Review Article

Occupational Noise-Induced Tinnitus: A Review of Auditory Behavioral and Electrophysiological Evaluations

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Highlights

- Occupational noise exposure is one of the established risk factors for tinnitus
- Self-report surveys are the best choice for tinnitus assessment and management
- The findings of behavioral and physiological studies have not been conclusive

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ABSTRACT

Background and Aim: The increasing prevalence of Noise-Induced Tinnitus (NIT) is considered one of the major occupational health threats these days. Despite the devastating effect of tinnitus on a subject's performance, auditory functions and life quality, there is a lack of standard protocol for its diagnosis and management. Furthermore, the mechanisms of NIT are not clear yet. So, this review summarized data on NIT mechanisms as well as questionnaires, behavioral and physiologic assessment tools in NIT studies.

Recent Findings: Based on the authors' research, 27 eligible articles were included in this review. NIT was mainly bilateral with moderate severity with an overall prevalence ranging from 4% to 73.7%. Self-report questionnaires, tinnitus handicap inventory, auditory brainstem response, otoacoustic emissions and speech in noise tests were the most frequent NIT assessment methods in the reviewed studies. Our review highlights increased latencies in brainstem evoked potentials in tinnitus workers, but the knowledge gap about changes at subcortical and cortical levels remains.

Conclusion: This review suggests speech in noise test as a useful extension to routine tinnitus assessment by questionnaires among workers. Due to insufficient studies and inconsistent results in NIT subjects, more electrophysiological research is suggested in large and homogeneous samples.

Keywords: Noise; tinnitus; occupational; questionnaire; physiological

Introduction

Tinnitus is defined as a conscious perception of an independent auditory stimulus in the head or ears [1-4]. Tinnitus and hearing loss due to noise exposure are among the most common complaints of adults and one of the major health threats in modern societies [1, 5]. Occupational noise exposure is one of the established risk factors leading to noise-induced hearing loss and Noise-Induced Tinnitus (NIT). Previous studies indicated adverse effects of tinnitus on different auditory skills, patients' hearing performance, communication and health-related quality of life [6, 7]. It is estimated that 8.7% to 29.7% of noise-exposed workers suffer from tinnitus worldwide [8-11]. The higher percentage of tinnitus in high-risk occupations than in non-exposed ones (20.7–42% vs. 5–7.5%), emphasizes the adverse impact of noisy workplaces [12]. Also, temporary NIT with a prevalence of 45%–75% is considered a prognostic factor for future permanent tinnitus [4, 13]. It was usually bilateral, continuous and non-pulsating with a persistent nature [1, 11]. However, it is shown that NIT could affect approximately 20–40% of industrial workers during work life [14].

The estimate of NIT prevalence is likely to be confounded by hearing impairment [2, 15, 16]. Studies demonstrated that 83% of subjects with tinnitus experience hearing loss, particularly in the high-frequency range [17, 18]. Tinnitus may trigger events to increase neural activity at different levels of the auditory pathways from the cochlea to the cortex [11]. Current tinnitus theories mainly focus on abnormal activities in the central nervous system. Involvement of auditory and non-auditory brain regions, including the loss of connection with the limbic system that normally "tunes out" tinnitus signals originating from auditory pathways, and the dysfunctional network of auditory-sensory and fronto-striatal circuits were highlighted in the pathophysiology of tinnitus as well [19]. Evidence of cochlear synaptopathy and dysfunction of the auditory efferent pathways were found in tinnitus subjects with normal hearing or slight hearing loss [17, 20]. So, these abnormalities possibly cannot be detected by medical history and even basic hearing tests [17, 21].

Currently, there is a growing interest in NIT research. A variety of diagnostic methods have been applied for the detection and evaluation of NIT in previous studies but there is no gold standard for tinnitus assessment, diagnosis and management [17, 22]. Understanding NIT mechanisms, features and outcomes is key to strengthening the capacity of hearing conservation programs and surveillance for healthy working life [21, 23]. Therefore, this review aimed to provide a global overview of occupational NIT and find out the role of behavioral and physiological assessments in NIT with a focus on its pathophysiology, diagnosis, and outcomes.

