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Influence of noise level and seniority in the workplace on the SAL, ELI and percentage of hearing loss indices in the diagnosis and prevention of hearing loss in the working population

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ABSTRACT

Introduction: This research relates the most important work-related factors affecting the development of hearing loss to the main methods used as medical assessment criteria in the diagnosis of occupational deafness. These criteria are the Speech Average Loss Index (SAL), the Early Loss Index (ELI) and the Percentage of Hearing Loss, and are applied to data obtained from audiograms performed on workers in occupational medical examinations. *Method:* Depending on the assessment method selected, these often return different results in grading an individual's hearing status and predicting how it will evolve. To address this problem, medical examinations (including audiograms) were carried out on a heterogeneous sample of 1,418 workers in Spain, from which demographic or personal data (gender, age, etc.), occupational data (noise level to which each individual is exposed, etc.) and other non-work-related factors (exposure to noise outside work, family history, etc.) were also gathered. Using Bayesian Networks, the conditional probability of an individual developing hearing loss was obtained taking into account all these factors and, specifically, noise level and length of service in the workplace. Sensitivity analyses were also carried out using the three scales (SAL, ELI and Percentage Hearing Loss Index), proving their suitability as tools the diagnosis and prediction of deafness. These networks were validated under the Receiver Operating Characteristic curve (ROC) criterion and in particular by the Area Under the Curve (AUC). *Results:* The results show that all three methods are deficient in so far as detecting preventive hearing problems related to noise in most workplaces. The most restrictive methods for detecting possible cases of deafness are the SAL index and the Percentage Loss Index. The ELI index is the least restrictive of the three methods, but it is not able to discriminate the causes of hearing problems in an individual caused by exposure to noise, either by its intensity level or by the time of exposure to noise. The use of the three methods in the field of occupational risk prevention is extremely limited and it seems reasonable to think that there is a need for the construction of new scales to correct or improve the existing ones.

1. Introduction

It is estimated that between 17% and 22% of the population in the European Union suffer from noise levels that are considered unacceptable, as they are exposed to noises exceeding 65 dB, which is the World Health Organization (WHO) tolerance level (Sanz, 2013). The National Institute for Occupational Safety and Health (NIOSH) reports that approximately 30 million Americans are exposed to noise levels capable of causing significant hearing loss (Díaz, Goycoolea, & Cardemil, 2016). When it comes to hearing loss, noise-induced hearing loss (NIHL) is the most common form of acquired deafness, especially in industrialized countries, where hearing loss often develops as a result of exposure to sounds loud enough to damage the sense of hearing and cause temporary or permanent hearing loss. Hearing damage can be caused instantaneously (by a single loud noise exceeding for example 130 or 140 dB) or progressively (by a high noise level, as a result of continuous exposure to moderate or high intensity noise; Sanz, 2013).

It seems to have been demonstrated that noise is, of all pollutants, the most frequent in industrial facilities (Fernando Pablo, 1996). But it is not the only factor of occupational origin to be considered for the development of hearing loss, since, for example, the incidence of variables such as seniority (number of years) in the workplace or the very nature of the activities carried out have been studied (Barrero, García-Herrero, Mariscal, & Gutierrez, 2018). Also

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noteworthy are various working conditions such as the number of hours of daily exposure to noise, the use or not of personal protective equipment, the distance from the noise source, and so forth, and the characteristics of the individuals themselves (gender, age, health status, etc.; Barrero, López-Perea, Herrera, Mariscal, & García-Herrero, 2020; Flodgren & Kylin, 1960; Pearson et al., 1995). This research focuses on the level of noise to which a worker is exposed during significant periods of their life (exposure time measured in years performing the same job).

In the scientific literature, as early as the 1970s, we find research that relates the time of exposure to noise and its intensity (Kryter, 1970). In the same decade, the International Organization for Standardization published the ISO 1999 Standard on the determination of the auditory risk due to noise exposure. Years later, the International Labour Organization gave the green light to Convention 155 of 1981, on workers' safety and health and the working environment (Occupational Safety and Health Convention 155, 1981), which, by means of Royal Decree 1316/1989, laid the foundations for Spanish regulations on noise (Real Decreto 1316, 1989). Sometime later, in 2006, under Law 31/1995 on Occupational Risk Prevention (Ley 31, 1995), which was the result of the transposition into Spanish law of Directive 89/391/EEC on the application of measures to encourage improvements in terms of the health and safety of workers in Community prevention policy (Directive 391, 1989), Royal Decree 286/2006 was published; this is the current reference framework for the protection of workers against the risks derived from exposure to noise and, particularly, against risks to hearing (Real Decreto 286, 2006). In the same year, Royal Decree 1299/2006 was approved in Spain, which includes the list of occupational diseases in the Social Security system and establishes criteria for their notification and registration (Real Decreto 1299, 2006). This decree is one of the relevant legal bases for our research, as it determines the conditions for the consideration of hypoacusis or deafness caused by noise as an occupational disease. Although at European level, Spain, together with France, is one of the countries with the highest number of declared diseases caused by work (Observatory of Occupational Illnesses, 2020), hypoacusis is a residual disease in terms of the number of people affected, as for example in 2020 only 1.32% of all occupational diseases processed were due to occupational deafness. It is important to note that although in 2020, due to the health crisis caused by COVID-19, there was a 32.58% fall in the processing of occupational illnesses, the percentage of occupational hearing loss in relation to the total number of occupational illnesses is similar to that of 2019, which stood at 1.43% (Observatory of Occupational Illnesses, 2021).

At this point, the question arises whether the low number of detected deafness cases is due to general good hearing health of workers or whether hearing assessment methods may also play a role. In Spain, the preventive activity of companies is regulated through Prevention Services according to Royal Decree 39/1997. With regard to physical pollutants, such as noise, two specialties or preventive disciplines are of vital importance. On the one hand, Industrial Hygiene, as a set of technical and human means aimed at preventing the onset of occupational diseases (in this case, hypoacusis) and which includes actions such as, for example, the measurement and control of noise in the workplace (Real Decreto 39, 1997). On the other hand, health monitoring, as a medical or healthcare preventive specialty through which the health of workers is assessed and preserved (Ley 31, 1995; Real Decreto 39, 1997). One of the main activities of health monitoring is to carry out periodic medical examinations of workers according to the risks inherent in their job. These medical examinations are carried out by health personnel with technical competence, training, and accredited skills (Ley 31, 1995), that is, health professionals specialized in occupational medicine, who are supported by health guidelines and protocols regulated by the public administrations (Guisasola Yeregui & Altuna Mariezkurrena, 2011; Uña Gorospe, Martínez de Ibarreta, & Hernando, 2000).

According to the specific health surveillance protocol for noise, during the medical examination, otoscopy and tonal liminal audiometry through the airway shall be carried out in accordance with the UNE 74-151-92 standard. If the audiometry shows a scotoma greater than 25 dB(A) from 3,000 to 6,000 Hz, bilaterally, symmetrically, and irreversibly, the doctor will proceed to report the suspicion of occupational illness as established in Art. 5 of Royal Decree 1299/2006 to the competent administrative authorities (Guisasola Yeregui & Altuna Mariezkurrena, 2011; Real Decreto 1299, 2006). The assessment criteria for audiometry are generally based on observed changes in hearing threshold through the so-called "significant threshold drop," which, for preventive purposes, is considered to occur when the average hearing loss between initial and periodic audiometries is 10 or more dB(A) at the frequencies 3,000, 4,000 and 6,000 Hz. Apart from this criterion, each doctor normally relies on contrasted diagnostic methods that classify the audiograms into different degrees of deafness (Uña Gorospe et al., 2000). The methods that are the subject of this research are the indices: SAL, ELI, and Percentage of Hearing Loss. The reasons for their selection are mainly two. The first is because these indices are among the most widely used methods, and the second is because they present great differences in their calculation principles.

