hospital, Faridpur.
7. Dr. Shahed Hasan, MBBS, MCPS, MS (ENT), Indoor Medical Officer, Department of ENT & Head-Neck Surgery, Faridpur Medical College Hospital, Faridpur.
8. Dr. Mohammad Jalal Uddin, MBBS, DLO, Resident Surgeon, Department of ENT & Head-Neck Surgery, Faridpur Medical College Hospital, Faridpur.
9. Dr. Bepari Mohammad Lutfar Rahman, MBBS, Assistant Registrar, Department of ENT & Head-Neck Surgery, Faridpur Medical College Hospital, Faridpur.
10. Dr. Md. Hasan Ali, MBBS, FCPS, Medical Officer, Department of ENT & Head-Neck Surgery, Faridpur Medical College Hospital, Faridpur.

Address of correspondence:

Professor Dr. Nripendra Nath Biswas, MBBS, DLO, FCPS, Professor & Head of the department, Department of ENT & Head-Neck Surgery, Faridpur Medical College, Faridpur. Phone: +88-01712003407, E-mail: nripendranathbiswas96@gmail.com

life[1-4]. Tinnitus is categorized into two types: subjective and objective. Subjective tinnitus is the most common form, where individuals perceive sound without an external source, making it inaudible to others. The sounds are often described as ringing, buzzing, or hissing but can occasionally be more complex, like music or voices, though lacking clear meaning. It is commonly linked to hearing loss, noise exposure, ear infections, or age-related hearing decline. The condition is believed to arise from abnormal neural activity in the auditory system, where damaged cochlear sensory cells misfire, and sending incorrect signals to the brain[5,6]. Objective tinnitus is a rarer form with a physical origin, often linked to abnormal blood flow or muscle contractions near the ear. Unlike subjective tinnitus, it can sometimes be heard by a clinician during an examination. Conditions like pulsatile tinnitus, caused by abnormal vascular flow near the middle ear, or muscle contractions such as palatal myoclonus, can lead to rhythmic or repetitive sounds. Objective tinnitus is usually caused by specific medical conditions like vascular anomalies, aneurysms, or neurological disorders and can be diagnosed through imaging or specialized procedures. Treatment typically focuses on addressing the underlying physical cause[7-9].Tinnitus is one of the most prevalent and distressing otological conditions[10,11], often affecting a person's overall well-being. While some individuals experience tinnitus as a manageable annoyance, for others, it can manifest with severe accompanying symptoms, including anxiety, depression, insomnia, hearing loss, and hyperacusis (an increased sensitivity to normal environmental sounds). These symptoms can significantly reduce the quality of life, even when the actual loudness or psychoacoustic characteristics of the tinnitus are not particularly severe[11,12]. Interestingly, the intensity of the tinnitus sound does not always correlate with how much distress it causes; even mild cases can trigger significant emotional and psychological responses. For some, tinnitus leads to debilitating anxiety or depression, resulting in extreme changes in lifestyle, social interactions, and mental health[5,13]. Tinnitus can be constant or intermittent, with many individuals reporting multiple types of sounds at once. These sounds may be perceived in one or both ears or centrally in the head and sometimes seem to originate externally. Tinnitus can have an abrupt onset, but it typically develops gradually, worsening over time. Its intensity often fluctuates, becoming more pronounced during stress or emotional arousal, indicating a connection between tinnitus severity and stress levels[14]. The aim of this review was to review the evidence for different causes and mechanisms of tinnitus as identified through clinical diagnostic tests in the adult population.

