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OCCUPATIONALLY-ACQUIRED NOISE-INDUCED HEARING LOSS: A SENSELESS WORKPLACE HAZARD

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Abstract
Objectives: Occupational noise-induced hearing loss (ONIHL) describes an acquired hearing deficiency directly attributable to excessive workplace noise exposure. Data suggest that excessive noise attributes to ~37% of all adult causes of hearing loss and remains a significant contributor to employment-related morbidity internationally. Typically insidiously-acquired, often without frank progressive symptomatology, regional medical agencies continue to struggle with this potentially debilitating condition. The aim of the study was to provide a synopsis of the current understanding of ONIHL, its impact on individual workers and the wider international community, and to identify barriers to more uniform adoption of personal hearing protection. **Materials and Methods:** A review of the contemporary literature was performed using defined keyword searches and OVID, PubMed, and Google Scholar as primary electronic search engines. **Results:** A number of published works were identified, describing aspects of the relationship between workplace-related noise exposure and subsequent development of employee hearing impairment, which demonstrate an overwhelming gender imbalance, with up to 97% of affected individuals being male. Industry-specific associations (e.g., mining, manufacturing and heavy construction) were well documented, as were links to toxin-specific exposures, in the recognized development of hearing loss. However, evidence of integration of appraisal of the topically-current area of genetic susceptibility was often lacking. Much discordance still exists among international agencies in the prescriptive regulation and enforcement of "safe" exposure limits. **Conclusions:** Despite a high level of public awareness regarding the importance of hearing preservation and increasingly stringent international occupational health, safety and welfare requirements mandating provision of safer work environments, ONIHL continues to be a significant occupational hazard. ONIHL is permanent and may cause significant disability, for which there currently exists no cure, but is largely overtly-preventable. The impact of ONIHL on the global transition toward dominant communication-rich white-collar employment roles is difficult to quantitate, but is likely to be substantive upon the afflicted individual. In the mainstream setting, exposure-avoidance strategies aimed to reduce the incidence of ONIHL remain the focus of public health and occupational medicine approaches.

Key words:
Noise-induced hearing loss, Work-related noise exposure, Occupational hazards

INTRODUCTION

The impact of hearing loss worldwide is manifestly under-appreciated [1], with studies suggesting that one in six adults are afflicted with some degree of physiologic hearing impairment [2]. Recent publications have postulated that excessive noise exposure (ENE) attributes to ~37% of all causes of hearing loss [2,3]. Despite enhanced awareness of the hearing impact of ENE [4–6], and the increasingly-stringent focus on occupational health, safety, and welfare (OHSW), occupational noise-induced hearing loss (ONIHL) remains a significant source of potentially-avoidable morbidity [7–9]. Occupationally-acquired noise-induced hearing loss is a sub-categorization of acquired hearing impairment whereby workplace ENE can be rationally attributed to a quantifiably-reduced hearing capacity [10]. The pathogenesis of ONIHL involves the in-

