Noise Induced Hearing Loss estimation and sound pressure limits' main issues: A systematic review

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Summary
The aim of this article was to analyse the actual issues about the sound level limits that cause Noise Induced Hearing Loss (NIHL). A systematic review directed to the search in the electronic databases: SCOPUS®, WEB OF SCIENCE® and PUBMED® was done. The obtained results lead to some crucial aspects when NIHL is assessed. These shortages are related to assumptions that must be taken in account: contribution of non-occupational noise, impulsive noise, susceptibility to noise and use of hearing protection. Non-occupational noise, in some circumstances, can have a significant contribution for NIHL. The impulsive noise, which can also be found in non-occupational noise, has a particular contribute to NIHL and it is basically neglected. Individual susceptibility can also be an important factor. On the other hand, the audiometry and the use of hearing protection can contribute to a large bias. The current limit levels don´t contemplate the integration of all these variables.

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1. Introduction

Nowadays the communication ability of a person is perhaps the most valued talent as communication is highly necessary for our Society. Communication is essential to interact with Society, to learn, to teach, to make relationships and to maintain them, to education, to up-date oneself, to entertainment and to understand the world, and one of the main channels is the sound.

The auditory system is responsible for transforming sound to something capable to be understandable for our brain. However, as a person becomes older, the auditory system will show the cumulative damage caused by a high level unpleasant sound or noise, especially in susceptible persons. This will impair the quality of life and in fact, someone who has no job and suffers from poor communication skills, will have more difficulties to be employed.

Noise is one of the most occupational assessed risk and the main external factor for hearing loss. Based upon the current understanding of the causes of Noise Hearing Loss (NIHL), it would not have been expected to find significant hearing losses in humans before the age of metals, except for those associated with diseases and aging (presbycusis). Nevertheless there are ancient reports of this problem. It was with the Industrial Revolution that new sounds of high intensity were introduced in a greater scale than ever before. This problem has induced governments to take measures to control exposure levels [1].

The possible adverse effects of excessive noise exposure on hearing have been well-established [2] [3]. To prevent occupational noise-induced hearing loss, collective measures can be taken to reduce the overall noise level at the work layout [4]. Hearing protection is only used when these interventions are

insufficient or unfeasible. Noise can be controlled by blocking the noise at the source, along its path from the source to the receiver, and at the end receiver [5].
Although it is widely recognised that implementing collective measures, such as engineering and/or administrative controls, is the most efficient way to minimise the risk of hearing loss, hearing protection devices (HPDs) are still widely adopted in noisy workplaces. The popularity is most likely related to its ease and low-cost implementation, especially compared to the complexity and the high cost associated with implementing technical and organisational noise reduction measures [6].
Noise is intrinsic to work activity, but its problems are particular marked in the industry. The hearing loss due to occupational noise exposure is the most prevalent industrial disease [7].
The European Directive 2003/10/EC, of 6 February 2003, states that hearing protection should be available when noise exposure over an 8h working day (L_{EX}, 8h) equals or exceeds 80 dB (A), and for L_{EX},8h from 85 dB (A) its use is compulsory. Despite these regulations, occupational hearing loss persists [8].
The international standard ISO 1999 Acoustics — Estimation of Noise Induced Hearing Loss (NIHL) presents a methodology to estimate the relationship between noise exposure and "noise-induced permanent threshold shift" (NIPTS) considering age, gender and exposure to noise (LAeq and years of exposure) at frequencies between 500 Hz and 6000 Hz. The model assumes that hearing threshold level (HTL) of an occupationally noise-exposed population is a combination of hearing threshold level associated with age, according to ISO 7029, and noise-induced permanent threshold shift (NIPTS). It can be applied to the calculation of the risk of hearing loss due to occupational noise exposure. It uses a data base of three populations, Norway, Sweden and United States to define correlations between hearing disability and hearing factors, being therefore only applicable in populations with the same characteristics. Nevertheless, Noise Induced Hearing Loss isn't only the result of occupational noise exposure but also of the total noise exposure of the population. It may be important to take in account the non-occupational exposure of individuals (at home and during recreational activities). Only if this non-occupational exposure is negligible compared with the occupational exposure, is this estimation allowed. Otherwise, it should be used to calculate the hearing loss to be expected from the combined (occupational plus non-occupational) total daily noise exposure.
One of the other limitations is that the ISO 1999 standard undertakes the concept of equal acoustic energy assuming the value of 85 dB (A) for 8 hours a day and in some cases this concept may be not valid when impulsive noise is considered. As a matter of fact, most important strong impulses are practically ignored by ISO1999 [9]
In the end, the individual susceptibility can depend on the interaction of intrinsic and environmental factors.[10]
This systematic review starts to question the basis of the occupational noise safety, the exposure limits values, as the key to preventive programs and also the approach of ISO 1999 standard. Are this values the safety barrier to ensure hearing protection? What are the main concerns? The Hearing Conservation Programs (HCP) are mainly based on that issues.