Materials & Methods:

This review was conducted using PRISMA guidelines. The review consisted of 5 steps: (1) problem identification; (2) Literature searching; (3) Data review and evaluation; (4) Data synthesis and analysis; and (5) Data presentation. The review conducted an extensive search in PubMed, Google Scholar, and Embase using terms related to cochlear, neural, cortical, and somatosensory tinnitus, exploring its mechanisms, prevalence, and risk factors. High-quality studies, including RCTs, cohort studies, and case-control studies, were prioritized, while non-primary sources like editorials were excluded. Relevant citations were screened, and full texts were reviewed based on pre-defined criteria, focusing on English or translated works for comprehensive evidence coverage. We systematically gathered data from various studies, focusing on key factors such as study design, sample size, and outcomes. After screening abstracts, we reviewed full articles and extracted relevant data to create an overview of tinnitus causes and mechanisms. Database searches identified 120 records, of them 30 has been excluded due to duplication. Among 90 remaining articles, full text articles were 35 & records of title and abstract were 55. Twenty full text article has been excluded due to not meeting inclusion criteria and finally 15 article fully met inclusion criteria, of them research study were 10 and review article were 5.

Results:

In this review, we included 15 studies: two cross-sectional, five case-control, two experimental, one purposive sampling, and five review articles. A descriptive summary outlines the study type, research design, sample size, measurement methods, and key findings (Table I & II).

Table-I: Summary of the published articles (Research study)

Reference	Study design	Sample size (n)	Test-performed	Outcome
Bhatt JM et al.[15]	Cross sectional analysis	n=75764	Survey questionnaire, Tinnitus questionnaire	Loud workplace (odds ratio: 3.3) and recreational (odds ratio: 2.6) noise exposure significantly increase tinnitus risk, with longer work-related exposure correlating to higher prevalence (correlation coefficient: r = 0.13).
Cai Y et al.[16]	Case control study	n=78	PTA, IA, tinnitus pitch and loudness	Significant differences in high-frequency thresholds were found between tinnitus and non-tinnitus ears.
Kujawa SG et al.[17]	Experimental study	N=128 (mice)	ABR, ECOGG, DPOAE, cochlear mapping software	Hair cell damage leads to neurodegeneration that isn't fully detected by standard hearing tests. This damage can worsen hearing difficulties in noisy environments and is often linked to tinnitus, which commonly results from inner ear damage.
López-González MA et al.[18]	Purposive sampling	n= 47	PTA with extended high frequency	Statistically significant differences were found between tinnitus frequency measurements using conventional and high-frequency audiometers. A correlation was also observed between high-frequency tinnitus and the level of distress reported by patients.
Norena SK et al.[19]	Experimental study	Animal study (cat)	-	Noise-induced hearing loss leads to a reorganization of the tonotopic map in the auditory cortex, increasing spontaneous firing rates and neural synchrony, which may serve as a neural indicator of tinnitus.
Makar SK et al.[20]	Case-control study	n=60	PTA, IA, ABR, DPOAE, Tinnitus, pitch and loudness	DPOAE results indicate cochlear involvement, while ABR findings suggest that prolonged tinnitus with multiple features affects the function of the entire brainstem.
Samarei R et al.[21]	Cross-sectional	n=184	PTA, OE, questionnaire	The most prevalent causes of tinnitus include noise exposure (19.6%), ototoxicity (16.8%), and age-related hearing loss (presbycusis) at 16.3%.
Shim HJ et al.[22]	Case control study	n=510	High frequency PTA, ABR, tinnitus pitch & loudness	Patients with tinnitus who exhibit normal hearing up to 8 kHz show reduced hearing sensitivity at higher frequencies, specifically at 10 kHz, 12 kHz, 14 kHz, and 16 kHz.

Reference	Study design	Sample size (n)	Test-performed	Outcome
Tang et al.[23]	Case control study	n=200	ENT, IA, PTA with high frequency	In patients with unilateral tinnitus, the hearing threshold difference between the tinnitus ear and the contralateral ear (0.125 to 8 kHz) was statistically significant, but no significant difference was found at extended high frequencies (above 10 kHz).
Yildirim G et al.[24]	Case control study	n= 154	PTA, IA, OE, tinnitus pitch and loudness matching	Significant age-related hearing loss was observed in the 8,000-20,000 Hz range in tinnitus patients, with increased loss at higher frequencies.