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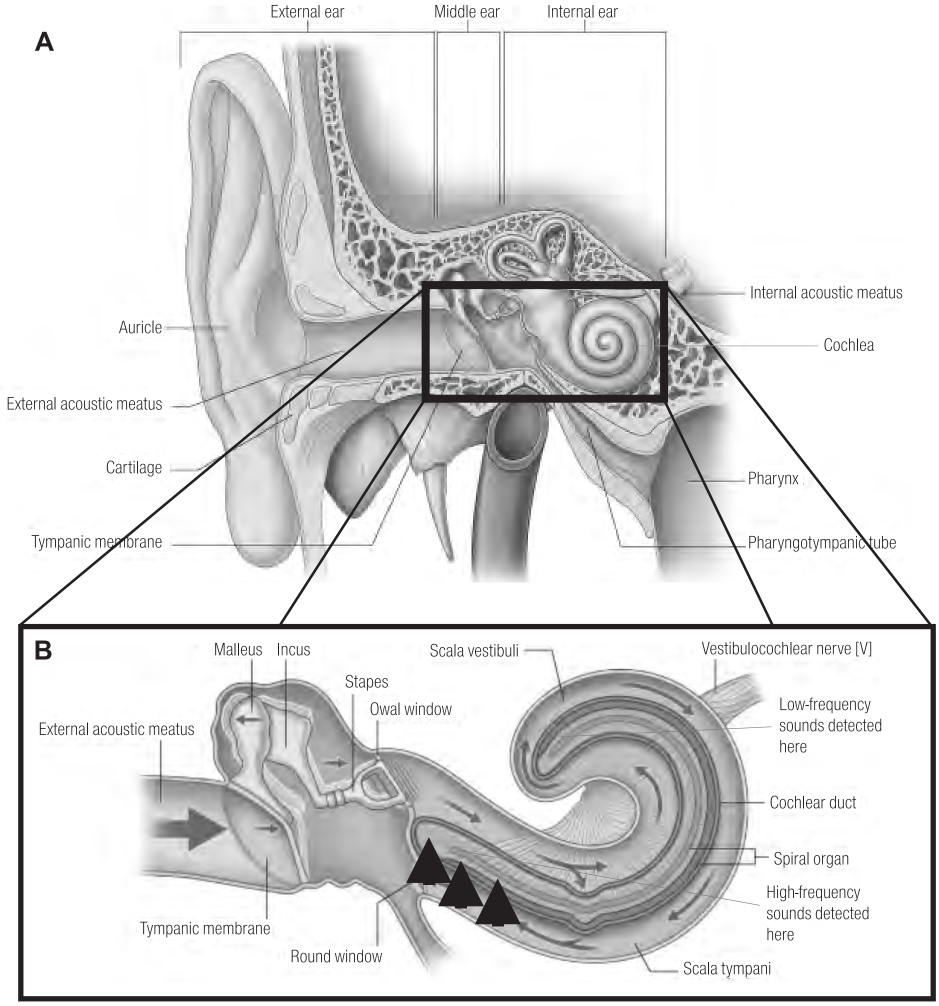

Fig. 1. (A) The ear. (B) Showing regions of the cochlear most frequently damaged by prolonged excessive noise exposure and associated with ONIHL (large arrowheads). Adapted from [15].

duction of a progressive, sensorineural, hearing deficit [2], resulting from irreversible damage to sensory hair cells of the cochlea within the inner ear [9,11–14] (the regions of the cochlear system most frequently affected by ENE are demonstrated schematically in Fig. 1).

Stereotypically, ONIHL is unmasked by a decline in communicative capacity (often recognized by close social/family contacts) facilitating Family Practitioner/GP consultation followed by an audiological referral for definitive hearing assessment. Clinically, affected individuals show a deteriorating appreciation for sounds within the high frequency tones [9], typically noted as a "threshold dip"/"hearing notch" between 4000–6000 Hz on pure-tone audiometry testing (Fig. 2). Given the correlation between the affected frequency range and specific (high-frequency) tones of the speech spectrum (Fig. 2), impaired individuals often show reduced capacity to understand and discriminate speech, a problem that may be further compounded by ambient background noise (e.g., in the work setting). Interestingly, despite the almost universally-accepted diagnostic convention of the "hearing notch", a recent study from the U.S. suggested that fewer than 38% of individuals with diagnosed ONIHL actually demonstrated this characteristic (pseudo-pathognomic) feature [17]. The limited study cohort size may, however, undermine generalizability.

Limited treatment options are currently available for ONIHL, the condition being largely managed *ex facto* using hearing aids or other sound-amplification devices. However, despite significant and ongoing advances in hearing aid technology, even state-of-the-art devices can-

