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The assessment of auditory damage risk in particularly noisy environments

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ABSTRACT

The most negative effects caused by noise exposure related to the hearing system are well known and may produce professional or even permanent deafness. Since these effects have very important influence on worker's health and well-being, it is necessary to evaluate the hearing loss caused by occupational exposure to noise in order to propose preventive solutions.
A large number of compensation claims are submitted each year in Italy for the occupational disease "hypoacusis". The criticalities for assessing the risk of auditory damage is related to the fact that a scientifically accepted relation between hearing loss and noise frequency still not exist for the Italian population. Besides, at today there is not criterion of damage accepted by the scientific community for several different work field. In this work, we present a methodological approach for calculating the provisional risk of auditory damage for the airport ramp's operators. The calculation method is based upon on the definitions and the Annexes of the ISO 1999/90, the table of biological damage to the hearing loss of D.M. 12/07/2000 (Italian Ministerial Decree) and the four damage criteria defined by S. Casini (Italian National Institute for Insurance against Accidents at Work). The approach considers the hearing loss as caused not only by the occupational exposure to noise, but also by biologic ageing. The risk matrices have been evaluated basing on the numerical results obtained by simulations performed with the software Rumours. One matrix for each criterion of damage has been developed.

INTRODUCTION

Exposure to intense noise, even for a short period of time, can cause irreversible hearing loss. The same type of hearing damage can be caused by prolonged exposure to noise in moderately noisy environments.

The harmful effects of noise on humans are divided into specific auditory effects that interest the hearing apparatus [1], and extra-auditory effects, that can cause different disturbs [2], like stress, loss attention, increase of blood pressure,and many others. The cardiovascular system would appear to be the one that is most influenced by noise, directly as well as indirectly. Analysis of available literature shows that, with an intensity generally higher than 85 dB(A), there is an increase in cardiac frequency, blood pressure, peripheral vascular resistance and the concentration of noradrenaline, and often of adrenaline, present in the blood and urine, when an intensity higher than 85 dB(A) occurs.

The damage that can be produced by continued exposure professional to noise is called "hypoacusis".

Hypoacusis, that is the impairment and eventual loss of hearing, is the best known and most studied type of noise induced damage. However, noise also interacts in a very complex way with other bodily organs and systems (cardiovascular system, endocrinous system and central nervous system among others) through the activation or repression of central or peripheral neuroregulatory systems [3]. Noise also has a concealing effect that hampers verbal communications and the perception of acoustic safety signals (with a consequent increase of the probability of occupational accidents). It favours the onset of mental fatigue, reduces the efficiency of professional performance, causes learning disorders and interference with sleep and rest [4].

In Italy, noise induced hypoacusis is the most frequently reported of all occupational diseases. INAIL (Italian National Institute for Insurance against Accidents at Work) data shows that noise induced hypoacusis and deafness constitute approximately half of all occupational diseases.

In terms of hearing related effects, noise acts on the ear primarily through acoustic energy. Exposure to noise at high intensities and for long periods causes a series of alterations to the neurosensorial structures of the inner ear. The organ of Corti, located inside the cochlea, is the area most prone to noise-induced damage.

Exposure to noise can also cause irreversible damages if it is prolonged over time. Such irreversible lesions demonstrate with a permanent rise of the hearing threshold. Noise damage typically emerges as bilateral perceptive hypoacusis [5]. Higher intensity noise, not lower than 120-130 dB, also affects the vestibule portion of the inner ear, with dizziness, nausea and balance disorders, that are usually reversible, disappeaning with the interruption of the acoustic stimulus.

A healthy ear with complete hearing ability has a threshold sound level of zero, which indicates the minimum intensity of perceivable sound. Hearing loss, or hypoacusis, measured in decibels, expresses the difference between the minimum sound level that the ear is able to perceive and zero, conventionally considered as standard. In a subject with normal hearing, the curve resulting from audiometry tests will not deviate greatly from zero (in any case it will be less than 25 dB).