Table-II: Summary of the published articles (Review Articles)

Reference	Outcome
THan BI et al.[25]	Theoretical models suggest tinnitus generators are located within the auditory pathway, with mechanisms involving both peripheral and central systems. These theories include auditory plasticity, crosstalk, and the influence of the somatosensory, limbic, and autonomic nervous systems.
Henry JA et al.[26]	Tinnitus is a condition characterized by neuroplastic changes in the central auditory structures that occur when the brain is deprived of its usual sensory input due to damage or dysfunction in the cochlea.
Koehler SD et al.[27]	Tinnitus results from imbalances between excitatory and inhibitory inputs to auditory neurons, driven by the loss of normal auditory input. This disruption triggers plastic adjustments in the central auditory system, leading to the perception of tinnitus.
Lockwood AH et al.[28]	Cochlear damage causes central auditory pathway reorganization, where reduced auditory nerve input disinhibits the dorsal cochlear nucleus (DCN), leading to increased spontaneous activity and the perception of tinnitus.
Noreña AJ et al.[29]	Cochlear-type tinnitus arises from abnormal cochlear nerve activity. Reduced cochlear activity triggers plastic changes, including cortical reorganization and heightened central gain, leading to hypersynchrony and tinnitus perception.

Several studies suggest that tinnitus originates in the cochlea due to dysfunction that creates a subtle imbalance of neural activity in the central auditory pathway. This imbalance, detected at low signal levels, is perceived as a novel signal and amplified by subcortical centers before reaching the auditory cortex, where it manifests as tinnitus. In prolonged cases, the auditory system's involvement extends to the limbic and autonomic nervous systems, implicating the entire brainstem. Tinnitus with multiple features is also associated with abnormal activity within the central auditory pathway [27, 30, 31]. Abnormal activity in the inferior colliculus (IC), cochlear nucleus (CN), medial superior olivary complex (MSOC), and brainstem disrupts the tonotopic organization of auditory maps. These initial changes can lead to secondary alterations, explaining the variability in tinnitus pitch, loudness, and residual inhibition (RI) over time. Cochlear-type tinnitus likely originates from aberrant activity in the cochlear nerve, where outer hair cells regulate the endocochlear potential, enhancing spontaneous cochlear activity. Reduced cochlear activity triggers tinnitus-related plastic changes, including cortical reorganization, hyperpolarization of thalamic neurons, increased facilitation of non-auditory limbic inputs, and heightened central gain. These adaptations result in abnormal spontaneous activity patterns in the auditory pathway, marked by hypersynchrony. Additionally, the

somatosensory system, along with the limbic and autonomic nervous systems, contributes to tinnitus generation and modulation[32-35].

Causes of tinnitus:

- **Hearing loss:** Sensorineural hearing loss is commonly accompanied with tinnitus. Some researchers believe that subjective tinnitus cannot exist without hearing loss (American Tinnitus Association)[36]. Objective tinnitus is often linked to hearing loss, even in individuals with normal hearing, who may show significant loss at extended high frequencies (10,000 to 20,000 Hz)[37]. It was reported that there were significant differences in high-frequency thresholds between the tinnitus ear and the non-tinnitus ear ($P < 0.01$). Additionally, there were significant differences in high-frequency thresholds between tinnitus and non-tinnitus ears within each group ($P < 0.01$)[38]. Shim et al[22] reported that patients with tinnitus, despite having normal hearing below 8 kHz, exhibited reduced hearing ability at extended high frequencies of 10 kHz, 12 kHz, 14 kHz, and 16 kHz. Statistically significant differences ($p < 0.01$) were observed in the determination of tinnitus frequency using conventional versus high-frequency audiometers. Additionally, a correlation was found between high-frequency tinnitus and the level of distress reported by patients[27,39,40]. Tinnitus is influenced by frequency, particularly between 8,000 Hz and 20,000 Hz, where higher frequencies correlate with greater hearing loss. Multiple triggers, like hearing loss, stress, and noise exposure, often combine to cause tinnitus[17, 41-44].