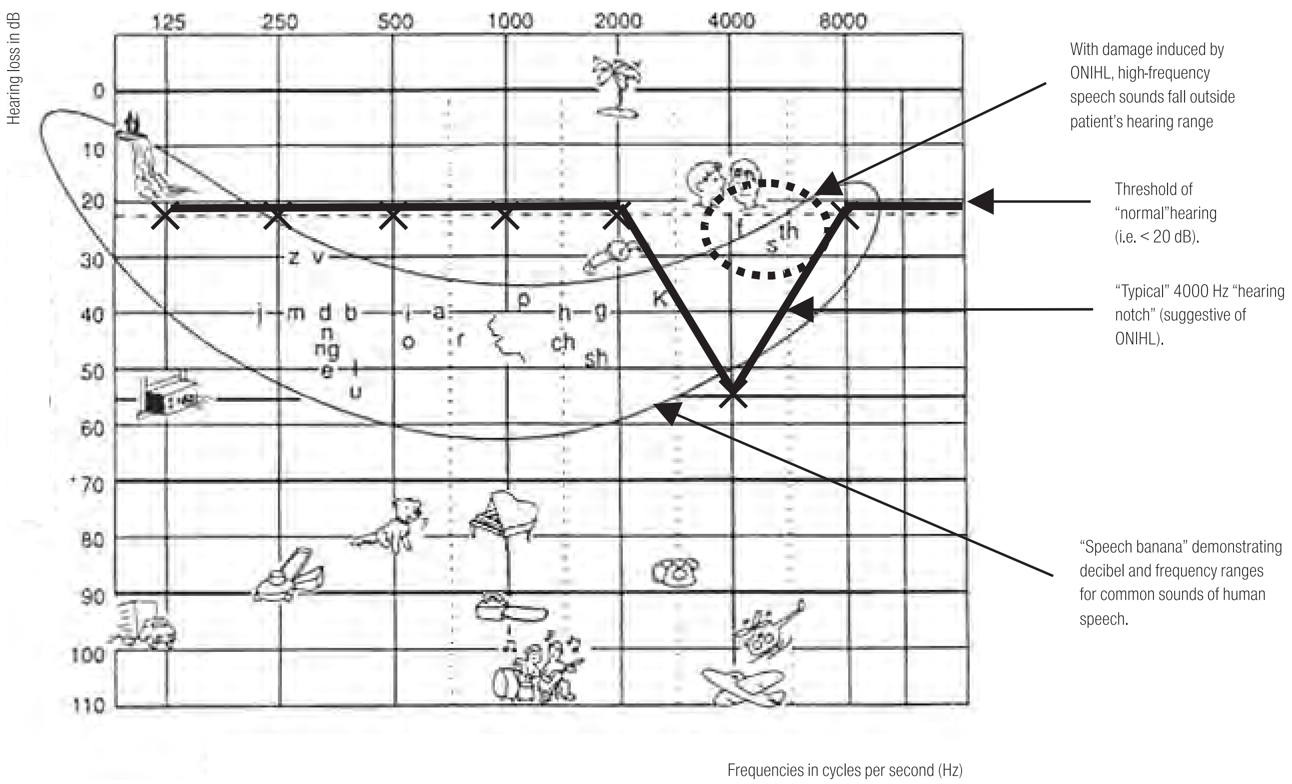

Fig. 2. Standard audiogram with "speech banana" overlay demonstrating a "typical" occupationally-acquired noise-induced hearing loss (ONIHL) pattern at 4000 Hz. Adapted from [16].

not produce the same level of hearing precision afforded naturally by the human ear. This considered, preventing noise exposure and reducing ENE remain the mainstay of hearing protection management.

MATERIALS AND METHODS

Electronic database and real-time online literature searches were performed, primarily using the OVID, PubMed, and Google Scholar search engines. Author-defined keyword searches were performed using Boolean descriptive tools (e.g., "noise-induced" AND "occupation*" AND "hearing loss"), with initial searches limited to materials available with complete abstracts (to govern suitability for full-text retrieval) and those available in the English language. Searches were not actively limited by the date of original publication, but papers were excluded whereby reasonable access to full text could not be achieved. Additionally, where relevant, references to key web-based sources were sought for inclusion to both reinforce specific citations (largely demonstrating contemporary descriptive statistic data) and to provide contemporary and easy-to-access points-of-reference to which clinicians may find some value in directing patients who may wish to seek additional understanding of a topic area relevant to their own health. While the authors acknowledge that the current work may not make direct reference to a number of influential publications within the larger field, by the nature of the constraints of publication limitations and subjective author selection, we have, however, attempted to incorporate those citations we deemed most relevant to the intended contemporary nature of our review and trust readers seeking a deeper level of appreciation will be able to use our truncated reference list as a solid starting point for further inquisition.

