Statistical analysis applying standard deviation in the application of ABNT NBR 16077 method for calculating the sound pressure level in the protected ear

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Resumo. Este artigo tem como objetivo realizar um estudo de caso de aplicação da metodologia de cálculo contida na ABNT NBR 16.077 Equipamentos de proteção individual – Protetores auditivos – Método de cálculo do nível de pressão sonora no ouvido protegido. Os protetores auditivos têm a função de fornecer proteção auditiva aos trabalhadores submetidos a níveis de pressão sonora que podem causar danos ao ouvido humano. A legislação trabalhista prevê limites auditivos que não podem ser ultrapassados durante a jornada de trabalho, sem risco de danos à saúde do trabalhador. Os protetores auditivos colocados à venda são fornecidos com C.A. (Certificados de Aprovação), que contêm tabelas com níveis de atenuação em decibéis para cada frequência sonora destinada à proteção do ouvido. O estudo de caso em questão analisa tipos de protetores auditivos escolhidos aleatoriamente no mercado para verificar o grau de proteção por faixa de frequência, considerando as incertezas do método.

Abstract. This article aims to carry out a case study of the application of the calculation methodology contained in ABNT NBR 16.077 Personal protective equipment - Hearing protectors - Method for calculating the sound pressure level in the protected ear. Hearing protectors has the function of providing hearing protection for workers subjected to sound pressure levels that can cause damage to the human ear. Labor legislation provides hearing thresholds that cannot be exceeded during a working day, without risking damage to the worker's health. The hearing protectors offered for sale are supplied with C.A. (Certificates of Approval), which contain tables with attenuation levels in decibels for each sound frequency intended to protect the ear. The case study in question analyzes hearing types protectors chosen randomly from the market to verify the degree of protection by frequency band, considering the uncerties of the method.

1. Introduction

Noise is a public health issue and can cause a series of problems the health. Exposure to high levels of noise can lead to hearing impairment, cardiovascular disease, hypertension, sleep disorders, psychological, social and behavioral problems. The World Health Organization (WHO) reports that 466 million people worldwide have disabling hearing loss and 34 million of them are children [1]. Occupational hearing loss is the most common work-related illness in the United States; the National Institute for Occupational Safety and Health (NIOSH) estimates that approximately 22 million US workers are exposed to hazardous noise [2]. Still according to WHO [1] by 2050 the number of people impacted by hearing loss should reach 1 billion worldwide.

In Brazil there are about 10.7 million people with hearing impairment. Of this total, about 21.5% have severe deafness. Of the total number of people affected, 9% of people with hearing impairment were born with this condition and 91% acquired it throughout their lives [3]. Data from the Deaf Accessibility Week reveals the existence, in Brazil, of 10.7 million people with hearing impairment [4]. Of this total, 2.3 million have severe disabilities. Deafness affects 54% of men and 46% of women. The predominance is in the range of 60 years of age or older (57%) [5].

2. Brief review of the literature

This section aims to present the main technical references and parameters considered in the case study.

2.1. Noise control

Firstly, it is necessary to distinguish the concept of sound and noise. Sound is the sensation produced in the auditory system; and noise is an undesirable sound, generally with a negative connotation [6]. In this sense, quantifying noise levels is important to measure the sound effect that can have deleterious consequences to the human body is of vital importance. "In a 2014 study, nearly 30% of employees in an OSHA-based hearing conservation program were not receiving adequate attenuation for their workplace noise exposures." [7]

2.2. *Acceptance criteria for occupational exposure to noise.*

The NHO 01 - Technical Standard aims to establish criteria and procedures for the assessment of occupational exposure to noise, which implies a risk of occupational deafness [8]. This technical procedure is applied to occupational exposure to continuous noise and impact noise in any work situation, however it is not focused on the characterization of acoustic comfort conditions [9].

Regarding acoustic comfort, NR17 [10] establishes that background noise for comfort must respect the reference values for indoor environments according to their purpose of use established in official technical standards. For other cases, the acceptable background noise level for acoustic comfort purposes will be up to 65 dB (A), equivalent continuous sound pressure level weighted in A and in the Slow (S) response circuit.

2.3. Noise monitoring

The monitoring of noise in the work environment and its consequent proposals for control measures are provided for in international standards, such as the recent translation of the international standard ISO 11690-1, to ABNT ISO NBR, [11]. In this sense, for decision-making regarding the levels of impact on the human body, it is necessary to observe the so-called Occupational Exposure Limits, the English Threshold Limit Values (TLVs), which inform the thresholds to which workers may be subjected. without risk of compromising their health [12]. At the national level, this technical reference, contained in the TLVs, is published and updated periodically by ABHO [13].