- **Noise:** According to ASHA[45], loud noise exposure is a potential cause of tinnitus. Noise exposure is the second most common cause of tinnitus, responsible for 18% of cases. It may lead to tinnitus by causing temporary changes in outer hair cells, increasing gain in the central auditory system[18,28,46,47]. Noise-induced hearing loss (NIHL) is the leading cause of tinnitus, with environmental factors, particularly noise exposure, damaging the auditory system and cochlear microstructures [48-50]. Both prolonged exposure to loud noises and single traumatic noise events can lead to hearing loss and, in many cases, tinnitus (American Tinnitus Association) [36].

- **Age:** Any pathologic lesion in the auditory pathway or any reduction in auditory nerve function due to ageing has the potential to produce tinnitus[51]. Bilateral subjective tinnitus is often associated with presbycusis, or age-related hearing loss[52]. The significant association between tinnitus and older age (60 to 69 years) suggests that vascular disease may play a significant role in its etiology[53]. Aging can lead to partial deafferentation of the central auditory system, causing a net down regulation of functional inhibition, potentially resulting from maladaptive plastic compensatory changes[54]. Hearing loss commonly worsens with age, typically beginning around 60 years old, and often affects both ears by reducing the ability to hear high-frequency sounds. This age-related hearing loss helps explain the high prevalence of tinnitus among older adults (American Tinnitus Association, 2023)[36].

- **Psychological Status:** Excessive stress is a common trigger for tinnitus, with around 75% of new cases linked to emotional stress (ASHA)[45]. A study with over 14,000 participants found that 39.5% of individuals with depression experienced tinnitus, compared to 19% without depression. Tinnitus was also linked to hearing disorders, with a prevalence rate of 30-37%. Overall, tinnitus affected 25.3% of the population[55]. Tinnitus is significantly associated with hypertension ($p<.01$), suggesting vascular disease as a key factor. Changes in neurosteroid levels linked to depression may also contribute to its onset. The American Tinnitus Association highlights psychiatric disorders, including depression, anxiety, and stress, as major triggers for tinnitus[36, 56].

- **Ototoxicity:** Bilateral subjective tinnitus can be linked to ototoxicity[57] which may arise as a side effect of certain oral medications. These include salicylates, nonsteroidal anti-inflammatory drugs (NSAIDs), aminoglycoside antibiotics, loop diuretics, and chemotherapy agents[58]. Tinnitus can be a temporary side effect of many medications, but ototoxic drugs like NSAIDs, antibiotics, cancer treatments, diuretics, and quinine-based medications may cause permanent tinnitus (American Tinnitus Association)[36].

- **Medical problem:** Tinnitus can be linked to neurologic conditions (e.g., head injury, vestibular schwannoma), infections (e.g., otitis media, meningitis), and medical issues (e.g., hypothyroidism, anemia, high blood pressure). It can also be triggered by traumatic brain injuries, vestibular disorders, Ménière's disease, migraines, and ototoxic drugs (American Tinnitus Association)[36]. A study by Shargorodsky further noted a significant association between tinnitus and diabetes mellitus ($p<0.01$), suggesting a potential vascular component to the condition[59].

- **Somatosensory cause:** Research has shown that somatic maneuvers like jaw clenching or neck muscle tensing can affect tinnitus loudness and pitch by modulating auditory neuron activity through trigeminal stimulation. This integration occurs in the inferior colliculus. Tinnitus related to temporomandibular joint (TMJ) disorders, where nerve damage affects the middle ear, can often be alleviated by treating the TMJ issue (American Tinnitus Association)[36].

Pathophysiological mechanism:

The pathophysiology of subjective tinnitus remains poorly understood, particularly the neuroplastic changes that occur in central auditory structures when the brain is deprived of its normal auditory input due to cochlear pathology.

- **Cochlear pathophysiology:** According to Job A et al[35] there is evidence suggesting tinnitus to cochlear OHC dysfunction due to noise exposure, leading to increased neural activity in the DCNs. This is believed to be a central gain adaptation mechanism, where the auditory system amplifies signals to compensate for reduced input. Tinnitus can be tonal or complex, depending on the extent of cochlear dysfunction. In contrast, complex tinnitus stems from multiple areas of discordance, causing more varied and intricate auditory perception (Jastreboff PJ)[6]. However, when patients clearly have the central type of tinnitus, such as after transaction of the auditory nerve, the OHC concept is not applicable and alternative mechanisms need to be considered[59].