RESULTS

Employment and ONIHL

Although many vocations may forseeably expose an individual to hazardous noise levels significant enough to damage the auditory system (Table 1), epidemiological research has demonstrated that certain careers show

Table 1. Common sound sources and approximate corresponding decibel exposure levels, correlated with likely qualitative assessment perceived by an exposed individual and estimated time to induction of hearing damage

Common sounds	Noise level (dB)	Qualitative assessment of sound	Exposure time to hearing damage
Heavy weapons, cannon (10 m) (max. level), rocket launching pad (no ear protection)	180	Irreversible hearing loss	Single exposure
Small firearm (50 cm) (max. level)	175		
Slap on the ear, fire cracker exploding on shoulder	170		
Toy pistol fired close to ear (max. level)	165		
Hammer stroke on brass tubing/steel plate (1m) (max. level)	160		
	155		
Hammer stroke in a blacksmith (5 m)	150		
	145		
Aircraft carrier deck during jet takeoff, air raid siren	140	Painfully loud	
	135		
Thunderclap, loud hand clapping (1 m) (max. level)	130		
	125		
Jet takeoff (60 m), car horn (1 m), whistle (1 m)	120	Maximum vocal effort	
Starting noise of planes (10 m)	115		1 min
Pile driver, siren (10 m), frequent sound level in a nightclub, violin close to the ear of an orchestra musician (max. level), close to rock concert loudspeakers	110	Extremely loud	5 min
Chain saw (1 m), banging car door (1 m) (max. level), racing car (40 m), possible level with music head phones	105		10 min
Frequent level with music via head phones, jack hammer (10 m), garbage truck, firecrackers	100	Very loud	30 min
Loud crying, hand circular saw (1 m)	95		1 h
Heavy truck (15 m), city traffic, angle grinder (1 m)	90	Very annoying	2 h
Motor chain saw (10 m), loud WC flush (1 m)	85		8 h
Hair dryer, very loud traffic noise of passing by lorries (7.5 m), high traffic of an expressway (25 m), alarm clock (1 m),	80	Annoying	
Passing car (7.5 m)	75		
Noisy restaurant, freeway traffic, low hair dryer (1 m)	70	Makes telephone use difficult	
Business office, close to a main road by day	65		
Air conditioner, conversational speech, noisy lawn mower (10 m)	60	Intrusive	
Low volume of radio or TV (1 m), noisy vacuum cleaner (10 m)	55		
Light auto traffic (30 m)	50	Quiet	
Normal live noise, talking, or radio in the background	45		
Quiet office	40		
Room fan at low speed (1 m)	35		
Library, soft whisper (5 m)	30	Very quiet	
Breathing noise (1 m)	25		
Broadcasting studio	20		
	15		
	10	Just audible	
	5		
	0	Auditory threshold	

Adapted from [22].

a higher-than-baseline predilection (Table 2). Given the historical gender-typing of specific employment roles (i.e., construction/heavy manufacturing), the majority of patients presenting with ONIHL in the contemporary setting are male [14,18,19] (European research has suggested that up to 94–97% of sufferers were men [14,20]). However, with increasing female penetration into traditionally male-dominated fields-of-work, this balance may redress in the future. While increasing mechanization ensures that contemporary workers are often less likely to endure ongoing levels of ENE (many roles previously incumbent with such hazards have been made redundant by the evolution of mechanization) [18,21], the negative impact of hearing loss on workers is now greater-than-ever as workforces move away from blue-collar industries into communication-rich white-collar roles [2].

While an anticipated degree of variability exists internationally with regard to regional noise-exposure standards, specific regulatory values have now been incorporated into most national and state workplace safety guidelines. As an example, in the United States, the formal Washington Industrial Safety and Health Act (WISHA) defines the maximum "permissible" exposure limit as being "an eight-hour, full-shift average exposure of 85 dB [decibels]" [44], a sentiment largely reflected by the legislature of the majority of Northern America and most other first world countries [9,10,14,45]. Despite this, many developing, and often "industrializing", countries still widely accept a higher permissible safe sustained exposure threshold of up to 90 dB [9,46,47]. A 2003 directive of the European Parliament and the Council of the European Union, provisioned for amendment to regulatory conditions within member states to take effect in February of 2006, further reduced the "lower [acceptable] exposure action values" in this region to 80 dB(A) [48]. This provision was widely championed among audiological and occupational medicine domains to reflect a higher level of awareness of the recognized causal relationship between sustained occupational noise exposure and the development of hearing impairment, in light of a considerable body of scientific evidence, and as a strong international endorsement of the need to actively protect employees. Given the recent passing of the sanctioned implementation deadline, data are not yet available to attest the clinical impact of this legislative change on the prevalence of work-related hearing loss.