Taking into consideration that the aforementioned audiogram classification methods may provide different results, classifying the same individual with different degrees of deafness, the present research focuses on relating these methods to work factors whose influence on hearing has been widely proven, such as noise level at the workplace and seniority on the job. The ultimate goal is to enable physicians to select the most appropriate method or index for classifying deafness according to these occupational factors. To this end, a large sample of 1,418 workers was used, from which, in addition to collecting their personal data and audiometric tests, measurements were taken of the noise levels at their workplaces.

The processing and analysis of all these data was possible due to applying Bayesian Networks, the use of which has been widely tested in the scientific health field (Friedman, Linial, Nachman, & Pe'er, 2000; Lucas, Van der Gaag, & Abu-Hanna, 2004) and specifically in research focused on deafness (Nouraei, Huys, Chatrath, Powles, & Harcourt, 2007; Wang et al., 2016). In this way, results can be obtained that provide clearer data regarding the dependencies and relationships between various factors (Acciardi, 2008) and even enable the user to interpret them intuitively through directed acyclic graphs (Koller & Friedman, 2009). In other methods, such as regression, direct bivariate dependencies are obtained; however Bayesian networks allow for the representation of complex, direct or conditional, linear, and non-linear relationships (Kratzer, Furrer, & Pittavino, 2018; Pittavino et al., 2017). Therefore, given the large amount of data generated in this research, we consider network learning to be one of the most appropriate methods for its analysis. In this way, we depart from the hypothesis that the combination of all the demographic and personal variables, as well as the work and non-work factors mentioned herein, have an influence on people's hearing health, generating a model that involves all these factors. Once this is done, we specifically perform a sensitivity analysis that predicts the likelihood of an individual's hearing being classified as having a certain degree of deafness depending on the method of diagnosis of hearing loss used (SAL, ELI, or Percentage Hearing Loss), the noise level present in their job, and their length of service. This will provide us with information regarding the suitability of these scales.

2. Noise level and seniority in the workplace as influencing factors in the development of hearing loss

It is quite common for occupational risk prevention technicians to encounter physical pollutants in many workplaces, such as: poor temperature and humidity conditions, low lighting levels, vibrations, or even radiation. However, one of the most frequent physical pollutants is noise. Many researcher have found that the sole existence of noise is a problem that has a negative impact on the health of workers (Babisch, 2005; Hernández, 2007), and is considered especially dangerous when its level exceeds 80 dB A (Real Decreto 286, 2006). However, it is not only the level of noise that is important, as the way in which the worker is exposed to noise (i.e., the duration of said exposure, whether or not they use protective elements, etc.) can also influence the worker's hearing health.

Several researchers refer to particularly relevant characteristics of noise that can make it more or less harmful, such as the type of noise, its intensity, and chronicity (Nowak, 2003), as well as its nature in relation to its continuity (continuous or discontinuous), stability (stable or intermittent), or the way it is produced (fluctuating or impact) (Fernando Pablo, 1996). Depending on their intensity, impact noises can generate immediate damage (Daniel, 2007; Heupa, de Oliveira Gonçalves, & Coifman, 2011) and those that are of higher frequencies are usually more annoying and dangerous than those that are of lower frequencies (Brusis, Hilger, Niggeloh, Huedepohl, & Thiesen, 2007; Ellotorp, 1973; McBride & Williams, 2001). Even the way in which the noise is produced and where its origin is located seem to influence whether one ear is more impaired than the other. This phenomenon known as "laterality" has been studied by several researchers, with some finding vast similarity between right and left-sided thresholds (Grenner et al., 1990), while many others finding a worse hearing level for the left ear than for the right ear at all frequencies (Axelsson, Aniansson, & Costa, 1987; Kannan & Lipscomb, 1974; Rudin, Rosenhall, & Svärdsudd, 1998; Ruiz, 1997). In short, it seems that all the parameters that define a given type of noise are related to the hearing loss of the people who suffer from it, either linearly in terms of intensity and exposure time (Sanz, 2013), or even exponentially (Fernando Pablo, 1996).

Exposure to noise can be measured by the number of hours that the worker remains in the workplace daily or weekly facing the noise source and also by the number of years during which they have been working (Fernando Pablo, 1996). With regard to this exposure, there are studies that state that the harmful effect of noise is proportional to the duration of exposure to it (Clemente Ibáñez, 1991; Dobie, 1993, 1995; Howell, 1978) and that most of the hearing loss occurs at the beginning, in the first years, and gradually slows down (Bergemalm & Borg, 2001; López González, 1989). It also seems to have been demonstrated that discontinuous exposure is less detrimental to hearing, due to the phenomenon of auditory fatigue recovery (Ward, 1995).

Finally, research has linked the combination of high noise levels and prolonged temporary exposure to a significant increase in the likelihood of developing hearing problems (Barrero et al., 2018; Calviño del Río, 1982; Ruiz, 1997).

3. Relationship between the main methods of hearing assessment with noise level and seniority in the workplace

In the field of occupational risk prevention, the aim of health monitoring is to diagnose and prevent the appearance of hypoacusis as an occupational disease. The assessment of a person's hearing status can be carried out by means of various methods that classify the hearing level into different degrees of deafness based on the data obtained from the audiograms. For their calculation, these methods make use of formulas where values corresponding to one or several frequencies are generally entered. Several researchers have argued that these criteria may have some drawbacks, the most recurrent being the fact that they are cross-sectional analyses that do not allow us to deduce how quickly an individual evolves towards deafness (Vilanova, 2016; Marqués, Moreno, & Sole, 1988). Some of the assessment criteria recommended by the Spanish health guides are the SAL, ELI, and Percentage of Hearing Loss indices (Uña Gorospe et al., 2000), although each specialist physician determines, according to his or her own criteria, which indices or methods to use for the assessment of their patients' hearing capacity, such as the diagnostic classification proposed by Klockhoff et al. (Nota Técnica de Prevención 193, 1989).

The SAL (Speech Average Loss) index assesses the conversational frequencies of 500, 1,000 and 2,000 Hz, and is defined as the arithmetic mean of the hearing loss in decibels of these frequencies (Uña Gorospe et al., 2000). In principle, it seems appropriate for diagnoses caused by noise since it is usually considered that a noise that is distributed in frequencies higher than 500 Hz causes greater harmfulness than others whose dominant frequencies are lower (Fernando Pablo, 1996). This index establishes a classification in different degrees of hearing A-B-C-D-E-F-G, so that the degree SAL-A indicates that both ears are within normal limits, and the degree SAL-G acquires the meaning of total deafness. The main criticism of this method is that it only takes into account the hearing of the better ear of the two and therefore ignores the evolution of the worse ear. It also fails to make an early diagnosis as it only assesses frequencies of 500, 1,000 and 2,000 Hz, failing to detect 90% of people with noise-induced pathology (Vilanova, 2016). Its use could be limited to the most advanced cases of deafness (Marqués et al., 1988), that is, when the loss affects conversational frequencies. Even in these cases, it may present some deficiencies due to the exclusion of some of these frequencies, such as 3,000 Hz (Pérez, Caicedo, Macías, López, & Ossa, 2010).