At older ages a presbyacusis, age related hearing loss, which usually affects the higher frequencies, may appear. Hearing loss can also be determined by other factors: non-occupational noise exposure, such as hunting, or attending nightclubs still taking harmful drugs to the organ of hearing. Therefore, in the individual, it is necessary to distinguish the causes of hearing loss in the individual, reconstructing past exposure to noise as a function of activity.

This is especially true in the developed countries, where the models of social and economical organization, the technological development and the growth of population are key factors in the increase of noise pollution.

According to analyses carried out by the OECD (Organization de Cooperation et de Development) and EPA (Environmental Protection Agency), at least 15% of the population would be subjected to noise levels considered risky for hearing functions [6].

In a recent epidemiological survey, it has been discovered that in Italy the subjects with occupational hypoacusis are 4.3%. At the moment, hearing impairment keeps on being the most reported work related illness in Italy, with a close to 50% rate compared with the total [7].

This anomaly is due to the fact that there is not a general criterion of evaluation. In particular, there is not a table of damage assessment accepted by proposing bodies, no single damage criterion can be applied to different operating environments. Lastly, there is insufficient knowledge of the medical aspects and epidemiological studies on this [8].

So far, there is the need to define in a concrete way general criteria to evaluate the workers risk exposure to noise. The criteria should be derived from consolidated epidemiological acknowledgements, and not from "feeling" or sensation of risk of the interest actors.

In this paper, we propose a methodological approch for calculating the hearing impairment, using the definitions and database issued in ISO 99/1990 International Standard [9], and the "biological damage" hearing impairment table stated in Italian law D.M. 12/07/2000 [10]. The four damage criteria defined by S. Casini are considered here too [11]. The matrix of risk have been evaluated basing on the numerical results obtained by simulations carried out with the software Rumours [12].

The approach considers the hearing loss as caused not only by the occupational exposure to noise, but also by biological ageing. It can be applied in particularly noisy environments, where it is necessary to evaluate the hearing loss caused by occupational exposure to noise in order to propose preventive solutions for the protection of workers. This work concentrates on airport ramp's operators, working in especially noisy environment, where there are several and complex sources of noise.

BACKGROUND ON CALCULATION METHODS

Since hearing loss from noise has been included among occupational diseases for compensation (D.P.R 1124 of 1965) [13], the assessment of auditory damage is far from easy.

At the moment, a single method to assess the damage caused by noise that can be applied to different working environments does not exist.

The issues to consider in assessing the risk of hearing loss are related to the choice of a table of auditory damage, accepted by scientific community, and the preference of a criterion of damage, that is most suitable to the reality in question.

Tables for the assessment of damages are different, owing to:

- the different weighted value assigned to each frequency,

- the range of acoustic frequencies considered,

- different values corresponding to the initial damage, and so on. Several tables have been developed by International bodies officially recognized (American Medical Association - 1947) and by individual Authors, which: (Arslan-Rubaltelli, 1958), Bocca-Pellegrini (1950), Finulli (1966), Giaccai-Gardenghi(1962), Ghirlanda (1958), Introna-Solito (1991), Maggiorotti (1966), Mauceri-Pappalardo (1984), Motta-Chiarini (1974), Rossi (1978), Marello-Monechi (1981), Marello (1991), Caretto-Amico (1991) [14].

A lot of tables have been elaborated over the years, including Table INAIL-Social Partners (March 31, 1992), and Table INAIL - Social Partners (August 1, 1994). After the Legislative Decree n. 38/2000 [15] and the subsequent introduction of the biological damage, INAIL has elaborated a New Table for occupational hypoacusis, in force since July 2000. This table, contained within the Italian Ministerial Decree 12 July 2000, shows the threshold rise for each frequency due to biological aging (Table 1). In this Decree, biological damage means: "lesion to psycho- physical integrity of the person, susceptible to coroner check".