2. Methods

This systematic review was conducted in the electronic databases: SCOPUS®, WEB OF SCIENCE® and PUBMED® and presents the most important articles related to the theme. The searching terms were the same in all the used resources: "Any word= ("occupational noise") AND Any word= ("hearing threshold")" and "Any word= ("occupational noise") AND Any word= ("hearing impairment")". The number of articles found in the used databases was consistent with expectations. Only the articles that complied with the eligibility criteria were used in this review.
The identified articles were screened by date, titles and abstracts of all retrieved references. The search was limited to articles, written in English, since 2004 to present. Electronic copies of articles were also identified. The articles retrieved for this review of the electronic databases were complied with the following inclusion criterion: relationship between sound levels and hearing loss.
To allow a direct comparison of the data across the studies reported in the retrieved articles, the data extraction was conducted according to the following criteria: authors, year of publication, objectives, methodology, results and conclusions.

3. Results

From the article selection process, 2342 articles were found. After eliminating the duplicate articles (n=610), published before 2004 (n=656) and revision articles (n=18), 1731 articles were screened. The abstract articles were then read and the articles that did not meet the inclusion criteria were excluded. Thus, 22 full articles were assessed for eligibility and 11 studies were included in this systematic review (Figure 1).

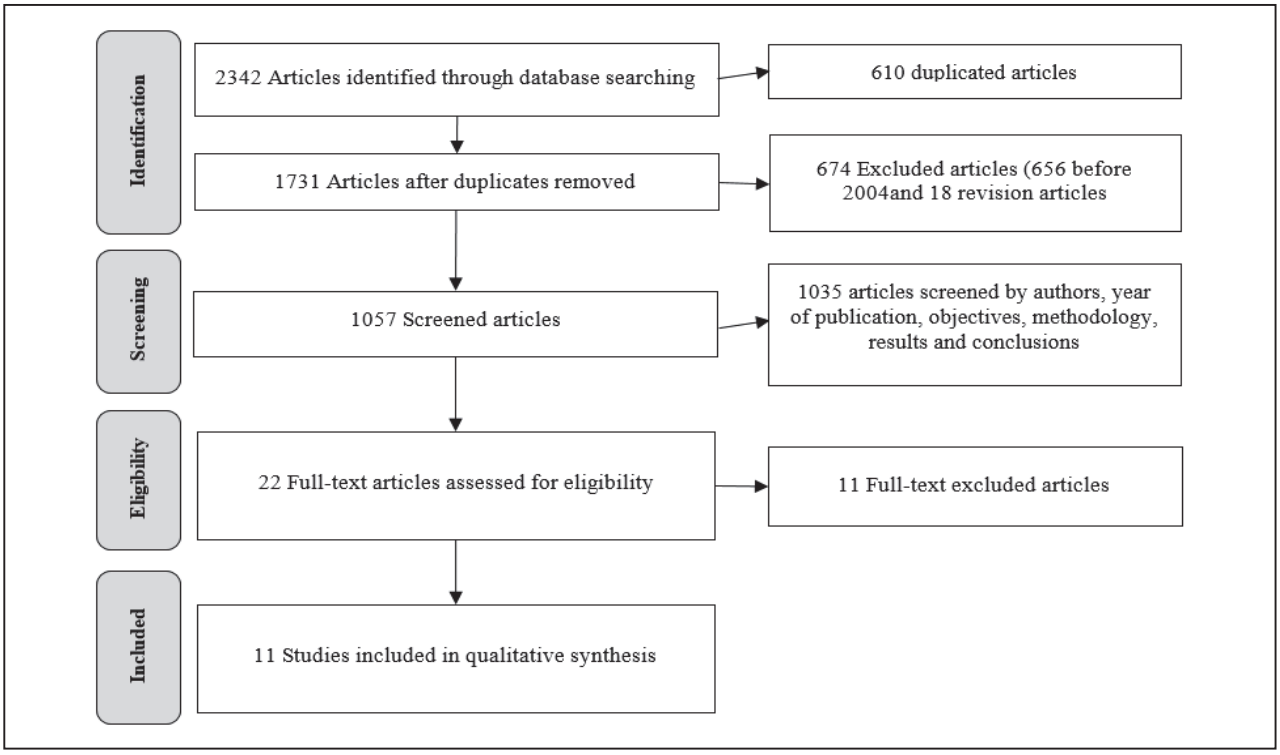

Figure 1. Flow of studies through the review, based on PRISMA

4. Discussion

The main objective of any Hearing Conservation Program (HCP) must be the prevention or, at least the limitation of NIHL. After that, the other objectives are the reduction of employees' stress and absenteeism, the reduction of workplace accidents as well as workplace quality. The current regulatory levels for occupational noise exposure (European Directive 2003/10/EC and ISO 1999) were based on cross-sectional studies performed a few years ago and before the implementation of hearing conservation programs.

When analysing these studies it could be find some shortcomings like variable use of hearing protection by study subjects, fairly crude assessment of ambient noise exposure levels, and limitations of hearing assessed at only one point in time. They had limited or even no data to address the effects of noise exposures below 85 dB (A) [11].

There are two independent harmful mechanisms that lead to NIHL: chronic degeneration due to long-term high noise-levels and acute acoustic trauma due to powerful impulses close to the ear. [12]