Like the SAL Index, another index that in principle does not seem to include diagnoses of pathologies other than those caused by noise is the ELI (Early Loss Index). This method provides results for each ear individually, considering only the 4,000 Hz frequency. On this issue, it is important to note that traditionally literature has referred to a typical fall in audiometric recording at 4,000 Hz, which has long been considered characteristic of noise-induced hearing loss (Rytzner & Rytzner, 1981). Furthermore, hearing losses at this frequency and adjacent frequencies have been related by many researchers to the duration of the noise exposure (Burns and Robinson, 1970; Dobie, 1993, 1995; Howell, 1978; Sataloff, 1953). The ELI index is calculated by subtracting a correction value that takes into consideration the age and gender of the patient from the loss at the mentioned frequency (4,000 Hz). As a result, a classification of acoustic trauma is obtained on an increasing scale A-B-C-D-E, from greater to lesser hearing ability (Uña Gorospe et al., 2000). The main criticism of this method is that it is not a preventive method, given that it only considers the 4,000 Hz frequency, and fails to detect 79% of individuals with noise-induced hearing pathology (Vilanova, 2016). One example of this would be high-frequency hearing losses, undetectable on this scale, which have been reported by several researchers in the 12 KHz frequency range (Fausti, 1981) and even from 15 to 17 KHz (Kiukaanniemi, Lopponen, & Sorri, 1992). These high-frequency hearing losses can also occur within a few years of exposure (Hallmo, Borchgrevink, & Mair, 1995). Another common criticism of this method is based on the fact that NOISH does not consider it technically appropriate to make corrections in the audiogram for presbycusis, since it is ultimately a matter of making corrections on a statistical population value (Vilanova, 2016; Pérez et al., 2010).

Various medical studies have found that although the SAL and ELI indices have high specificity (proportion of individuals with good hearing correctly identified), their low sensitivity (ability to estimate as positive cases those who are really ill) does not make them recommendable in epidemiological monitoring programs (López, 1999; Pastrana-González, Ospina, Osorio, & Aguirre, 2013; Pérez et al., 2010).

The Hearing Loss Percentage Index is a widely used and intuitive method (Uña Gorospe et al., 2000) as it considers a "social" assessment of hearing loss, where preliminary thresholds are assessed for the 500, 1,000, 2,000 and 3,000 Hz tones. For its calculation, the losses in dB(A) at these frequencies are added up and the result of the overall hearing loss is obtained, either by means of tables or by using formulas that weight the data obtained at the mentioned frequencies. This index can be calculated for each ear separately and through a further weighting for both ears together (binaural loss). This method is a benchmark in Spanish legislation, since it is used in the classification of disability due to deafness or hypoacusis (Real Decreto 1971, 1999). Its main criticisms are that the assessment favors the better ear, and that hearing impairment is only detected when cases are at an advanced stage (i.e., when the loss affects conversational frequencies), and therefore its use could be reduced to the analysis of cases of disability (Vilanova, 2016).

4. Data and methodology

4.1. Origin of the sample and data extraction

For this research, a sample of 1,418 workers from different economic sectors working in Spanish companies was used. The collaboration of the occupational risk prevention service Ingemédica S.L., enabled the extraction of data relating to the factors that can influence the hearing of these people. On the one hand, occupational factors such as the job they hold, the job's noise level, and seniority in their respective jobs, as well as their time of exposure to daily noise, the conditions of such exposure (use or not of hearing protection or limitation of temporary exposure to noise), or the existence of ototoxic agents. On the other hand, factors unrelated to work, focused on the habits and circumstances of the individuals, such as whether they are frequently exposed to noisy activities (hunting, discotheques, etc.), whether they have a history of deafness in the family, or have suffered from hearing diseases or a history of otology, and whether they take any medication that may affect their hearing. Finally, personal data such as age, gender, nationality, as well as an assessment of their hearing status were also gathered.

It is important to note that of all the data mentioned above, the noise level of the work posts and the hearing status of the individuals are of particular relevance for our analysis. These data are reliable and objective given that, in the case of noise levels, they were obtained through qualified personnel (industrial hygiene technicians) who carried out measurements using the techniques and means set out in the regulation in force (Real Decreto 286, 2006). Likewise, the data for the assessment of the hearing status of the workers were gathered through medical examinations, including otoscopy and audiogram, which were carried out by health personnel specialized in occupational medicine (Ley 31, 1995; Real Decreto 39, 1997). All these data were obtained with the consent of the participants and with the appropriate medical confidentiality, thus the University of Burgos approved this study under code IR28/2020 through its bioethics committee.

4.2. Theoretical model

The model of this research integrates numerous factors that may be related to people's hearing. It is therefore a multifactorial model which, as can be seen in Fig. 1, includes personal, occupational, and extra-occupational variables, whose influence is assessed subjectively through the individual's own perception of their hearing and objectively through different methods of diagnosis and medical assessment (SAL, ELI, and Percentage of Hearing Loss indices), the suitability of which this research aims to assess.

The personal variables involved in this research are gender, age, blood pressure, height, weight, and nationality. The occupational factors are noise level in the workplace, exposure (daily hours, number of years in the current job and/or previous jobs), existence of ototoxic substances, type of activity, and protection against noise (use or not of personal protective equipment, time limitation, etc.). The variables of an extra-occupational origin that have been considered are extra-occupational exposure to noise, existence of a family history of deafness, general illnesses with possible ototoxic effects, otological history, and use of otototoxic medication.

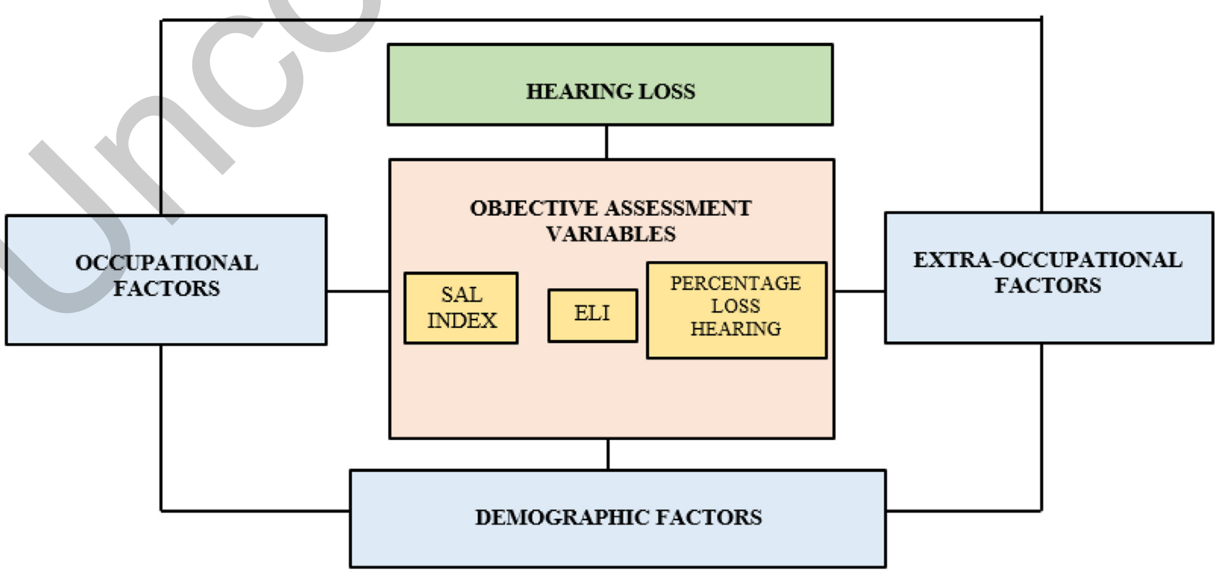

Fig. 1. Theoretical model of the influence of occupational, extra-occupational and demographic factors on the assessment of the degree of hearing loss. Source: Compiled by authors.