Methods

In this review, electronic research databases (PubMed, Scopus, Medline, Web of Science, and Google Scholar) were searched in line with PRISMA guidelines. The following keywords were used alone or in combination: "tinnitus", "noise-induced", "occupational", "questionnaire", "Noise Exposure", "behavioral" and "physiological" to search relevant articles. International research articles published in English between 2005 and 2022 were included consisting of adults (≥18 years) exposed to occupational noise. Review studies, case reports, non-English articles, abstracts, book chapters, animal studies and letters to the editor were excluded. After the initial search, 105 original articles were included. The identified articles were reviewed by all authors independently. Based on the initial title and abstract screening, 36 articles were retrieved for full-text review. Finally, according to the eligibility criteria, 21 articles with a total of 115022 participants were considered for review (Figure 1). The quality of each article was evaluated by two members of the research team.

Findings: noise-induced tinnitus epidemiology and psychoacoustic evaluations

Nine out of 26 articles (34.61%) were published during the last five years. The reviewed articles used a variety of study designs including prospective, retrospective, cohort, and cross-sectional designs. Studies mainly originated from Europe and America and were mostly cross-sectional. All reviewed articles included both sexes except two studies that focused on males [24, 25]. Details of studies on the prevalence of NIT and relevant clinical findings are documented in Table 1.

The prevalence of NIT ranged from 4% to 73.7% in the reviewed studies. The high prevalence of NIT in three studies [13, 27, 33] would be due to the differences in the study population, methodology and measures. NIT prevalence was reported as 3 times higher among occupational noise-exposed subjects compared with non-exposed ones (15% vs. 5%) [41]. NIT was mostly bilateral [24, 28, 30, 32-34, 39] with moderate severity [24, 32, 39]. A difference in dominant tinnitus pitch was observed between the reviewed studies [24, 27]. Although

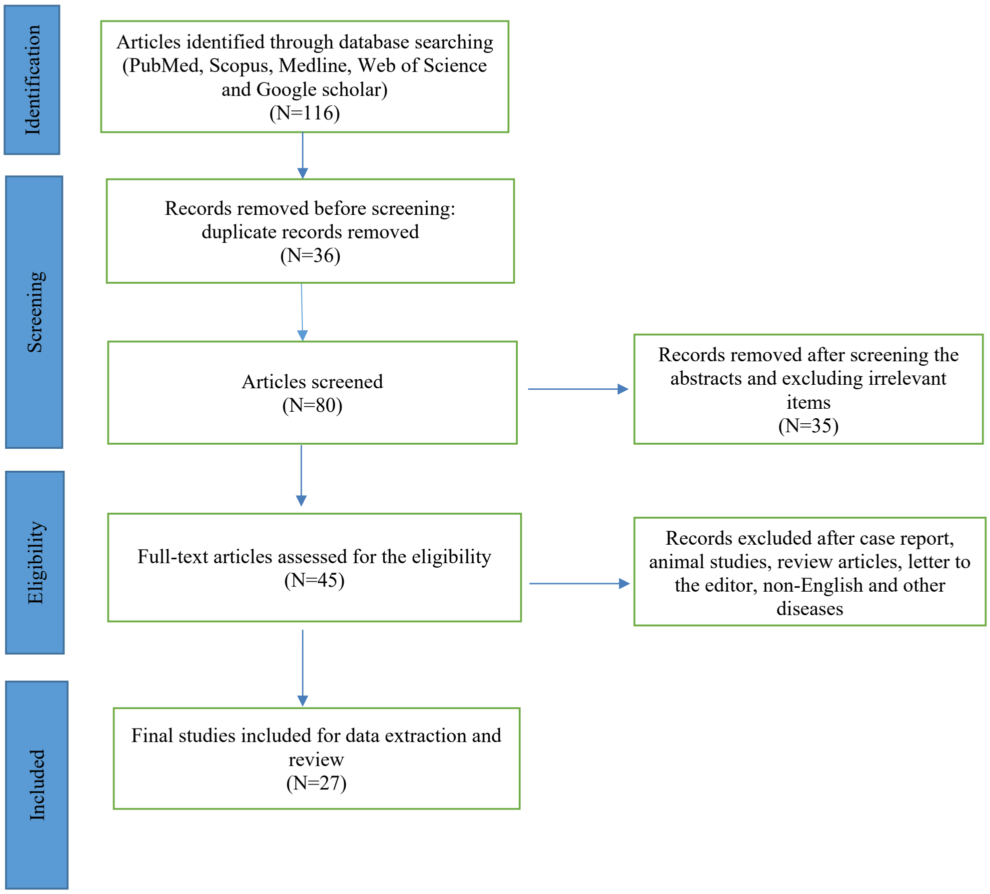

Figure 1. Flow diagram for the literature search in the study

subjects with noise-induced hearing loss who were exposed to more intense and prolonged noise experienced louder tinnitus [25], there were no significant differences in NIT prevalence and its characteristics between high-risk and low-risk occupations [7, 30]. Also, there was no association between tinnitus severity and work experience in noisy workplaces [24].