The relationship between noise exposure and "noise-induced permanent threshold shift" (NIPTS) can be expressed in the relative standardised scale based on the ISO 1999 standard that allows to compare hearing status of subjects of different age and noise exposure [13] but some results lead to data indicating that hearing loss at low noise exposure levels are much greater than predicted and by the other side at high levels hearing loss is lower than predicted. [14]. Also the interpolation described in the ISO model, that predicts hearing loss developed during the first 10 years of exposure, is not consistent with data and seems to be inapplicable as referred by Leensen, (2011). One reason may be the hypothesis of pre-existing hearing loss from non-occupational noise exposure. [14]. Occupational exposure limits are based on damage criteria that assume non-occupational time is spent at noise levels which allow the ear to recover. [15].

In the old studies the non-occupational effects were not considered and its contribution could have more influence the lower was the $L_{EX,\ 8h}$. Exposure to non-occupational noise should be assessed for example through individual responses on an annual

hearing questionnaire [9]. This kind of information should be contained in the databases. Pyykkö et al., 2007, include four separate entities in their study that most contribute for non-occupational noise: music noise, shooting noise, military noise and power tool noise. But toys, fire-crackers, pistols, celebrations, are a source of non-occupational noise and consequent ear damage as well. Some of this noise has characteristics off impulsiveness, and one single event is enough to provoke damage. Rarely occurring, impulses cause much more damage than continuous noise. [12]. The peak level of the impulse may be the critical factor in the development of hearing loss [16]. Even exposures lower than permissible levels may lead to acoustic trauma [17].

Rabinowitz et al. (2007) found that workers with higher ambient noise exposure experience had less hearing loss than co-workers in less noisy areas. The presented explanation could be related to the differential use of hearing protections, The majority of workers who developed standard threshold shifts in hearing had average noise exposures of 85 dB(A) or less. This indicates that more could be done to prevent hearing loss in moderately noisy jobs. Hearing protection may have its greatest effect at high ambient noise levels. Workers exposed to higher noise intensities are obliged to wear hearing protection and are more bothered by ambient noise, making them more consistent in wearing their protection [9].

Even though, contribution of non-occupational noise could have less weight, as mentioned by Neitzel et al., 2004, that nearly 80% of the cohort examined in his studies would be at low risk of hearing loss resulting from non-occupational exposure it shouldn't be neglected. [15]

The risk of hearing loss depends on several factors: work noise and its characteristics, lei-sure noise and its characteristics, exposure to ototoxic agents and individual susceptibility and the use of hearing protection devices [10]. All these factors potentiate the risk, so interactions between them are important to better understand its effects and to develop hearing prevention programs.

5. Conclusion

Exposure to noise tends to vary and workers are often exposed to different tasks with different noise levels, in their work and out of work. An integrated approach is needed to combine the different levels into a single number that is related to risk of hearing impairment. The present limit levels do not contemplate the integration of all this variables.