Table 1. Table of biological damage of D.M. 12/07/2000 (Italian Ministerial Decree)

	Frequency				
Hearing Loss (dB)	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz
25	0,00	0,00	0,00	0,00	0,00
30	1,25	1,50	1,75	0,40	0,10
35	2,50	3,00	3,50	0,80	0,20
40	5,00	6,00	7,00	1,60	0,40
45	7,50	9,00	10,50	2,40	0,60
50	11,25	13,50	15,75	3,60	0,90
55	15,00	18,00	21,00	4,80	1,20
60	17,50	21,00	24,50	5,60	1,40
65	18,75	22,50	26,25	6,00	1,50
70	20,00	24,00	28,00	6,40	1,60
75	21,25	25,50	29,75	6,80	1,70
80	22,50	27,00	31,50	7,20	1,80
85	23,75	28,50	33,25	7,60	1,90
90	25,00	30,00	35,00	8,00	2,00

Another problem for the assessment of auditory damage risk is the choice of a damage criterion.

For example, according to criterion of ISO 1999/90, the damage value is equal to the average of hearing loss at the frequencies 1000, 2000 and 4000 Hz that is greater than 27 dB. In new table INAIL, the damage calculated is greater than or equal to the minimum compensation, corresponding to 11%. Stefano Casini (Inail) proposed four damage criteria:

- DBO (biological damage >0): the border value is overcome if the threshold rise is greater than 25 dB in any of the following 5 frequencies (0.5,1,2,3,4 kHz).

- DBM (minimal biological damage): the border value is overcome if the biological damage is greater than or equal to 1%.

- DBI (reimbursable biological damage): the border value is overcome if the biological damage is greater than or equal to 6% (maximum level of compensation provided by INAIL - Italian Worker's Compensation Authority).

- DB25 (average biological damage): the border value is overcome if the average threshold rise is greater then 25 dB).

In literature, there are 3 technical standards for the assessment of auditory damage risk: criteria of risk CHABA, developed in 1966 in the U.S.; OSHA rules (1971), recommendations ISO 1999 (1975). The differences are basically three: the descriptor index adopted; the maximum limit of daily or weekly exposure considered admissible, and the exposure factor. Following the ISO 99/75 has been revised for the calculation of auditory damage (ISO 1999/90). The latter regulation is an essential reference for the study and forecast of occupational hypoacusis, establishing a criterion for statistical correlation between elapsed noise exposure and the auditory damage found.

Basing on the development of statistical data, it is possible to see the increases provided by the threshold of audibility at different audiometric frequencies, depending on the level of daily personal noise exposure and the number of years of exposure (Article 5, ISO 1999/90). In addition to hearing loss caused by occupational exposure to noise, defined NIPTS (Noise Induced Permanent Threshold Shift) are added increases the threshold of audibility caused by biological aging, defined HTLA (Hearing Threshold Level Associated with Age), which are often in absolute terms, more relevant first. In Italy, there is not a database for calculating HTLA, related to "real" people. Therefore, the A database of ISO 1999/90 is selected, relative to an ideal "skimmed otologic" population. It is known as the B database published in the same rule, refers to population of areas industrialized of northern Europe, that for anthropomorphic characteristics and lifestyle may differ from the average Italian.

The threshold rise of audibility in dB, associated to noise and age (HTLAN), is calculated using the following empirical formula (1):

$$HTLAN = HTLA + NIPTS - \frac{HTLA \cdot NIPTS}{120} \qquad 1)$$

Subsequently, are individuate values HTLA and HTLAN for each fractile that exceed the criterion of damage chosen. The highest value of fractile that exceeds the criterion of damage is equal to the risk of auditory damage.

Therefore, the risk of auditory damage due to noise exposure varies according to the criterion of damage selected and to the choice of database for calculating HTLA.

This regulation can be used to calculate the risk of auditory damage, defined as damage caused by regular exposure to professional noise or repeated daily exposure to noise.