- **Auditory and Vestibular Nerve pathophysiology:** Schaette R et al.[60] found that tinnitus can occur despite normal audiograms, suggesting "hidden hearing loss" due to cochlear damage. Their study showed that while ABR wave I amplitudes were reduced in tinnitus patients, wave V amplitudes remained normal, indicating decreased neural output from the cochlea. Despite no significant differences in ABR amplitudes between experimental and non-experimental ears, reduced sound tolerance in both ears suggested increased central gain, potentially due to hidden synaptopathy. This suggests that lateral olivocochlear efferents balance the neural activity between ears[22].

- **Dorsal Cochlear Nucleus pathophysiology:** The dorsal cochlear nucleus (DCN) plays a key role in tinnitus, with damage to outer hair cells (OHCs) causing hyperactivity in the DCN, leading to tinnitus related neural signals. This hyperactivity results from reduced auditory nerve input, and studies show altered auditory brainstem responses (ABR) in tinnitus patients, with decreased wave I and increased wave V amplitudes. This suggests heightened activity in the ventral cochlear nucleus (VCN) and the spherical bushy cell (SBC) pathway, which may be potential treatment targets[22].

- **Auditory cortex pathophysiology:** Tinnitus may originate in the temporal lobe, with increased activity in areas like the right middle temporal gyrus and superior frontal gyrus. Longer tinnitus durations correlate with higher activity in the right SFG. MRI also shows a shift in the auditory cortical representation of the tinnitus frequency.

- **Somatosensory pathophysiology:** Tinnitus is influenced by the Dorsal Cochlear Nucleus (DCN) and its interaction with nonauditory structures, particularly the somatosensory system. Somatic tinnitus arises from activation of otosomatic interactions, with nerve fibers from the medullary somatosensory nuclei influencing the DCN[46]. This can be modulated by psychological factors like anxiety and depression, which are linked to increased tinnitus severity. Voluntary somatosensory or motor actions can also influence tinnitus perception, indicating a complex interaction between auditory and somatosensory systems. Additionally, limbic structures and autonomic nervous systems play a role in the emotional and stress related exacerbation of tinnitus. fMRI studies show hyperactivity in both auditory and limbic areas, correlating with the tinnitus frequency[61].

Discussion:

The systematic review underscores the complex nature of tinnitus, linking it to factors like sensorineural hearing loss, noise exposure, aging, stress, and conditions like vestibular schwannoma or somatosensory damage. Beyond the auditory system, it involves neural networks, including the limbic and autonomic systems. Cochlear damage triggers neuroplastic changes, reorganizing auditory pathways and increasing neural activity, which affects both auditory and non-auditory regions, contributing to the perception of phantom sounds. The review analyzed studies with various designs and methodologies, highlighting the importance of diagnostic tools like PTA, IA, DPOAE, ABR, fMRI, and PET scans. Findings suggest that reduced cochlear activity leads to neural changes causing hyper synchrony in the auditory system, with involvement of the limbic system contributing to emotional distress. High quality studies and a multidisciplinary approach to diagnosis and treatment are needed. Causes of tinnitus include viral infections, vascular issues, immune responses, and inner ear abnormalities.

Conclusion:

A comprehensive case history and physical examination of patients experiencing tinnitus can help identify potential underlying causes, such as trauma, cerebrovascular accidents, or ear surgeries. If inconclusive, MRI scans can rule out vestibular schwannoma. Tinnitus often results from neuroplastic changes in central auditory structures due to cochlear pathology, even with normal audiograms. Specialized tests like Otoacoustic Emissions (OAE) and Auditory Brainstem Responses (ABR) can detect subtle neuronal changes. Prolonged tinnitus involves complex interactions between auditory and non-auditory systems, emphasizing the need for a comprehensive diagnostic and management approach. The present review has several limitations that should be considered. First, the relatively small number of studies included may have limited the comprehensiveness of the findings. Additionally, only studies written in English were considered, which means relevant literature in other languages was not included in the analysis, potentially restricting the scope of the review.