Application of questionnaires and behavioral methods in noise-induced tinnitus evaluations

Different assessment tools were used in studies to identify NIT, related mechanisms, and outcomes. Questionnaires, Tinnitus Handicap Inventory (THI), Auditory Brainstem Response (ABR), Otoacoustic Emissions (OAEs) and speech-in-noise tests were the most frequently used tools to investigate NIT. We considered self-report questionnaires, two tinnitus-related questions and hearing questionnaires as target questionnaires in this review. Hearing Questionnaires (Hearing Q1 and Q2) consist of questions about the occurrence of bothersome tinnitus and degree of annoyance respectively [23]. THI, a 25-item standard tool, is applied as a screening and brief diagnostic tool for grading the tinnitus severity [24]. Mild to moderate handicap was observed in NIT cases with the greatest impairment in the functional and emotional scale of THI [28, 39, 40]. Higher mean scores (more handicapped) were identified in THI and Hearing Handicap Inventory(HHI) in tinnitus subjects in high-risk occupations compared with low-risk ones [30].

Speech recognition in noise is a valid evaluation, which is sensitive to noise-induced injury and strongly correlated with Pure Tone Audiometry (PTA) thresholds. Although more hearing difficulties in recognition and understanding of speech in noise were reported in NIT sufferers in three out of four studies [6, 22, 28], an association was found between poorer SRT in noise and longer history of tinnitus in only one study [23]. Forward masking occurs when an auditory signal cannot be perceived due to the masker's presence. Only one study applied forward masking to investigate tinnitus in subjects with normal or near-normal hearing in which poorer results were correlated to louder matched tinnitus [17].

Table 1. Studies on prevalence, characteristics of noise-induced tinnitus and diagnostic tests findings among occupants

Authors (year)	Country	Subjects	Tests	Outcome	
				Prevalence	Key findings
Edwall [26] 2022	Sweden	NTG=(177) Occasional tinnitus (N=92) Constant tinnitus (N=136)	ABR test	--------	- Increased latency of wave in constant tinnitus compared with occasional tinnitus or NTG
Kang et al. (2021) [27]	Korea	N=730 TG (N=389) NTG (N=341)	Questionnaire, PTA, DPOAE, TEOAE, Tinnitogram, ABR test	53.3%	- Mostly MF and HF tinnitus pitch with no association between frequency of hearing loss and tinnitus pitch - Abnormal results in DPOAEs, TEOAEs - More prolonged latencies in the TG than NTG with no significant differences between groups
Lewkowski et al. (2021) [4]	Australia	N=4970	Tinnitus-related questions	26.5%	- Highest prevalence and likelihood of constant tinnitus in HR occupations
Asghari (2021) [7]	Iran	N=836 LR group (N=339) HR group (N=497)	Tinnitus questionnaire, PTA test	6.3%	- Mostly left-sided tinnitus and mild hearing loss in HR group compared with bilateral tinnitus and slight hearing loss in LR group.
Alazzam et al. (2020) [21]	Syria	N=111	Demographic questionnaire, PTA test	28.8%	- Higher prevalence of tinnitus than hearing loss
Couth et al. (2019) [6]	UK	N=22,936 Construction (N=9,249) Agriculture (N=2081) Music (N=395) Finance (N=11,211)	Self-report questionnaire, DIN-s test	17-29%	- Higher prevalence of tinnitus in the construction and music groups - Poorer SPIN scores in the construction and agricultural groups
Otoghile et al. (2018) [28]	Nigeria	N=420	THI questionnaire	9.8%	- Mostly bilateral slight tinnitus with higher THI and subscale scores
Bramhall et al. 2018 [29]	------------	TG (N=15) NTG (N=59)	ABR test SPIN	-------	- Reduced amplitude of ABR wave I which was strongly associated with report of tinnitus
Ralli et al. (2017) [30]	Italy	N=136 HR (N=68), LR (N=68)	Questionnaire, PTA test, THI, HHI questionnaires	-------	- Mostly bilateral tinnitus with longer duration in the left ear in HR occupations - Higher mean scores in THI and HHI in HR group with significant difference in mean score of HHI between groups
Boger et al. (2016) [13]	------	N=150	Demographic questionnaire, DPOAE test	66.6%	- Higher prevalence of bilateral tinnitus and OAE rejection with Significant relation between OAE failure and experiencing tinnitus
James and Banik (2016) [24]	------	N=42	Questionnaire, THI questionnaire, tinnitus match test	-------	- Mainly bilateral ringing tinnitus with moderate severity, low-frequency pitch and weekly occurrence - Moderate handicap in THI in most cases
Masterson et al. (2016) [12]	US	N=23393	self-reported questionnaire	8%	-Higher prevalence/ risk of tinnitus and concurrent hearing loss in HR occupations
Van Eynde et al. (2016) [22]	Leuven, Belgium	N=37	TQ, THI questionnaire, SRT and DTT test	-------	- Bilateral tinnitus with longer duration in most cases associated with poorer SRTs. - Mild score in TQ with no or only a mild handicap in THI in most cases
Cantley et al. (2015) [31]	------	N=8818	LF PTA, HF PTA, frequency specific HTLs test	16%	- A significant relation between tinnitus and frequency-specific HTL
Dos Santos Filha et al. (2015) [15]	Brazil	N=60 TG (N=30) NTG (N=30)	MLR test	-------	- Increased latency with more alterations in Na-Pa amplitude with no significant differences between groups