In satisfying such definitions, noise exposure is usually "measured at the employee's ear position, without taking into account any protection" [45] and sustained levels ≥ 85 dB are considered to pose an "unacceptable risk to hearing" [45,49]. In interpreting these definitions, it becomes apparent that, in addition to employee obligations under general OHSW stipulations requiring the use of provided safety equipment, employers internationally are now (legally) obliged to create and maintain environments whereby noise emissions do not exceed acceptable standards [44]. Despite such guidelines, workers internationally continue to demonstrate suboptimal hearing protection practices [28,50,51]. In a U.S. study of trades people working in high-noise environments, 98% indicated that they were "supposed to wear protection", but actual/reported use was only marginally above 50% [52]. Similar studies internationally have shown that proper and diligent use of adequate personal hearing protective equipment (PHPE) is indeed rare [28,32,38,44]. Various theories have been proposed to account for this discrepancy, although the true reasoning is likely to differ between both individuals and common employment roles.

Table 2. Professions associated with an increased exposure to occupationally-acquired noise-induced hearing loss

Profession
Mining [9,21,23,24]
Armed forces [20,23,25,26]
Manufacturing [9,23,27–29]
Construction work [9,14,30,31]
Farming [32–36]
Pilots and flight mechanics [37]
Engineering and laboring [20]
Night club work [38]
Woodwork machinery [8,20]
The music industry [39,40]
Road side work (e.g., vehicle traffic co-ordination) [41]
Dockyard workers [42]
Police dog handling [43]

In an earlier investigation exploring why employees fail to use provided PHPE appropriately, Lusk and Kelemen [52] concluded that "perceived benefit and self-efficacy of use" correlated strongly with compliance. Other factors cited as influencing PHPE use include the conditions/environment, in which use is required, interference with other protective equipment (i.e., prioritizing safety equipment based on perceived benefit), levels of training in correct use, and the level of physical restriction imposed by PHPE on employment function (e.g., overly cumbersome or limits use of other essential equipment) [51,53].

Collectively, these findings point to a role for interventional/educational approaches to increase awareness and highlight the importance of correct PHPE use [8,44,49,50]. Current standards recommend "good education, ear protection and information about how to preserve hearing and how to avoid noise-induced hearing loss (NIHL) when working in noisy environments should be readily available and provided as the norm in industry" [2]. Despite this, in the absence of local regulating/enforcing bodies, the true level of compliance remains difficult to ascertain [8,51].

Financial costs of ONIHL

The true cost of ONIHL in the USA and most parts of Europe is difficult to estimate due to differing international classification and recording protocols, and fragmentation of local health funding derivation and services [2,8]. Australian data from 2005 suggest the burden associated with hearing loss (of all causes) in that setting alone exceeded AUS$ 11.7 billion. This equated to ~1.4% of that country's gross domestic product [2], representing a significant burden on health/social services [10,45]. How directly such statistics can be extrapolated to Northern American and European environments remains unclear, although the burden of impairment is likely to be great.

While there is evidence to suggest that successful ONIHL-related workers compensation claims have steadily declined (suggesting, perhaps, the positive impact of hearing protection initiatives [2]), such statistics alone may be misleading. For example, in the 1990s, the "low fence" point for eligibility for ONIHL compensation was raised in many jurisdictions from 5% to 10% [54] (i.e., employees must demonstrate a decline in hearing function of ≥ 10%, attributable to occupational ENE, to be eligible for compensation). The impact of this on claim profiles is difficult to ascertain. Similarly, definitive data demonstrating the true impact of legislative changes and the effectiveness of community awareness campaigns on reducing workplace-related hearing damage are not readily available.