References:

1. Armstrong R, Hall BJ, Doyle J, Waters E. 'Scoping the scope 'of a Cochrane review. *Journal of public health*. 2011 Mar 1; 33(1):147-50.
2. Vernon JA. *Tinnitus: treatment and relief*. Illustrated ed. Boston: Allyn and Bacon; 1998.
3. Davis A, El Rafaie A. Epidemiology of tinnitus. In: Tyler RS, editor. *Tinnitus Handbook Thomson Learning*. San Diego; 2000. p. 1–23.
4. Andersson G, Baguley D, McKenna L, McFerran D. *Tinnitus: a multidisciplinary approach*. 1st ed. London: Whurr; 2005.
5. Snow JB. *Tinnitus: theory and management*. Vol. 1. Hamilton (ON): BC Decker Inc.; 2004.
6. Jastreboff PJ. Tinnitus retraining therapy. In: Møller AR, Langguth B, DeRidder D, Kleinjung T, editors. *Textbook of tinnitus*. New York: Springer; 2011. p. 575-96.
7. Henry JA, Dennis KC, Schechter MA. *General review of tinnitus*. J Speech Lang Hear Res. 2005;48(5):1204-35.
8. Stouffer JL, Tyler RS. Characterization of tinnitus by tinnitus patients. *Journal of Speech and Hearing Disorders*. 1990 Aug; 55(3):439-53.
9. Bhimrao SK, Masterson L, Baguley D. Systematic review of management strategies for middle ear myoclonus. *Otolaryngology--Head and Neck Surgery*. 2012 May; 146(5):698-706.
10. Lockwood AH, Salvi RJ, Burkard RF. Tinnitus. *N Engl J Med*. 2002; 347(12):904–10. Available from: http://dx.doi.org/10.1056/NEJMra013395
11. Seo JH, Kang JM, Hwang SH, Han KD, Joo YH. Relationship between tinnitus and suicidal behaviour in Korean men and women: a cross-sectional study. *Clinical otolaryngology*. 2016 Jun; 41(3):222-7.
12. Henry JA, Meikle MB. Psychoacoustic measures of tinnitus. *Journal of the American Academy of Audiology*. 2000 Mar; 11(03):138-55.
13. Chari DA, Limb CJ. Tinnitus. *Med Clin North Am*. 2018; 102(6):1081–93. Available from: http://dx.doi.org/10.1016/j.mcna.2018.06.014
14. Baguley D, McFerran D, Hall D. Tinnitus. *Lancet*. 2013; 382(9904):1600–7. Available from: http://dx.doi.org/10.1016/S0140-6736(13)60142-7
15. Bhatt JM, Lin HW, Bhattacharyya N. Prevalence, severity, exposures, and treatment patterns of tinnitus in the United States. *JAMA Otolaryngology Head & Neck Surgery*. 2016; 142: 959-65.

16. Cai Y, Tang J, Li X. Relationship between high frequency hearing threshold and tinnitus. *Journal of Clinical Otorhinolaryngology*. 2004 Jan 1; 18(1):8-9.

17. Kujawa SG, Liberman MC. Adding insult to injury: Cochlear nerve degeneration after "temporary" noise-induced hearing loss. *Journal of Neuroscience*. 2019; 29:14077-85.

18. López-González MA, Cambil E, Abrante A, López-Fernández R, Barea E, Esteban F. Tinnitus measurement with conventional audiometer versus high-frequency audiometer. *Acta Otorrinolaringologica* (English Edition). 2003; 63: 102-5.

19. Norena AJ, Eggermont JJ. Enriched acoustic environment after noise trauma abolishes neural signs of tinnitus. *Neuroreport*. 2006 Apr 24; 17(6):559-63.

20. Makar SK, Mukundan G, Gore G. Auditory system synchronization and cochlear function in patients with normal hearing with tinnitus: comparison of multiple feature with longer duration and single feature with shorter duration tinnitus. *The international tinnitus journal*. 2017 Dec 18; 21(2):133-8.