A NEW METHODOLOGICAL APPROCH

In this work, a methodological approach for calculating the provisional risk of auditory damage for severe environment is presented. To explain the procedure to follow, the proposed method is applied to ramps' operators, working in the airport apron. In severe environments, many noise sources that cause high levels of sound pressure Leq (A), above the upper limit of action, according Legislative Decree n° 81/2008 are present. Airport apron is considered a severe environment, as different types of noise sources are present: noise from aircraft engine, noise emitted by ramp equipment used, by Auxiliary Power Unit, and so on. Therefore, workers are subjected to high sound pressure levels Leq (A) during the entire work shift, above the 85 dB(A), to this end it is necessary to assess the hearing loss caused by occupational exposure to noise in order to propose preventive solution for safeguard the employees themselves.

Moreover, this approach can be applied in other working sectors, which are especially noisy.

The calculation method is based upon the definitions and the Annexes of the ISO 1999/90, the table of biological damage of D.M. 12/07/2000 (Italian Ministerial Decree) and the four damage criteria defined by S. Casini (Italian National Institute for Insurance against Accidents at Work).

AN EXAMPLE OF APPLICATION

The numerical calculations have been made using Rumours software. Results are presented in the form of "risk matrices", easy and immediate to be read.

The processing of statistical data, shows the expected increases in the threshold of audibility at different audiometric frequencies for fractile of the population, according to the level of daily personal noise exposure and years of exposure, called NIPTS (Table 2). A population exposed to a sound pressure level of 90 dB after 30 years of noise exposure has been considered. The calculation procedure is given in Art. 5 of ISO 1999/90.

The introduction of age and sex of the population into the software Rumour, allowed to calculate the value of HTLA to different audiometric frequencies for fractile of the population (Table 3).

Table 2. NIPTS – Noise Induced Permanent Threshold Shift

Years of exposure: **30** Leq (A): **90 dB**						
q (%)	**500 Hz**	**1000 Hz**	**2000 Hz**	**3000 Hz**	**4000 Hz**	**6000 Hz**
5	0	0,2	9,9	19,8	20,7	16,1
10	0	0,1	8,8	17,9	19,2	14,6
15	0	0,1	8,2	16,6	18,2	13,5
20	0	0,1	7,6	15,6	17,4	12,7
25	0	0,1	7,1	14,8	16,7	12
30	0	0,1	6,7	14	16,1	11,4
35	0	0,1	6,3	13,3	15,5	10,8
40	0	0,1	6	12,6	15	10,3
45	0	0,1	5,6	11,9	14,5	9,7
50	0	0,1	5,2	11,3	13,9	9,2
55	0	0,1	5,1	11	13,6	8,9
60	0	0,1	4,8	10,7	13,2	8,4
65	0	0,1	4,6	10,3	12,8	8,1
70	0	0,1	4,4	10	12,4	7,6
75	0	0,1	4,2	9,6	12	7,2
80	0	0,1	3,9	9,2	11,5	6,7
85	0	0,1	3,6	8,8	10,9	6,1
90	0	0,1	3,2	8,2	10,2	5,4
95	0	0,1	2,6	7,3	9,1	4,3

This value take account of biological aging due to age (database A from ISO 1999/90). A population of 50 years old men as been considered.

Subsequently a calculation of HTLAN has been performed (Table 4), pointing out raising of the threshold audibility for each frequencies due to age and noise, using the empirical formula reported in (1).

Table 3. HTLA– Hearing Threshold Level associated with Age

Age:**50** Sex:**M** Table: **Biological**							
q (%)	**500 Hz**	**1000 Hz**	**2000 Hz**	**3000 Hz**	**4000 Hz**	**6000 Hz**	**Damage (%)**
5	16,3	17,2	24,3	33,2	42,1	47,5	0,6
10	13,5	14,3	20,5	28,5	36,4	41,1	0,3
15	11,6	12,3	18	25,3	32,6	36,7	0,1
20	10,1	10,8	15,9	22,7	29,5	33,3	0
25	8,8	9,5	14,2	20,6	26,9	30,3	0
30	7,6	8,3	12,6	18,6	24,6	27,7	0
35	6,6	7,2	11,2	16,8	22,4	25,2	0
40	5,5	6,1	9,8	15,1	20,3	22,9	0
45	4,6	5,1	8,5	13,4	18,4	20,7	0
50	3,6	4,1	7,2	11,8	16,4	18,4	0
55	3	3,5	6,3	10,7	15,1	17	0
60	2	2,5	5,1	9,1	13,2	14,9	0
65	1,2	1,7	4	7,7	11,6	13	0
70	0,4	0,8	2,8	6,3	9,8	11	0
75	-0,6	-0,2	1,5	4,7	7,9	8,9	0
80	-1,6	-1,2	0,2	2,9	5,9	6,5	0
85	-2,8	-2,5	-1,5	0,9	3,4	3,8	0
90	-4,3	-4	-3,5	-1,7	0,4	0,3	0
95	-6,6	-6,3	-6,5	-5,5	-4,2	-4,8	0