Authors (year)	Country	Subjects	Tests	Outcome	
				Prevalence	Key findings
Dos Santos Filha et al. (2015) [32]	Brazil	N=60 TG (N=30) NTG (N=30)	Demographic questionnaire, ABR test	-------	- Bilateral moderate tinnitus in TG with relation between tinnitus location and ABR alterations - Longer latencies in TG with no significant differences between groups.
Lindbald et al. (2014) [17]	Sweden	N=193	Demographic questionnaire, Bekesy Audiometry, TEOAE, DPOAE, forward masking, SPIN, tinnitus matching test	22%	- Significant louder tinnitus correlated with poorer results of forward masking - Poorer hearing thresholds in Bekesy audiometry and abnormalities in TEOAE, DPOAE and SPIN with no significant difference between groups
Soalheiro et al. (2012) [33]	Brazil	N=495 Environmental (N=130) Occupational (N=365)	SRI test, questionnaire	73.7%	- Mild tinnitus in majority of workers in both groups - Greater difficulty in SRI in workers with tinnitus
Lalaki et al. (2011) [34]	------	N=63 NIT and NIHL (N=28) NIT and normal hearing (N=35) Controls (N=30)	TEOAE with contralateral suppression test	-------	- Significant difference in mean amplitude suppression between NIT group and other groups
Engdahl et al. (2011) [23]	Norway	N=49948	Hearing questionnaire	12.1%	- Relative impact of occupation with adding hearing loss as a predictor - A moderate but significant relation between occupation and prevalence of bothersome tinnitus
Santos Filha et al [35] 2010	Brazil	TG (N=30) NTG (N=30)	ERP test (N100, P200, P300)	-------	- Increase in latency values with significant difference
Mohammadkhani et al. 2009 [36]	Iran	TG (N=30) NTG (N=30)	ABR test	--------	Increased latencies in NIT group
Muluk and Ogˇuztu¨rk (2008) [25]	------	N=31 TG (N=16) CG (N=15)	Questionnaire TLL, PTA test	--------	- Louder tinnitus and greater hearing loss in workers with high level and long-term noise exposure
Steinmetz et al. (2008) [37]	----	N=52	Questionnaire, PTA test THI questionnaire	22%	- Mostly bilateral moderate tinnitus in the form of hiss sound - A significant correlation between frequency of tinnitus occurrence and noise exposure level.
Rubak et al. (2008) [38]	-------	N=752	Questionnaire, PTA test	9%	- More hearing handicap in tinnitus cases - No association between tinnitus and current noise level, duration of noise exposure in normal hearing cases
Steinmetz et al. (2008) [39]	Brazil	N=52	PTA test, THI questionnaire	-------	- Significant correlation between tinnitus frequency and noise exposure level - Greatest effect of tinnitus on functional scale using THI.
Mrena et al. (2007) [40]	Finland	N=857	Hearing disability categories, tinnitus questionnaire	4%	- No hearing disability in majority of tinnitus patients - Higher proportion of unreported tinnitus using tinnitus questionnaire