The auditory damage caused by noise, NIHL, depends on exposure type: sound level, duration, type of noise, and frequency, as well as personal factors like susceptibility to noise, age, smoking, prior history of hearing/ear damage [17]. The approach to evaluate and prevent this should be multidisciplinary task, covering all aspects related to noise and noise effects and their combined interactions. Actually, these interactions, impulsiveness of noise, genetic susceptibility, ototoxic chemicals and leisure noise cannot be modelled [11].

The HCP`s should take in consideration non-occupational noise exposure, medical history and details of hearing protector usage, audiometric measurements at much more frequencies than those declared important in ISO 1999 and particularly for higher frequencies extensive information on job history, serial audiometry with a baseline measurement at job, pattern recognition. The knowledge about the exposure pattern may facilitate the introduction of counter-measures against work noise, environmental and behavioural factors (smoking, and socioeconomic status). To further reduce rates of occupational hearing loss, more attention needs to be directed towards prevention in workers in jobs with noise exposures lower than 85 dB (A)

References

[1]. Thurston FE. The worker's ear: a history of noise-induced hearing loss. American journal of industrial medicine. 2013;56(3):367-77.

[2]. Sliwinska-Kowalska M, Kotylo P. Evaluation of individuals with know or suspected noise damage to hearing. Audiological Medicine. 2007;5(54-65).

[3]. Nandi SS, Dhatrak SV. Occupational noise-induced hearing loss in India. Indiam Journal of Occupational and Environmental Medicine. 2008;12:53.

[4]. Bies DA, Hansen CH. Engineering noise control. 3rd ed. London: Spon Press; 2003.

[5]. Hsu Y-L, Huang C-C, Yo C-Y, Chen C-J, Lien C-M. Comfort evaluation of hearing protection. International Journal of Industrial Ergonomics. 2004;33(6):543-51.

[6]. Arezes PM, Miguel AS. Assessing the use of hearing protection in industrial settings: A comparison between methods. International Journal of Industrial Ergonomics. 2013;43(6):518-25.

[7]. Sataloff J, Sataloff RT. Occupational hearing loss. 4th ed. New York: Taylor and Francis; 2005.

[8]. Mrena R, Ylikoski J, Kiukaanniemi H. The effect of improved hearing protection regulations in the prevention of military noise-induced hearing loss. Acta Oto-Laryngology. 2008;128:997-1003.

[9]. Rabinowitz PM, Galusha D, Dixon-Ernst C, Slade MD, Cullen MR. Do ambient noise exposure levels predict hearing loss in a modern industrial cohort?

Occupational and environmental medicine. 2007;64(1):53-9.
[10]. Pyykkö I, Toppila E, Zou J, Kentala E. Individual susceptibility to noise-induced hearing loss. Audiological Medicine. 2007;5(1):41-53.
[11]. Rabinowitz PM, Galusha D, Dixon-Ernst C, Clougherty JE, Neitzel RL. The dose-response relationship between in-ear occupational noise exposure and hearing loss. Occupational and environmental medicine. 2013;70(10):716-21.
[12]. Fleischer G, editor Effective protection of the sense of hearing is prevented by ISO1999 noise standard. 7th European Conference on Noise Control 2008, EURONOISE 2008; 2008; Paris.
[13]. Dudarewicz A, Toppila E, Pawlaczyk-Łuszczyńska M, Śliwińska-Kowalska M. The Influence of Selected Risk Factors on the Hearing Threshold Level of Noise Exposed Employees. Archives of Acoustics2010. p. 371.
[14]. Leensen MCJ, Van Duivenbooden JC, Dreschler WA. A retrospective analysis of noise-induced hearing loss in the Dutch construction industry. Int Arch Occup Environ Health. 2011;84(5):577-90.
[15]. Neitzel R, Seixas N, Goldman B, Daniell W. Contributions of non-occupational activities to total noise exposure of construction workers. Ann Occup Hyg. 2004;48(5):463-73.
[16]. de Toro MA, Ordonez R, Reuter K, Hammershoi D. Is it necessary to penalize impulsive noise +5 dB due to higher risk of hearing damage? The Journal of the Acoustical Society of America. 2011;129(6):3808-17.
[17]. Rezaee M, Mojtahed M, Ghasemi M, Saedi B. Assessment of Impulse Noise Level and Acoustic Trauma in Military Personnel. Trauma Monthly. 2012;16(4):182-7.