Finally, as measurement tools, subjective variables (referred to as such because they are based on opinions and sensations expressed by the sampled individuals themselves and extracted by means of a questionnaire: perception of their own hearing, assessment of the quality of their communication, consideration of the necessary TV volume, hearing in a noisy environment and annoyance caused by intense noise) and objective variables (referred to as such because they originate from data obtained from the audiograms carried out and processed on the basis of the SAL, ELI, and Percentage of Hearing Loss methods) were used.

4.3. Variables

Of all the variables that make up the model, the ones chosen for this study as target variables are the SAL, ELI, and Percentage of Binaural Loss indices. The influence of the noise level present in the workplace and the worker's seniority (number of years working on the job) on these variables will be analyzed.

4.3.1. Sal

The SAL index evaluates the conversational frequencies at 500 Hz, 1,000 Hz, and 2,000 Hz and then takes the arithmetic mean of the hearing loss in decibels of these frequencies and establishes a classification in grade from A to G according to the worsening of the worker's hearing, thus a SAL-A grade indicates that both ears are within normal limits while the SAL-G grade indicates total deafness. Our sample presents the distribution shown in Table 1.

4.3.2. Eli

This index is calculated by subtracting a correction value for presbycusis from the loss at the 4,000 Hz frequency (weighting the loss according to the age and gender of the subject). It is evaluated according to an increasing scale A-B-C-D-E, from greater to lesser hearing capacity, assessing the two ears individually. The sample for this study is distributed according to Table 2.

4.3.3. Hearing loss Percentage rate

This index takes into consideration the loss in decibels at the frequencies of 500, 1,000, 2,000 and 3,000 Hz. To calculate the percentage loss in a single ear, the values of these losses for each tone are added together, the result is divided by 4 and 25 units are subtracted from the value obtained. Finally, this last value is multiplied by a coefficient of 1.5 to obtain the final value. To calculate the overall percentage of loss in the two ears, which is referred to as binaural loss, the loss in the better ear is multiplied by 5 and the loss in the worse ear by 1, the losses are added together and the result is divided by 6. In our sample, this variable has been discretized into groups of intervals of percentage hearing loss and the distribution shown in Table 3 has been obtained.

4.3.4. Workplace noise level

The classification of the noise level present at the workplace was carried out in accordance with the current regulations on the protection of the health and safety of workers against risks related to exposure to noise (Real Decreto 286, 2006), based on the measurement parameters: LAeq.d (Daily Equivalent Noise Level in dB A) and Lpeak (Peak Noise Level). For a better understanding of the results, the four levels have been divided into four groups of noise levels, from low to very high, as shown in Table 4.

4.3.5. Seniority on the job

The length of time performing the job is measured in terms of the number of years during which the subjects in the sample have held the same job. This variable has been discretized for our sample, as shown in Table 5, into different groups with values ranging from less than 3 years to more than 16 years on the job.

4.4. Analysis using Bayesian Networks

When building probabilistic models with many discrete variables, as is the case in our research, a large number of parameters are involved (Castillo, Gutierrez, & Hadi, 1997) that further complicated the process of estimating the joint probability distribution (Heckerman & Wellman, 1995). In order to facilitate the analysis of this type of data and to build probabilistic models that are not overly complicated, we have used Bayesian networks, which are capable of establishing the different dependencies between the variables to be related and also allow us to do so intuitively by

Table 1
Distribution of the sample according to the SAL Index. Source: Compiled by authors.

SAL Grade (Hearing rating)	No. of cases	Frequency %
A (Normal)	972	68.55
B (Almost normal)	419	29.55
C (Slight impairment)	24	1.69
D (Serious impairment)	1	0.04
E (Severe impairment)	2	0.07
F (Profound impairment)	0	0
G (Total deafness in both ears)	0	0
Total	1,418	100

Table 2
Distribution of the sample according to the Early Loss Index. Source: Compiled by authors.

ELI Grade (Hearing rating)	*Right ear*		*Left ear*	
	No. of cases	Frequency %	No. of cases	Frequency %
A (Normal excellent)	*590*	*41.61*	*477*	*33.64*
B (Normal good)	*271*	*19.11*	*285*	*20.10*
C (Normal)	*221*	*15.59*	*240*	*16.93*
D (Suspicion of deafness)	*116*	*8.18*	*148*	*10.44*
E (Clear indication of deafness)	*220*	*15.00*	*268*	*19.00*
Total	*1,418*	*100*	*1,418*	*100*

Table 3
Distribution of the sample according to the Percentage of Hearing Loss rate. Source: Compiled by authors.

Percentage hearing loss (%)	Right ear		Left ear		Binaural (Both ears)	
	No. of cases	Frequency %	No. of cases	Frequency %	No. of cases	Frequency %
0	1,299	91.61	1,256	88.58	1,221	86.11
≥0 < 15	70	4.94	103	7.26	163	11.50
≥15 < 30	32	2.26	35	2.47	28	1.97
≥30 < 45	6	0.42	16	1.13	4	0.28
≥45	11	1	8	1.00	2	0.00
Total	1,418	100	1,418	100	1,418	100

Table 4
Distribution of the sample by noise levels at the workplace Source: Compiled by authors.

Group	Workplace noise level	N° OF cases	Frequency %
1. Low noise level	LAeq.d < 80 and Lpeak < 135	435	30.68
2. Moderate noise level	80 ≥ LAeq.d < 85 and 135 ≥ Lpeak < 137	660	46.54
3. High noise level	85 ≥ LAeq.d < 87 and 137 ≥ Lpeak < 140	109	7.69
4. Very high noise level	LAeq.d ≥ 87 and Lpeak ≥ 140	214	15.09
	Total	1,418	100

Table 5
Distribution of the sample according to seniority on the job. Source: Compiled by authors.

Seniority on the job (Years)	No. of cases	Frequency %
<3	230	16.22
≥3 < 6	317	22.36
≥6 < 10	249	17.56
≥10 < 16	335	23.62
≥16	287	20.00
Total	1,418	100

means of directed acyclic graphs (DAG) (Jensen, 1996). In this way, one can proceed to the factorization of the joint probability distribution (JPD) and obtain the conditional probabilities of the variables that make up the model, $p(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} p(x_i|\pi_i)$, where π_i corresponds to the parents, that is, the nodes with direct incoming links, of x_i in the directed acyclic graph (Ben-Gal, 2008), which enables a reduction in the number of parameters. Both the learning process of the directed acyclic graph (known as structural learning) and the adjustment of the conditional probabilities of the factorization of the joint probability distribution can be performed automatically (Neapolitan, 2004) by progressively refining the model through the implementation of efficient algorithms.