However, in Brazil, the legal occupational reference for the so-called Tolerance Limits (LT) and Action Levels (NA) is determined by labor legislation, as contained in NR15 [9]. For occupational noise, LT and NA are parameterized in a legal document.

2.3.1. Prevention actions. According to NR 9 [14], regarding the evaluation of physical agents, changes were introduced in 2023. Thus, while the annexes to this Standard are not established, the following should be adopted for the purposes of preventive measures:

- criteria and tolerance limits contained in NR-15 and its annexes;
- as action level for the physical noise agent, is the half the dose;

In the absence of tolerance limits provided for in NR-15 and its annexes, those provided for by ACGIH [12] must be used as a reference for the adoption of preventive measures;

The action level (A.L.) is considered the value above which systematic control actions must be implemented in order to minimize the probability that occupational exposures exceed the exposure limits [14].

2.3.2. Evaluation criteria for occupational exposure to noise. As described in item 3.3.2, occupational noise dosimetry was performed using an instrument called a personal use integrator meter (noise dosimeter), adjusted (setup) according to the technical guidelines contained in [8], in item 6.2.1.1 of this technical procedure published by Fundacentro. All integration modeling parameters and criteria are described in the following subsections. The tolerance levels (T.L.), for 8 hours a day, and the bending factor (q=5) were adopted based on the legal reference [9].

2.3.3. Continuous or intermittent noise. According to [9] the reference criterion that supports the exposure limits adopted for continuous or intermittent noise corresponds to a dose of 100% for exposure of 8 hours at the level of 85 dB (A). NHO 01 [8] establishes the dose doubling increment (q) equal to 3 and the integration threshold level equal to 80 dB (A). However, the values adopted in this work were the values defined in the labor legislation [NR15], with q=5 and the lower integration limit equal to 80 dB(A), with the upper integration limit being 115 dB(A).

2.3.4. Assessment with personal use integrator meter. The determination of the dose of exposure to noise must be carried out, preferably, through the use of integrative meters for personal use (noise dosimeters), adjusted in order to meet the specifications contained in item 6.2.1.1 (measuring equipment) [8]. The occupational exposure limit for continuous or intermittent noise corresponds to a daily dose of 100%. The action level for occupational exposure to noise is a daily dose equal to 50%. The ceiling value exposure limit for continuous or intermittent noise is 115 dB(A).

3. Acceptance Criteria

This section presents the acceptance criteria for occupational noise levels and other parameters for characterizing this occupational risk.

3.1. *Evaluation criteria for occupational exposure to noise.*
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3.1.3. Human exposure to noise. Noise bothers people individually by interfering with concentration, conversation, leisure, sleep and other daily activities. It is possible, however, to characterize the effects of noise on an aggregate of people in communities subject to various types of environmental noise. Studies demonstrate a significant correlation between interference in communities and noise levels [15]. Noise pollution can be defined as any disturbance to the environment caused by sounds generated directly or indirectly by human action that make it difficult or impossible to use a certain environmental space for its purposes or, even, that may cause hearing damage to visitors or occupants. that space [15]. The risk of noise-induced hearing loss (NIHL), acquired in the occupational environment, is considered higher for those who work in industries; preventive measures help to avoid the problem [5].

3.2. The human ear
Figure 1 below schematically represents the human hearing aid.

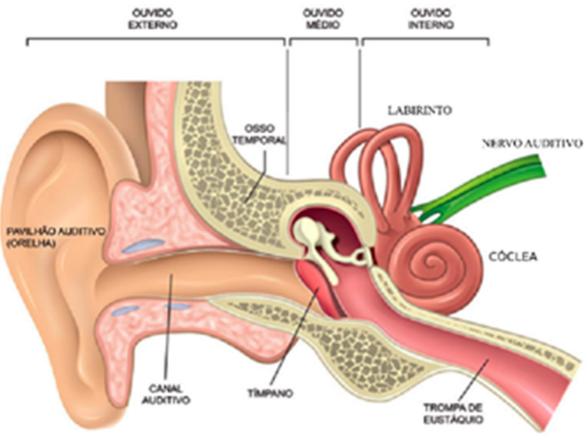

Figure 1. Schematic drawing of the human ear, [16]. The proposed hearing protection for noise control through personal protective equipment (PPE) may include the use of hearing protectors inserted in the ear canal, or the use of shell-type hearing protectors superimposed on the auditory pavilion (external ear). See figure 1.

4. Equivalent Sound Level (Leq)
The risk of hearing damage due to a certain type of noise depends not only on its level, but also on its duration in time. Typically, noise levels can fluctuate over a period of time. The equivalent sound level is a constant level that is equivalent in terms of acoustic energy to the varying levels of noise during the measurement period. Thus, a single value is defined, called equivalent sound pressure level, Leq, which is the average sound level, resulting from the integration over a time interval [6].