21. Samarei R, Fatholahi N. Causes of tinnitus in patients referred to ENT clinic of Imam Khomeini hospital in Urmia, 2012-2013. *Global Journal of Health Science*. 2014; 6:136-38.

22. Shim HJ, Kim SK, Park CH, Lee SH, Yoon SW, Ki AR, et al. Hearing abilities at ultra-high frequency in patients with tinnitus. *Clinical and experimental otorhinolaryngology*. 2009 Dec 31; 2(4):169-74.

23. Tang J, Jii B, Liu L. Study of hearing loss in 200 patients with subjective tinnitus. *Lin-Bed Journal of Otorhinolaryngology Head and Neck Surgery*. 2005; 25: 726-29.

24. Yildirim G, Berkiten G, Kuzdere M, Ugras H. High frequency audiometry in patients presenting with tinnitus. *The Journal of International Advanced Otology*. 2010 Oct 1; 6(3):401.

25. Han BI, Lee HW, Kim TY, Lim JS, Shin KS. Tinnitus: Characteristics, causes, mechanisms, and treatments. *Journal of Clinical Neurology*. 2009; 5:11-19.

26. Henry JA, Roberts LE, Caspary DM, Theodoroff SM, Salvi RJ. Underlying mechanisms of tinnitus: Review and clinical implications. *Journal of the American Academy of Audiology*. 2014; 25: 5-22.

27. Koehler SD, Pradhan S, Manis PB, Shore SE. Somatosensory inputs modify auditory spike timing in dorsal cochlear nucleus principal cells. *European Journal of Neuroscience*. 2011; 33:409-20.

28. Lockwood AH, Salv RJ, Burkard RF. Tinnitus. *N Engl J Med*. 2002; 347:904-10.

29. Noreña AJ. Revisiting the cochlear and central mechanisms of tinnitus and therapeutic approaches. *Audiology and Neurotology*. 2015 May 1; 20(Suppl. 1):53-9.

30. Henry JA, Dennis KC, Schechter MA. General review of tinnitus. *Journal of Speech, Language, and Hearing research*. 2006; 1:1-6.

31. Hobson J, Chisholm E, El Refaie A. Sound therapy (masking) in the management of tinnitus in adults. *Cochrane Database of Systematic Reviews*. 2011; 1:1-11.

32. Holt AG, Bissig D, Mirza N, Rajah G, Berkowitz B. Evidence of key tinnitus-related brain regions documented by a unique combination of manganese-enhanced MRI and acoustic startle reflex testing. *PloS one*. 2010; 5:14-260.

33. Jastreboff PJ, Jastreboff MM. Tinnitus retraining therapy. In: Snow JB, editor. *Tinnitus: Theory and management*. Hamilton (ON): BC Decker Inc.; 2004. p. 295-309.

34. Jastreboff PJ, Hazell JW. *Tinnitus retraining therapy: Implementing the neurophysiological model*. New York: Cambridge University Press; 2004.

35. Job A, Raynal M, Kossowski M. Susceptibility to tinnitus revealed at 2 kHz range by bilateral lower DPOAEs in normal hearing subjects with noise exposure. *Audiology and Neurotology*. 2003; 12:137-44.

36. American Tinnitus Association. Causes. American Tinnitus Association; 2023 Mar 3 [cited 2025 Mar 11]. Available from: https://www.ata.org/about-tinnitus/why-are-my-ears-ringing/causes/

37. Kaltenbach JA. Tinnitus: models and mechanisms. *Hearing research*. 2002; 6: 52-60.

38. Kaltenbach JA, Zhang J, Finlayson P. Tinnitus as a plastic phenomenon and its possible neural underpinnings in the dorsal cochlear nucleus. *Hearing research*. 2002; 6:200 -26.

39. Kaltenbach JA, Zhang J, Afman CE. Plasticity of spontaneous neural activity in the dorsal cochlear nucleus after intense sound exposure. *Hearing research*. 2003; 147:282-92.

40. Koester M, Storck C, Zorowka P. Tinnitus classification, causes, diagnosis, treatment and prognosis. *MMW Fortschritte der Medizin*. 2014; 146:23-24.