NTG; non-tinnitus group, ABR; auditory brainstem response, TG; tinnitus group, PTA; pure tone audiometry, DPAOE; distortion-product otoacoustic emission, TEOAE; transient otoacoustic emission, MF; mid-frequency, HF; high-frequency, LR; low-risk, HR; high-risk, DIN-s; digits-in-noise shortened version, SPIN; speech perception in noise, THI; tinnitus handicap inventory, HHI; hearing handicap inventory, TQ; tinnitus questionnaire, SRT; speech recognition test, DTT; digit triplet test, LF; low-frequency, HTL; hearing threshold level, MLR; middle latency response, SRI; speech recognition index, NIT; noise-induced tinnitus, NIHL; noise-induced hearing loss, ERP; evoked response potentials, CG; control group, TLL; tinnitus loudness level

Measuring auditory status and its relationship with tinnitus were conducted with Bekesy audiometry and PTA test in 12 studies. No hearing disability was reported in a majority of tinnitus patients using the hearing disability category [35]. Elevation of hearing thresholds was observed in subjects with tinnitus, especially at high frequencies (mostly 4 and 6 KHz) [21, 27, 30, 38]. A study showed a 25% increased rate of impairment among workers with a history of tinnitus and high-frequency hearing loss by adjusting noise exposure and other impairment predictors [31].

Physiological and electrophysiological evaluations of noise-induced tinnitus

OAEs are byproducts of the active cochlear mechanics and reflect outer hair cells' activity. They are widely used in noise-related research due to its objectivity, simplicity and non-invasive nature [13, 27]. High rejection rate and abnormalities in amplitude and SNR were observed mainly at higher frequencies in Distortion-Product Otoacoustic Emissions (DPOAE) and at all frequencies in Transient Evoked Otoacoustic Emissions (TEOAE) in NIT cases as well as abnormal suppression in the majority of cases [13, 17, 27, 34].

Electrophysiological evaluations are non-invasive objective techniques investigating neural responses along peripheral and central auditory systems. ABR is one of these techniques routinely used in clinical practice for localizing lesions affecting auditory pathways and for recognizing noise-induced synaptopathy [20]. Most studies indicated increased latencies of ABR waves in tinnitus sufferers than in those without tinnitus. However, there was no significant difference between groups [26, 27, 32, 36]. Reduced amplitude of wave I was associated with tinnitus in Bramhall's study as well [29]. Only one study investigated middle latency response latencies and amplitudes which indicated increased latencies and more alterations in amplitude for Na-Pa in NIT subjects than in non-tinnitus subjects [15]. P300 –a late latency response –has been postulated as a potential biomarker for tinnitus at the cortical level [42]. Increased latencies in negative and positive potentials (N100, P200, P300) with a significant difference in the tinnitus group were found in a study [35].

Discussion

In this review, 21 articles investigating occupational NIT, its features, and assessment tools were reviewed. To the best of our knowledge, this is the first systematic review focusing on occupational NIT from the comprehensive perspective of assessment tools with a narrative synthesis of findings.

According to the articles, tinnitus prevalence ranged from 4% to 73.7% among noise-exposed subjects with higher prevalence rates in high-risk occupations. It proposes that workers with prolonged exposure to loud noises were more predisposed to NIT [21]. NIT was mostly bilateral, high-pitch with moderate severity. Variety in NIT prevalence may be related to inconsistency in NIT definition, different study populations and diagnostic criteria. Individuals with the complaint of weekly tinnitus were probably exposed to higher noise levels than those with monthly tinnitus complaints [39]. There were no standard criteria for classifying tinnitus manifestation in publications. "Intermittent"," frequent" and "constant" were terms frequently used for describing tinnitus, but neither well defined nor applied consistently [43].

Almost three-fourths of studies used questionnaires as reliable and valid tools to estimate the prevalence and severity of NIT. Questionnaires vary in terms of areas and details. Tinnitus severity, distress and handicap were assessed by TQ, THI and HHI. Mild to moderate handicap and a higher score was reported in TQ, THI and HHI in tinnitus cases respectively. These self-reported questionnaires are essential for quantifying tinnitus severity and measuring changes in tinnitus handicaps over time [22, 29]. By using the appropriate tinnitus questionnaire, health professionals are better able to monitor or manage tinnitus based on individuals' needs. We found no evidence to support using one questionnaire over another.