Table 4. HTLAN– Hearing Threshold Level associated with Age and Noise

Years of exposure: **30** Leq (A): **90 dBA** Table: **Biological**					Age: **50** Sex: **M**		
q (%)	**500 Hz**	**1000 Hz**	**2000 Hz**	**3000 Hz**	**4000 Hz**	**6000 Hz**	**Dam-age (%)**
5	16,3	17,3	32,2	47,5	55,5	57,2	3,4
10	13,5	14,4	27,9	42,1	49,8	50,7	1,9
15	11,6	12,4	24,9	38,4	45,8	46,1	1
20	10,1	10,9	22,5	35,4	42,7	42,5	0,7
25	8,8	9,6	20,5	32,8	39,9	39,3	0,5
30	7,6	8,4	18,6	30,4	37,4	36,5	0,4
35	6,6	7,2	16,9	28,2	35	33,8	0,2
40	5,5	6,2	15,3	26,1	32,8	31,2	0,1
45	4,6	5,2	13,7	24	30,6	28,7	0,1
50	3,6	4,2	12,1	21,9	28,4	26,2	0
55	3	3,5	11,2	20,8	27,1	24,7	0
60	2	2,6	9,7	19	25	22,3	0
65	1,2	1,7	8,4	17,4	23,1	20,2	0
70	0,4	0,8	7,1	15,7	21,2	18	0
75	-0,6	-0,1	5,7	13,9	19,1	15,6	0
80	-1,6	-1,2	4	11,9	16,8	12,9	0
85	-2,8	-2,4	2,2	9,6	14	9,7	0
90	-4,3	-4	-0,2	6,6	10,5	5,7	0
95	-6,6	-6,3	-3,8	2,1	5,2	-0,3	0

Both HTLA and HTLAN have been calculated the value of biological damage, using the chart of the Ministerial Decree 12/07/2000, by making a linear interpolation for any given frequency of the fractile considered.

The values found corresponding to the loss in dB for each frequency are added together and the result is multiplied by 0.5. Therefore, a complete bilateral deafness has been assumed, equal for both ears. For each fractile, it has been verified whether the increase in the threshold of audibility in HTLA and HTLAN exceeds the damage criterion considered.

According the four criteria of damage proposed by Casini, for the example considered it is possible to define the percentage of the population exposed to auditory damage risk from exposure to noise only.

According to reimbursable biological damage criterion, the border value is overcome if the biological damage is greater than or equal to 6%. The percentage of population not exposed to noise that exceed the threshold of risk, is equal to 0%, (percentage damage for each fractile of population reported in table HTLA), and the same percentage of population refers to the exposed that exceed the threshold of risk (percentage damage for each fractile of population reported in table HTLAN). The difference between the values HTLAN and HTLA, defines the percentage of population at risk due to exposure to noise that is equal to 0 %. It is clear that none fractile of population reaches maximum level of compensation provided by INAIL- Italian Worker's Compensation Authority.

Considering the minimal biological damage criterion, the border value is overcome if the biological damage is greater than or equal to 1%. The percentage of population at risk due to exposure to noise is equal to 15 %, according to the evaluation procedure reported above.

Therefore, it is clear that the portion of the population exposed to noise risk depends on the criterion considered.

According to the calculation procedure presented an example of the risk matrix considering the reimbursable biological damage is reported (table 5).