The Equivalent Sound Pressure Level is defined mathematically according to equation (1):

$$L_{eq} = 10log\left(\frac{1}{T}\int_{T}\frac{P_A^2}{P_0^2}\,dt\right)\,dB(A)$$

Equation 1

Where:
L_{eq}: equivalent sound pressure level referring to the integration interval (T=t2 – t1)
T: measurement time interval;
P_A: instantaneous A-weighted sound pressure;
P_0: reference sound pressure, equal to 20 µPa

4.1. *Hearing protection*
According to [14] for the evaluation of Occupational Exposures to Physical, Chemical and Biological Agents, a preliminary analysis of work activities and data already available regarding physical, chemical and biological agents must be carried out, in order to determine the need for adoption direct prevention measures or carrying out qualitative assessments or, when applicable, quantitative assessments.
Quantitative assessment of occupational exposures to physical, chemical and biological agents, when necessary, should be carried out to:
a) prove control of occupational exposure to identified agents;
b) scale the occupational exposure of groups of workers;
c) subsidize the solution of preventive measures.

Also according to [14] the quantitative assessment should be representative of occupational exposure, covering organizational aspects and environmental conditions involving the worker in the exercise of his work activities.

4.1.1. Prevention and control measures. Control measures for the elimination or mitigation of risks due to physical, chemical, biological or ergonomic agents must obey a sequence of barriers, which go from the source to the worker [14].

• Figure 2 below demonstrates the trajectory of the risk agent, in this case the sound pressure, from the source towards the worker, passing through the propagation medium, barriers to be provided by administrative measures, until it reaches the worker. The reference sound source was used as an example Administrative measures.

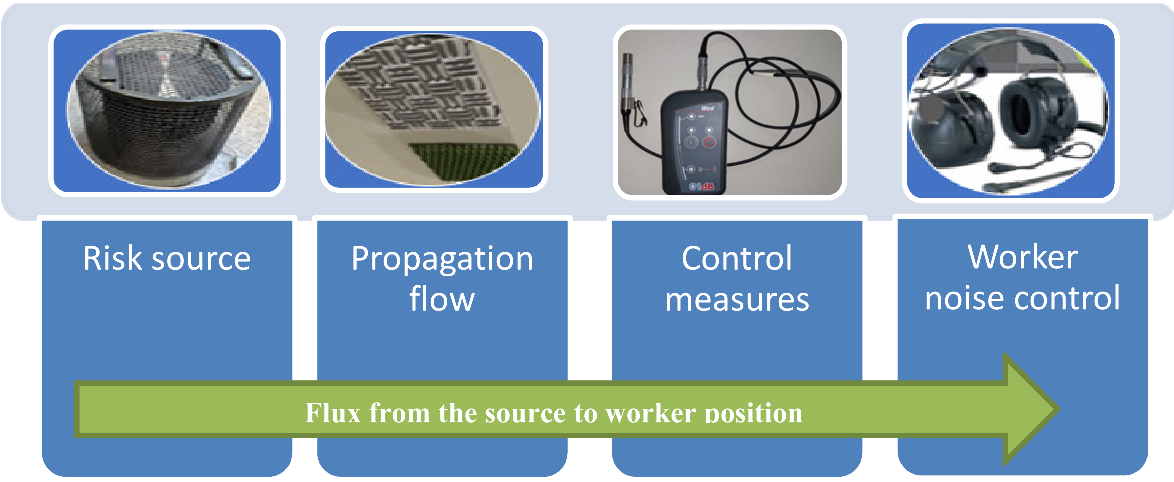

Figure 2. Illustrative example of the noise flow from the source towards the worker.

4.2. Application of noise control

The application of engineering measures, such as changes in the source, enclosure, sound absorption, acoustic insulation, among others, which depend on the project, can be time-consuming and costly. In this case, for the continuity of activities with high sound pressure levels until the final application of engineering measures, it may be necessary to specify PPE to protect the hearing aid and preserve hearing. In certain cases, depending on the sound pressure levels, the combined application of PPE and administrative measures may be necessary [14].

4.3. Sound attenuation by hearing protectors

Hearing protectors are divided into several categories mentioned in ABNT NBR 16076 [17]. However, the two main categories, most used are: internal insertion, in the middle ear (plug type) and external attachment to the external ear (shell type) [17]. It is true that for each category of plug or shell there are an infinity of models, each with its characteristic sound attenuation level, leaving the occupational safety professional to choose according to the adequacy of exposure levels.