Obtaining a history, performing a physical examination and hearing evaluation are recommended for subjects with tinnitus by Tunkel et al., but imaging technologies are strongly not recommended. Hence, a hearing examination comprised of PTA. Hearing loss was more pronounced at high frequencies [6, 25, 27, 31, 37-39]. This high-frequency impairment may be attributed to noise spectrum distribution in workplaces. However, the presence of tinnitus in workers with normal hearing and the lack of association between the frequency of hearing loss and tinnitus pitch in some cases leads us to propose that medical history and conventional audiometry do not always suffice to explain tinnitus complaints [27]. No review was found focusing on comparing auditory diagnostic measures and outcomes in high-risk fields versus the clinical setting.

The higher prevalence of abnormal DPOAEs at high-frequencies may be related to the concurrence of tinnitus and hearing loss at these frequencies. Abnormalities at all frequencies in TEOAE suggest the involvement of outer hair cells' function in tinnitus generation. So, DPOAE is considered a sensitive and useful marker for preclinical hearing loss and also an important tool in tinnitus studies [2]. Furthermore, abnormal findings in TEOAE with suppression in NIT cases propose abnormal activity of the efferent system that modulates the function of the cochlear hair cell system [34]. This fact demonstrates the necessity for a better understanding of the auditory pathway's function.

Speech-in-noise perception in workers with tinnitus could possibly be explained by the effect of tinnitus as a central masker on the central auditory system in the presence of background noise [22]. Difficulty in speech perception is one of the main causes of tinnitus-related handicaps not necessarily attributable to impaired hearing [45]. Hence, speech-in-noise could be a valuable addition to the standard test protocol of NIT subjects [22]. Worse results in forward masking were associated with louder matched tinnitus. It is in concordance with an increased risk of tinnitus in case of neural degeneration near intact inner hair cells or increased gain at higher levels of the auditory tract following the loss of inner hair cells [17].

In physiological studies, none of the studies reported significant differences in latencies between tinnitus subjects and controls. Prolongation of latencies in tinnitus patients could be explained by sensorineural hearing loss or other less-known modulating factors such as cochlear synaptopathy or somatosensory tinnitus generators [32]. The decrease in amplitude wave I was hypothesized to be caused by hidden hearing loss, or cochlear synaptopathy, without showing up on audiology assessments such as PTA and OAEs. More alterations in amplitude and increased latencies of Na-Pa waves in NIT subjects are possibly hyperexcitability of thalamocortical tracts and associated regions in tinnitus perception [46]. It may be of interest to acquire ABRs in tinnitus patients with normal hearing to diagnose the association of latency alteration with hearing loss at frequencies above 8 KHz. We were not able to draw definitive conclusion in middle latency response mainly due to difference in experimental parameters, studied populations and also insufficient studies. In addition, these evoked potentials are greatly influenced by advanced mental capabilities such as cognition and attention. ABR and other cortical auditory evoked potentials might complement each other to identify the various changes on different levels of the auditory pathway in tinnitus patients with identical or different hearing conditions. This would allow us to further understand the changes that occur in tinnitus patients along auditory pathways

Conclusion

This review indicated that noise-induced tinnitus was mostly bilateral with moderate severity. In the lack of objective measures of tinnitus, self-report questionnaires –as simple, cost-effective, and valuable techniques – are the best choice for tinnitus assessment, management, and follow-up among workers. More complex assessments such as the speech-in-noise test would be a valuable extension to the standard hearing evaluation of Noise-Induced Tinnitus (NIT) subjects. Overall, the findings of behavioral and physiological studies have not been conclusive. Inconsistencies and discrepancies in the results of the reviewed studies may be attributed to the difference in sample size, study design and tinnitus definition. The objective diagnostic techniques for tinnitus are controversial. Thus, our recommendation is to conduct cross-sectional studies measuring middle latency responses, and late latency responses in sufficiently large and homogeneous samples to eliminate other influencing factors and find specific indicators. As a proposal for future auditory conservation programs and policies, it would be reasonable to take into account not only the assessment of hearing loss but also NIT to improve this population's health.

Ethical Considerations

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Authors' contributions

BK: Study design, interpretation of the relevant literature and drafting the manuscript; MA: Study design, interpretation of the relevant literature and drafting the manuscript; MH: Interpretation of the relevant literature and drafting the manuscript. All authors approved the final version of the manuscript.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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