4.5. Model performance

Thanks to the Bayesian network obtained, for each group of the target variables (the three hearing impairment rating indices), a natural classifier has been obtained that defines a threshold of probability of belonging to certain groups. To evaluate this classifier in an appropriate manner, a 10-fold cross-validation (Kohavi, 1995) has been used, carried out by dividing the sample into 10 subsets of disjoint data. Each subset contains N/10 elements and is used once as a test set, so that the remaining data are used to train the model and finally obtain a prediction of the full set. Since we are dealing with binary probabilistic classifiers, we have chosen to perform the validation through the Receiver Operating Characteristic (ROC) curve (Fawcett, 2006). Specifically, we use the Area Under the Curve (AUC), which can be interpreted as a measure of overall accuracy (Fawcett, 2006; Hanley & McNeil, 1982), and whose value is between 0.5 and 1, depending on whether it is a random assumption or it represents a perfect fit. In our case, the mean values of the AUC for the groups into which our three target variables are divided reflect high accuracy of the model, as their coefficients are as follows: 0.90 for the SAL Index, 0.92 for the ELI Index in both ears, and 0.95, 0.93 and 0.90 for the Percentage of Hearing Loss Index for its three types respectively, right ear, left ear, and binaural loss.

5. Results

In order to analyze the results of this research, the following image is the subgraph of the Bayesian network obtained, which relates the target variables of this study (i.e., the SAL, ELI, and Percentage of Hearing Loss indices) with the occupational factors influencing the development of deafness: the noise level at the workplace (obtained through noise measurements) and the length of service at the workplace. The results of the sensitivity analyses for each method of hearing assessment carried out when the occupational factors are taken together are described below.

5.1. Model subgraph

Fig. 2 represents the subgraph relating the variables that are the object of this research, extracted from the general Bayesian network.

5.2. Influence of the noise level and job seniority for the SAL Index.

When analyzing the hearing status of the individuals in the sample using the SAL index, it can be seen from Table 6 that the majority of people have a grade of hearing A or B (i.e., normal or almost normal). With regard to group A (normal hearing), we find that the initial probabilities correspond to 70.32%, increasing to 83.43% in the case of people in jobs with low noise levels and who have only been on the job for a few years (≥3 < 6 years). The worst hearing levels are found in people with a longstanding job seniority (>16 years) in environments with noise levels rated as moderate or high. According to this index, the likelihood of good hearing decreases with seniority, becoming increasingly lower with increasing years of job seniority in virtually all cases, irrespective of the noise level associated with the job. Thus, the SAL index seems to clearly relate that hearing loss increases with job senior-

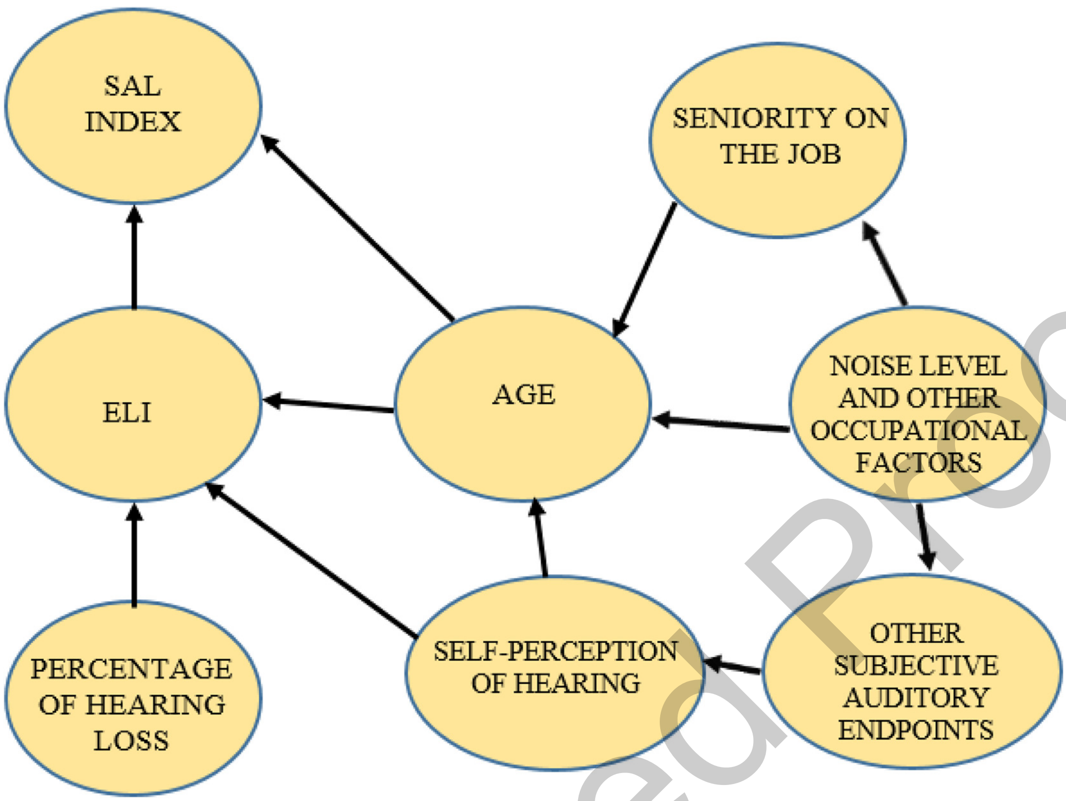

Fig. 2. Relationship subgraph of hearing assessment methods related to occupational factors. Source: Compiled by authors.

Table 6
Probability of hearing loss according to the SAL Index with respect to the variables Noise Level and Seniority in the workplace. Source: Compiled by authors.

Initial probabilities (%)		SAL Index						
		A	B	C	D	E	F	G
		70.32	28.80	0.89	0.00	0.00	0.00	0.00
Conditioned probabilities (%)		SAL Index						
Noise level in the workplace	Seniority on the job (Years)	A	B	C	D	E	F	G
Low	<3	81.90	17.25	0.85	0.00	0.00	0.00	0.00
LAeq.d < 80 and Lpeak < 135	≥3 < 6	83.43	16.09	0.47	0.00	0.00	0.00	0.00
	≥6 < 10	82.74	16.51	0.75	0.00	0.00	0.00	0.00
	≥10 < 16	78.05	20.66	1.29	0.00	0.00	0.00	0.00
	≥16	65.07	33.92	1.01	0.00	0.00	0.00	0.00
Moderate	<3	73.67	26.30	0.03	0.00	0.00	0.00	0.00
80 ≥ LAeq.d < 85 and 135 ≥ Lpeak < 137	≥3 < 6	71.08	28.62	0.30	0.00	0.00	0.00	0.00
	≥6 < 10	68.41	30.61	0.98	0.00	0.00	0.00	0.00
	≥10 < 16	61.61	37.61	0.78	0.00	0.00	0.00	0.00
	≥16	55.07	42.91	2.02	0.00	0.00	0.00	0.00
High	<3	78.79	21.20	0.01	0.00	0.00	0.00	0.00
85 ≥ LAeq.d < 87 and 137 ≥ Lpeak < 140	≥3 < 6	69.55	29.63	0.82	0.00	0.00	0.00	0.00
	≥6 < 10	70.19	26.83	2.98	0.00	0.00	0.00	0.00
	≥10 < 16	66.19	33.10	0.71	0.00	0.00	0.00	0.00
	≥16	56.58	39.74	3.68	0.00	0.00	0.00	0.00
Very high	<3	80.23	19.69	0.08	0.00	0.00	0.00	0.00
LAeq.d ≥ 87 and Lpeak ≥ 140	≥3 < 6	75.53	24.24	0.23	0.00	0.00	0.00	0.00
	≥6 < 10	75.22	24.22	0.55	0.00	0.00	0.00	0.00
	≥10 < 16	63.84	34.74	1.42	0.00	0.00	0.00	0.00
	≥16	61.75	36.95	1.30	0.00	0.00	0.00	0.00

ity, with a less clear relationship to the different noise levels associated with the job, as can be seen in Fig. 3.