41. Kraus KS, Canlon B. Neuronal connectivity and interactions between the auditory and limbic systems: Effects of noise and tinnitus. *Hearing Research*. 2014; 88:34-46.

42. Lanting CP, De Kleine E, Van Dijk, P. Neural activity underlying tinnitus generation: Results from PET and fMRI. *Hearing Research*. 2009; 255:1-13.

43. Leaver AM, Renier L, Chevillet MA, Morgan S, Kim HJ, Rauschecker JP. Dysregulation of limbic and auditory networks in tinnitus. *Neuron*. 2009; 69:33-43.

44. Levine RA, Abel M, Cheng H. CNS somatosensory-auditory interactions elicit or modulate tinnitus. *Experimental Brain Research*. 2009; 153:643-48.

45. Loud noise dangers [Internet]. American Speech-Language-Hearing Association. [cited 2025 Mar 2]. Available from: https://www.asha.org/public/hearing/ loud-noise-dangers/

46. Levin RA. Somatic tinnitus. In: Snow JB, editor. *Tinnitus: Theory and management*. Ontario: BC Decker Inc.; 2008. p. 108-24.

47. Lockwood AH, Salvi RJ, Burkard RF, Galantowicz PJ, Coad ML, Wack DS. Neuroanatomy of tinnitus. *Scand Audiol Suppl*.1990; 51:47-52.

48. McCormack A, Edmondson-Jones M, Somerset S, Hall D. A systematic review of the reporting of tinnitus prevalence and severity. *Hearing research*. 2010; 337:70-79.

49. Mirz F, Gjedde A, Sdkilde-Jrgensen H, Pedersen C. Functional brain imaging of tinnitus-like perception induced by aversive auditory stimuli. *Neuroreport*. 2010; 11:633-37.

50. Møller AR, Langguth B, DeRidder D, Kleinjung T. *Textbook of tinnitus*. Springer Science & Business Media. 2010.p.48.

51. Mühlnickel W, Elbert T, Taub E, Flor H. Reorganization of auditory cortex in tinnitus. *Proceedings of the National Academy of Sciences*. 2010; 95:10340-43.

52. Nuttall AL, Meikle MB, Trune DR. Peripheral processes involved in tinnitus. In: Snow JB, editor. *Tinnitus: Theory and management*. Ontario: BC Decker Inc.; 2004. p. 52-68.

53. Parra LC, Pearlmutter BA. Illusory percepts from auditory adaptation. *J Acoust Soc Am*. 2007; 121:1632-41.

54. Reyes SA, Salvi RJ, Burkard RF, Coad ML, Wack DS. Galantowicz, PJ, et al. Brain imaging of the effects of lidocaine on tinnitus. *Hearing Research*. 2002; 171:43-50.

55. Rauschecker JP, Leaver AM, Mühlau M. Tuning out the noise: limbic-auditory interactions in tinnitus. *Neuron*. 2007; 66:819-26.

56. Salvi RJ, Wang J, Ding D. Auditory plasticity and hyperactivity following cochlear damage. *Hearing Research*. 2007; 147:261- 74.

57. Schreiner CE, Cheung SW. Cortical plasticity and tinnitus. In: Snow JB, editor. *Tinnitus: Theory and management*. Ontario: BC Decker Inc.; 2004. p. 189-204.

58. Shargorodsky J, Curhan GC, Farwell WR. Prevalence and characteristics of tinnitus among US adults. *The American Journal of Medicine*. 2004; 123: 711-18.

59. Shore SE. Plasticity of somatosensory inputs to the cochlear nucleus–implications for tinnitus. *Hearing Research*. 2011; 281:38-46.

60. Shore S, Zhou J, Koehler S. Neural mechanisms underlying somatic tinnitus. *Prog Brain Res*. 2007; 166:107-23.

61. Schaette R, McAlpine D. Tinnitus with a normal audiogram: physiological evidence for hidden hearing loss and computational model. *Journal of Neuroscience*. 2011 Sep 21; 31(38):13452-7.