4.3.1. The long method – NRR. The information that should be taken into account to ensure adequate protection is the methodology presented in “Annex A, Examples of calculating the level of exposure with protection”, by the long method defined in [18], which presents the long method, contained in this Annex A, with the NRR - Noise Reduction Rating (Noise Reduction Level). The attenuation methodologies take into account indices that can be subtracted directly from the work exposure level, and according to annexes 1 and 2 of NR 15, the value for continuous noise is given in dB (A) [18].

4.3.2. The simplified method – NRRsf. The NRRsf = Noise Reduction Rate Subject Fit (Noise Reduction Level, means that the placement of the protector in the ear is subjective, and appears as one of the indices to be used. Unlike the NRR, the NRRsf is obtained not in an environment laboratory, but in an environment close to reality, so that each user is free to install their PPE without the guidance of third parties [18]. Currently, hearing protectors bring the NRRsf as the main information and no longer the NRR. in the C.A. it is possible to obtain the attenuation curve, which allows tracing the attenuation profile, as shown in figure 4.

NEp = NE – NRRsf   Equation 2

4.4. Application of Annex 1 of NR15
The decibel obeys a logarithmic scale and not arithmetic as we usually find in our daily lives. This is proven in annex 1 of NR 15 of the Ministry of Labor which shows us a remarkable fact, every 5 dB (A) the exposure doubles or decreases by half [9].

5. Case study

Figure 3 below shows the result of applying the method provided for in the ABNT NBR 16077 standard, method for calculating the sound pressure level in the protected ear [18]. The horizontal lines with 80 and 85 dB (A) represent the action level (AL) and the tolerance limit value (TLV), respectively. The solid line in dark blue represents the equivalent noise level (LAeq) emitted by the sound source under study. Note that the study presents the sound emission in 1/3 of an octave so that it is possible to compare it with the information of data sheet of each protective equipment analysed.

5.1. *Uncertainties associated with the standard deviation*
The distance found in the graph in Figure 3 between the lines that represent the acoustic attenuation provided by each example type of hearing protector demonstrates the degree of uncertainty of each measurement defined by the standard deviation calculated by the method.

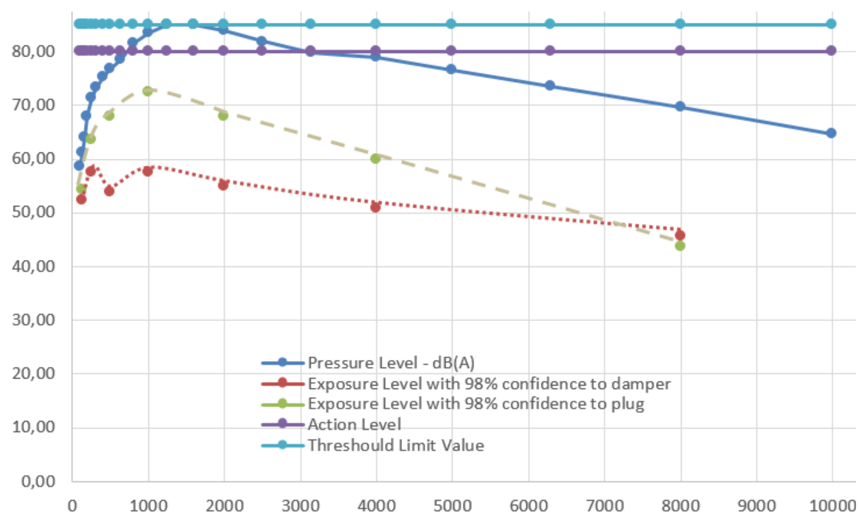

Figure 3. Exposure Level examples with 98% confidence to plug and damper hearing protection. Hearing protection level information was extracted from the data sheet contained in references [19] and [20].

The dashed lines in green represent the attenuation performed by the plug-type hearing protector and the red dotted line represents the attenuation performed by the shell or damper type hearing protector, respectively.

The distance found in the graph in Figure 3 between the lines that represent the acoustic attenuation provided by each type of hearing protector demonstrates the degree of uncertainty of each measurement defined by the standard deviation calculated by the method.

6. Conclusion

The study of the means associated with the standard deviation found in the method provided for in ABNT NBR 16077, the presented example for calculating the sound pressure level in the protected ear, may indicate degrees of uncertainty in the application of the method.

The case study of the application of different types of hearing protectors with different means and standard deviations demonstrates uncertainties that can point to different degrees of protection for the worker's ear.

Opportunity for new studies with expansion of the set of tested equipment and reproduction in an acoustic chamber for laboratory verification with the use of dynamic microphones.

7. References

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