5.3. Analysis of sensitivity of the noise level and seniority in the workplace according to the ELI index

In the analysis carried out using the ELI index, it can be seen that for both ears, most of the individuals present a grade of hearing type A (Normal Excellent), B (Normal Good), or C (Normal), as shown in Table 7. With regard to the phenomenon known as "laterality" or difference between the hearing of both ears, the results show that the individuals in the sample present better hearing in the right ear than in the left ear.

As for the variables related in this analysis, with respect to noise level, workers in jobs rated as low noise levels, regardless of their seniority on the job, have probabilities of being in the better hear-

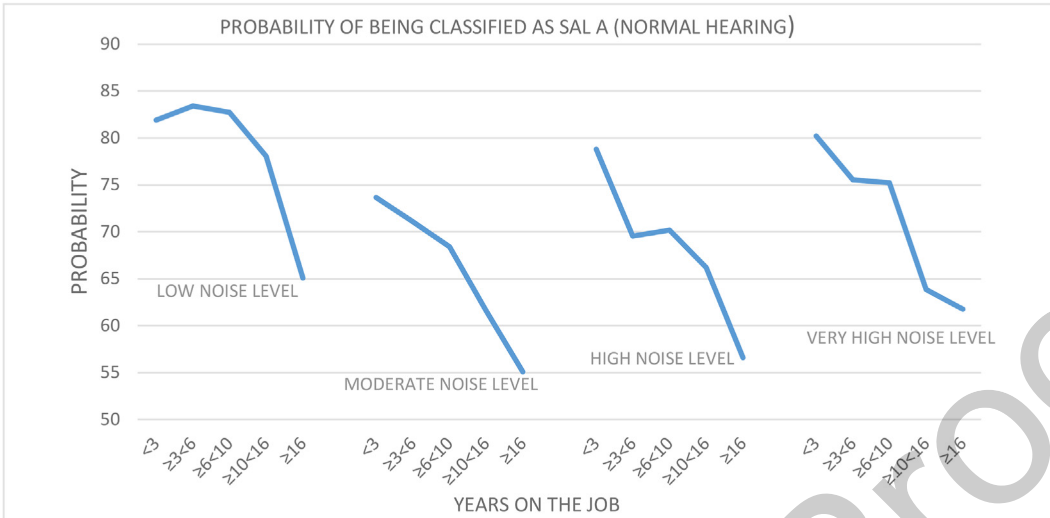

Fig. 3. Probability of normal hearing by Noise Level and Job Seniority according to the SAL Index. Source: Compiled by authors.

Table 7
Probability of hearing loss according to the ELI Index with respect to the variables Noise Level and Seniority in the workplace. Source: Compiled by authors.

		ELI Index									
		Right ear					Left ear				
Initial probabilities (%)		A	B	C	D	E	A	B	C	D	E
		45.36	18.70	16.03	6.55	13.36	35.84	20.21	16.45	10.18	17.33
		ELI Index									
Conditioned probabilities (%)		Right ear					Left ear				
Noise level in the workplace	Seniority on the job (Years)	A	B	C	D	E	A	B	C	D	E
Low	<3	55.70	19.48	18.27	1.50	5.05	49.38	20.84	19.33	3.90	6.55
LAeq.d < 80 and Lpeak < 135	≥3 < 6	60.34	19.63	13.57	2.51	3.95	48.70	23.01	16.03	6.52	5.75
	≥6 < 10	60.17	20.83	13.28	1.94	3.77	47.43	24.34	14.73	6.94	6.57
	≥10 < 16	60.46	18.38	13.07	2.68	5.41	52.52	18.58	13.68	5.51	9.70
	≥16	58.81	19.64	10.18	5.23	6.15	47.47	20.54	14.01	7.96	10.02
Moderate	<3	38.92	18.14	22.95	6.35	13.64	28.40	21.66	20.35	11.16	18.43
80 ≥ LAeq.d < 85 and 135 ≥ Lpeak < 137	≥3 < 6	35.78	20.59	21.04	7.71	14.87	29.59	19.31	20.27	10.56	20.27
	≥6 < 10	36.59	20.61	17.72	7.75	17.33	28.74	20.26	17.69	11.59	21.72
	≥10 < 16	37.35	20.57	15.17	9.77	17.14	30.19	18.99	15.18	12.45	23.20
	≥16	37.06	16.22	14.52	11.86	20.34	28.60	18.27	14.36	13.13	25.64
High	<3	76.09	8.28	10.93	0.94	3.75	46.00	19.51	24.50	2.41	7.59
85 ≥ LAeq.d < 87 and 137 ≥ Lpeak < 140	≥3 < 6	37.81	16.26	19.90	5.64	20.39	28.34	21.24	16.69	16.70	17.03
	≥6 < 10	46.16	17.34	14.27	5.24	17.00	27.15	27.20	16.11	12.77	16.76
	≥10 < 16	46.07	19.50	8.84	6.94	18.64	30.35	24.68	19.18	9.45	16.35
	≥16	47.08	11.39	11.09	5.22	25.23	29.58	22.78	14.74	9.34	23.56
Very High	<3	37.93	11.87	31.25	4.03	14.92	31.89	16.00	21.14	14.74	16.23
LAeq.d ≥ 87 and Lpeak ≥ 140	≥3 < 6	42.37	16.33	19.54	4.78	16.98	35.93	19.11	14.94	10.37	19.65
	≥6 < 10	39.48	20.10	15.09	7.05	18.29	32.35	20.32	13.95	12.79	20.60
	≥10 < 16	43.38	19.62	10.23	8.63	18.14	31.86	18.51	12.17	13.78	23.68
	≥16	50.79	15.07	9.46	9.25	15.43	37.04	18.44	11.44	11.75	21.33

ing group (see Fig. 4) above the initial probabilities (45.36% for the right ear and 35.84% for the left ear). This is not the case for the other groups (i.e., moderate, high and very high noise levels). Moreover, these groups generally show little difference between them in this index. This effect can also be seen if we analyze the probabilities of belonging to ELI E, which represents the worst possible hearing in this index (clear indication of deafness), as shown in Fig. 5, where it can be seen that the highest probabilities of poor hearing are for the moderate, high, and very high noise levels, where again there are few differences between them.

If we look at the job seniority variable, when analyzing the probabilities of belonging to the best hearing group (ELI A), both graphically and intuitively (Fig. 4), we see that this variable does not seem to have much influence, regardless of the noise level to which the worker is exposed. However, in the case of unfavorable hearing status, ELI E (clear indication of deafness), the influence of seniority is emphasized (see Fig. 5), especially for moderate and high noise levels. If we focus on the amplitude of the variation of the probabilities between the different groups established according to noise level and seniority, it seems that the ELI scale shows greater uniformity than the SAL index (i.e., in the ELI scale there is less variation between the maximum and minimum values of each group, therefore it seems to be less sensitive to the influence of these work-related variables).