Table 5. Risk matrix according to the reimbursable biological damage

95	7	8	9	9	10	10	11	11	11	12	12	13	13	14	14	15	15	16	16	16
94	6	7	7	8	8	9	9	9	10	10	10	11	11	12	12	13	13	13	14	14
93	5	6	6	7	7	7	8	8	8	8	9	9	10	10	10	11	11	11	12	12
92	4	5	5	6	6	6	7	7	7	7	7	8	8	8	9	9	9	9	10	10
91	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	8	8	8	8
90	3	3	4	4	4	4	5	5	5	5	5	5	5	6	6	6	6	6	6	7
89	2	3	3	3	3	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5
88	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4
87	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
86	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
85	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
84	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
83	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
82	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***

In the matrix the risk of auditory damage, is represented in operation of the years of exposure on the rows and of the level of personal exposure to noise on the columns. Reference age of 65 years has been considered acceptable for evaluation. The matrices are presented by three distinguished areas of different colors. The percentage of population exposed at no risk is white. The grey zone is the "attention", warning zone and it means that it is possible that exposed individuals may suffer damage, although slight, according to their sensitivity and consistency of actual exposure. In these cases, the consequence is that a constant monitoring of workers is required, offering audiological specialist visits. The black zone is a "danger zone", as it is pretty certain that the exposure to noise would cause damage on the average range of individuals.

This methodological approach can be applied to the reality of the airport, in order to identify workers exposed to high risk of hearing loss.

The example of push back operator is reported. To be more precise the operation consists into aircraft removal from ramp area to corresponding tarmac, for get ready to take off. This example has been chosen because from the results of phonometric measures executed, this typology of workers is exposed to high sound pressure levels during working shift.

Table 6 shows the percentage of risk associated to 4 criteria of damage (S. Casini) after 5, 10, 15, 20 and 30 years of exposure to the same sound pressure level equal 90 dB(A) for operator push back. In general, this kind of worker shows a very high percentage of risk in the 4 criteria considered, in a more marked way after 15 years of exposure to occupational noise, according to reimbursable biological damage criterion.

Table 6- Risk associated to 4 criteria of damage after 5, 10, 15, 20 and 30 years of exposure to sound pressure level equal 90 dB(A) for operator push back.

Exposure		CRITERION OF DAMAGE				
	Years of Exposure	Lex,8h	DB0	DBM	DBI	DB25
PUSH BACK	5	90	8	9	4	7
	10		11	13	5	9
	15		12	14	6	10
	20		13	15	7	11
	30		14	17	8	12

For propose preventive solutions, identifies the percentage of risk of auditory damage, according to the criterion DBM, after 20 and 30 years of exposure. The choice of minimal biological damage, as it consider a value of damage greater than or equal to 1%, with a narrower range, allowing better control of the situation. A percentage of risk of occupational origin that falls within the "danger zone" has been identified. As preventive measures is recommended, in addition to validate the requirement to wear ear protection devices (DPI), we suggest to alternate at least one day a week in a non-noisy place and carry out health checks periodically, for reduce risk of auditory damage.

CONCLUSIONS AND FUTURE DEVELOPMENTS

Purpose of this study is to demonstrate how the risk of auditory damage due to occupational exposure to noise can be recognized and calculated using objective criteria of damage.

Definitions of auditory damage and risk of hearing loss due to noise exposure of the International Standard ISO 1999/90 have been considered.

The risk of auditory damage has been calculated using the algorithms, the A database of ISO 1999/90, considering 4 criteria of damage proposed by S. Casini.

The numerical calculations have been made using Rumours software, presented in the form of "risk matrix".

The critical factors of the method are essentially: the choice of the criterion of damage to be used for calculations and the choice of A database (ISO, 1999/90), because of the lack of a national epidemiological database.

This methodological approach can be applied easily to assess the risk of who work in noisy environments.

The preparation of matrices for the remaining damage criteria are in progress, this will enable a comparison between them.

Eventually will propose the criterion of damage that fits to airport reality better, in order to safeguard workers.

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