Confounding considerations

Given the timeframe across which work-related hearing damage takes place (often many years at low-end intensity [14]), and the ensuing lag until symptomatic presentation (often decades), the role of confounding environmental exposures on ONIHL development has been difficult to determine. Indeed, high-yield prospective investigations do not exist, and would likely be prohibitively expensive and fundamentally near impossible to perform. Clinically, diagnosis of ONIHL is complicated by the potential for concurrent and retrospective compounding/contributory non-work-related (recreational) noise exposures [55,56], lifestyle considerations (e.g., smoking, ototoxic drugs/medications [57,58]), chemical exposures [59,60], previous surgery, infection or illness, prolonged exposure to part- or whole-body acoustic vibration [61–65], and genetic factors [66,67]. Not surprisingly, cigarette smoking has been strongly-associated with an increased frequency of hearing loss [12,13,68,69], acting synergistically with occupational ENE to accelerate both the severity and rate-of-acquisition of impairment [68,70]. The reality that high noise-exposure industries (e.g., manufacturing/construction) remain currently independently associated with high employee smoking rates complicates functional causality interpretations. Additionally, European and American-based investigations have suggested a link between workplace organic solvent exposure and fuel compounds (even at low levels) and ENE, with accelerated hearing loss [42,59,71–74], although substance-specific reproduction of these findings is limited. Finally, research into the role of genetic predisposition in hearing loss development has already demonstrated that individual animals and humans show differing susceptibility to noise damage, even under "very carefully controlled" exposure conditions [49,66].

It has been postulated that this may reflect "unknown" genetic elements [29], the description of which falls beyond the scope of the current review. This considered, the role of genetic variability in hearing loss development, and the interaction of biological factors with environmental stimuli (including occupational noise exposure), remains unclear and requires further investigation [49,67].

Functional impact of ONIHL

Of the primary senses, hearing forms the foundation for direct inter-human communication in most conventional settings [2]. Noise-induced hearing loss substantially affects an individual's capacity to interact, work, and function effectively in an increasingly communication-intense society, on top of other difficult-to-quantify influences on quality-of-life [2]. Thus, the impact of ONIHL on workers stems far beyond the workplace itself [75]. Although the mean age of diagnosis of ONIHL is 50–59 years [9,20], it is likely that individuals diagnosed at this stage-of-life have endured subtle degrees of hearing-impairment-related interference with activities-of-life for several years beforehand.

In non-work-related settings, ONIHL has been shown to impact widely [7,18], inducing persistent communication difficulties [9,14], impairment of interpersonal relationships, social isolation [9], and a "very real degradation in quality-of-life" [45]. Compounding the problem, ≥ 20% of NIHL patients also have tinnitus [45,75,76], bringing another set of challenging complaints [19,75]. On "general life impact", mild hearing loss has been compared in severity to mild asthma; moderate hearing loss to chronic pain from a slipped vertebral disc; and severe hearing loss to ongoing pneumonia [2]. The significance of this condition on an individual's health and well-being cannot be overstated.

One of the difficulties facing health authorities seeking to reduce the incidence/impact of ONIHL continues to be its insidiously progressive nature, linked with the extended lag period between exposure and symptom manifestation [2,20]. Acute damage contributing to ONIHL development is most often painless, but permanent [8], and without cure in the contemporary setting [10,11,13,45]. While ongoing development of hearing aid technologies continues to push rehabilitative boundaries, and provide some degree of active "sound recovery" (largely through directional field amplification), they cannot restore normal hearing [11]. Thus, prevention remains far better than available rehabilitative options.

CONCLUSION

Despite public awareness regarding the importance of hearing preservation, and increasingly stringent OHSW requirements mandating provision of safer work environments, ONIHL continues to be a significant international occupational hazard. ONIHL may lead to the development of significant personal disability, impinging upon both employment and social roles for the individual, for which there currently exists no cure. The lack of consolidated approaches facilitating ONIHL awareness and education urgently needs correction. Given the current state-of-understanding, further research is warranted to facilitate the prevention of hearing loss, exploration of individual, regional and industry-specific barriers to PHPE use, and investigation of bio-molecular and genetic factors which may influence both functional and pathologic hearing loss associated with ENE.

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