5.4. Influence of noise level and job seniority on the hearing loss percentage index

In this analysis we observe that the vast majority of the sampled individuals present a percentage hearing loss of 0% (no hear-

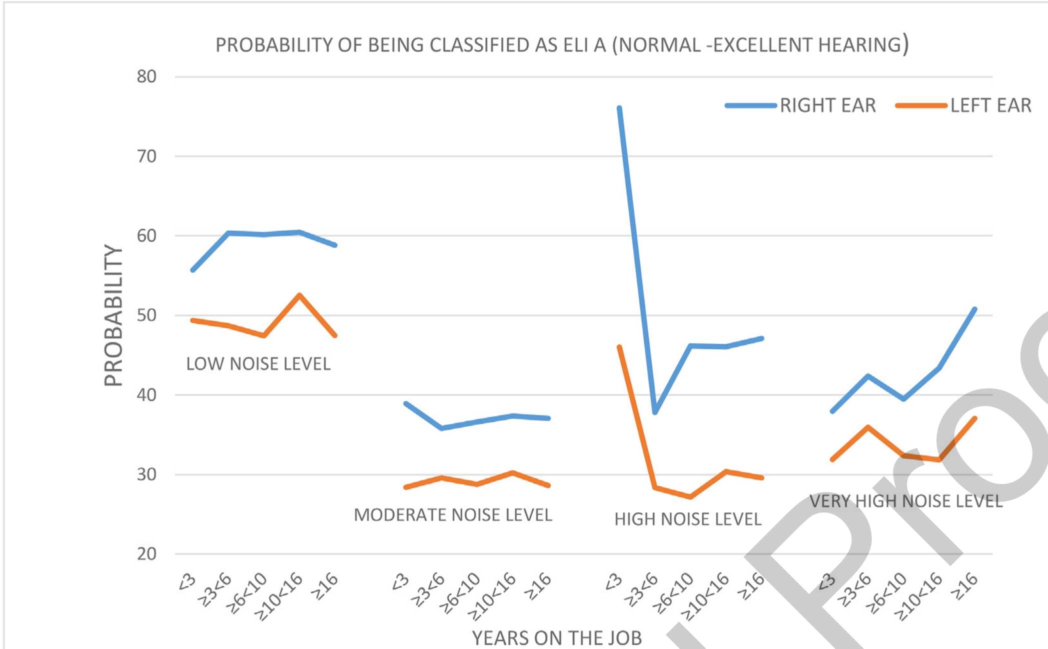

Fig. 4. Probability of normal-excellent hearing by Noise Level and Job Seniority according to the ELI scale. Source: Compiled by authors.

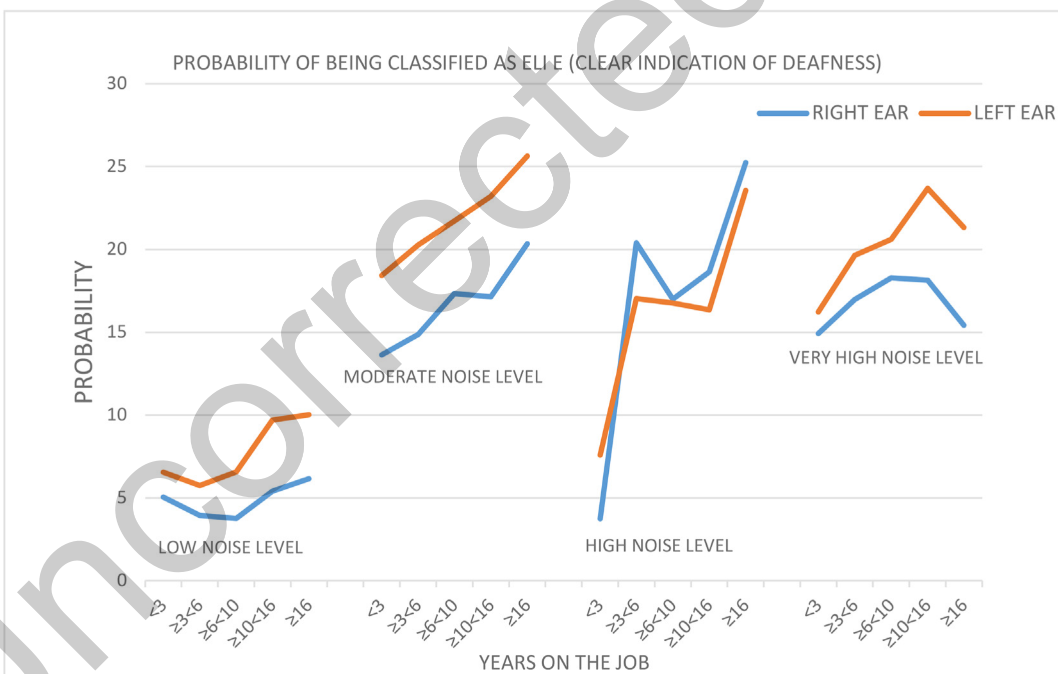

Fig. 5. Probability of "clear indication of deafness" by Noise Level and Job Seniority according to the ELI scale. Source: Compiled by authors.

ing loss), as shown in Tables 8 and 9. We also note that the individuals in the sample generally present better hearing in the right ear than in the left ear if we compare both ears. On the other hand, we found that the initial probabilities of belonging to the group without hearing loss: 94.63% for the right ear, 90.88% for the left ear, and 89.04% for the binaural calculation, increase to their maximum level in the case of people in jobs with low noise levels and low seniority (less than 6 years in the job), presenting in this case a probability of hearing without loss of 99.19% for the right ear, 97.24% for the left ear and 96.84% binaurally.

We find, as shown in Fig. 6, that workers' probabilities of good hearing decreases with increasing seniority, becoming lower and lower with increasing years of job seniority in virtually all cases, regardless of the noise level associated with the job. Furthermore, with respect to the noise level, we find that individuals in jobs rated at low noise levels, regardless of their job seniority, are likely to be in the best hearing group (no hearing loss) above the baseline probabilities in both ears and binaurally. This is not the case for individuals in jobs with moderate, high, and very high noise levels.

Table 8
Probability of hearing loss according to the Hearing Loss Percentage Index (Right and Left ear) with respect to the variables Noise Level and Seniority in the workplace. Source: Compiled by authors.

		Percentage hearing loss									
		Right ear (%)					Left ear (%)				
Initial probabilities (%)		0	≥0 < 15	≥15 < 30	≥30 < 45	≥45	0	≥0 < 15	≥15 < 30	≥30 < 45	≥45
		94.63	3.86	1.34	0.11	0.06	90.88	6.27	1.85	0.72	0.28
		Percentage hearing loss									
Conditioned probabilities (%)		Right ear (%)					Left ear (%)				
Noise level in the workplace	Seniority on the job (Years)	0	≥0 < 15	≥15 < 30	≥30 < 45	≥45	0	≥0 < 15	≥15 < 30	≥30 < 45	≥45
Low	<3	98.64	0.44	0.00	0.82	0.09	96.59	1.81	0.26	1.08	0.26
LAeq.d < 80 and Lpeak < 135	≥3 < 6	99.19	0.56	0.23	0.02	0.00	97.24	1.65	0.79	0.32	0.00
	≥6 < 10	98.90	0.54	0.51	0.04	0.01	96.99	1.97	0.54	0.39	0.11
	≥10 < 16	97.13	1.72	1.13	0.00	0.01	93.78	4.54	1.09	0.41	0.18
	≥16	95.43	3.59	0.95	0.03	0.00	89.91	7.11	2.35	0.44	0.19
Moderate	<3	97.69	2.26	0.00	0.00	0.05	95.68	3.02	0.43	0.43	0.43
80 ≥ LAeq.d < 85 and	≥3 < 6	95.36	3.73	0.89	0.02	0.00	92.66	4.61	1.90	0.83	0.00
135 ≥ Lpeak < 137	≥6 < 10	93.35	4.74	1.75	0.07	0.09	91.02	5.66	1.91	1.05	0.36
	≥10 < 16	90.65	6.97	2.26	0.00	0.12	84.45	12.22	2.16	0.78	0.39
	≥16	89.12	7.07	3.44	0.26	0.11	82.21	11.57	4.51	1.10	0.62
High	<3	98.54	1.46	0.00	0.00	0.00	96.84	2.21	0.32	0.32	0.32
85 ≥ LAeq.d < 87 and	≥3 < 6	93.58	5.28	1.08	0.06	0.00	89.63	6.49	2.71	1.16	0.00
137 ≥ Lpeak < 140	≥6 < 10	91.66	4.84	2.89	0.56	0.05	90.26	5.27	2.36	1.34	0.76
	≥10 < 16	91.60	6.40	1.87	0.00	0.14	86.76	10.53	1.77	0.62	0.32
	≥16	89.78	5.57	3.96	0.55	0.14	81.65	11.22	4.79	1.50	0.84
Very High	<3	98.55	1.41	0.00	0.01	0.04	96.69	2.31	0.33	0.34	0.33
LAeq.d ≥ 87 and Lpeak ≥ 140	≥3 < 6	96.42	2.84	0.65	0.09	0.00	93.63	4.08	1.62	0.66	0.00
	≥6 < 10	95.39	3.77	0.30	0.46	0.07	94.09	4.20	1.06	0.52	0.12
	≥10 < 16	92.06	5.59	2.15	0.00	0.19	86.10	10.67	2.11	0.75	0.36
	≥16	90.77	6.60	2.35	0.26	0.02	84.28	10.57	3.84	0.90	0.42

Table 9
Probability of hearing loss according to the Hearing Loss Percentage Index (Binaural) with respect to the variables Noise Level and Seniority in the workplace. Source: Compiled by authors.

		Percentage hearing loss Binaural (%)				
Initial probabilities (%)		0	≥0 < 15	≥15 < 30	≥30 < 45	≥45
		89.04	9.89	1.01	0.06	0.00
Conditioned probabilities (%)		Percentage hearing loss Binaural (%)				
Noise level in the workplace	Seniority on the job (Years)	0	≥0 < 15	≥15 < 30	≥30 < 45	≥45
Low	<3	96.06	3.12	0.00	0.82	0.00
LAeq.d < 80 and Lpeak < 135	≥3 < 6	96.84	2.99	0.17	0.00	0.00
	≥6 < 10	96.51	3.00	0.49	0.00	0.00
	≥10 < 16	93.36	5.55	1.09	0.00	0.00
	≥16	89.20	10.11	0.68	0.02	0.00
Moderate	<3	93.37	6.63	0.00	0.00	0.00
80 ≥ LAeq.d < 85 and 135 ≥ Lpeak < 137	≥3 < 6	90.00	9.42	0.58	0.00	0.00
	≥6 < 10	86.95	11.63	1.41	0.00	0.00
	≥10 < 16	82.54	15.81	1.65	0.00	0.00
	≥16	80.52	16.93	2.39	0.15	0.00
High	<3	95.37	4.63	0.00	0.00	0.00
85 ≥ LAeq.d < 87 and 137 ≥ Lpeak < 140	≥3 < 6	85.86	13.36	0.78	0.00	0.00
	≥6 < 10	85.92	11.31	2.77	0.00	0.00
	≥10 < 16	84.94	13.83	1.24	0.00	0.00
	≥16	80.31	16.05	3.33	0.31	0.00
Very High	<3	95.25	4.75	0.00	0.01	0.00
LAeq.d ≥ 87 and Lpeak ≥ 140	≥3 < 6	91.61	8.04	0.36	0.00	0.00
	≥6 < 10	90.57	9.06	0.37	0.00	0.00
	≥10 < 16	84.55	13.63	1.82	0.00	0.00
	≥16	82.82	15.44	1.55	0.19	0.00

These workers are only likely to be in the best hearing group above the initial probabilities if they have low or medium seniority.

In view of these results, it seems that the Hearing Loss Percentage Index is clearly related to job seniority, thus hearing loss

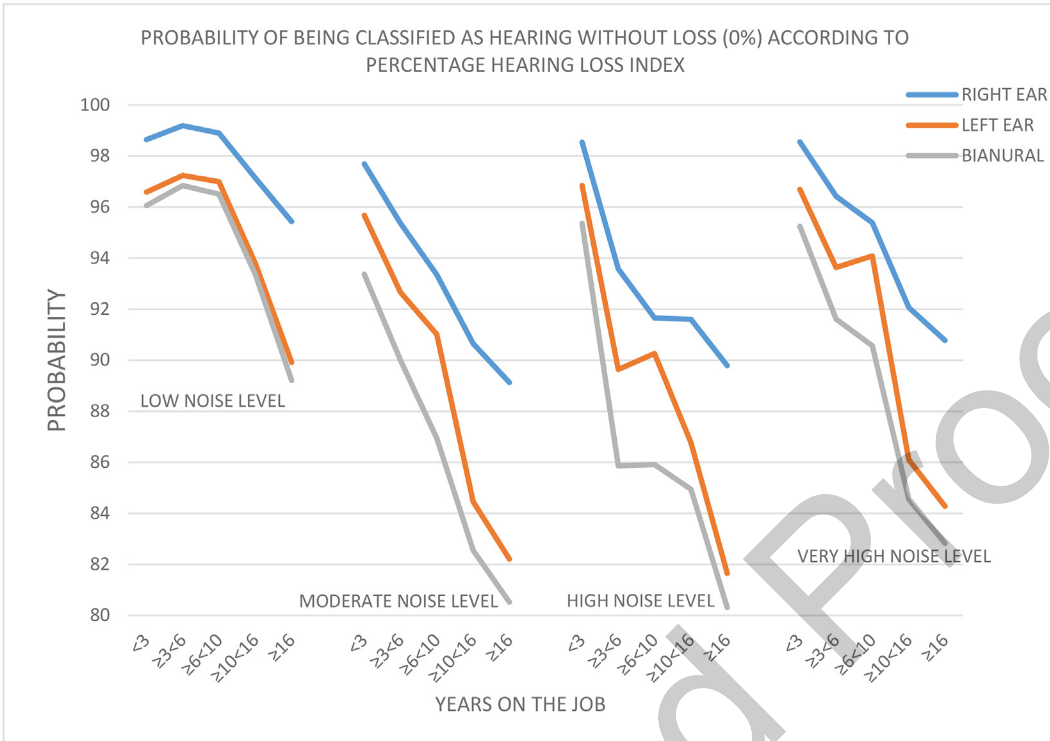

Fig. 6. Probability of No Hearing Loss (0%) by Noise Level and Job Seniority according to the Percentage of Hearing Loss Index. Source: Compiled by authors.

increases with length of service, but is not so clearly related to the noise level of the jobs, except when these levels are low.

6. Discussion

In this research, some of the most widely recognized methods used in the field of occupational risk prevention to assess the hearing status of workers have been contrasted. These methods are the SAL, ELI, and Percentage of Hearing Loss Indexes. The aim was to test the behavior of these indices under the influence of various factors associated with the development of deafness, and specifically, from an occupational perspective, the noise level, and the length of service of the workers in their respective jobs. The richness of the sample, with 1,418 individuals, and the multitude of data gathered from each of them, have led to their analysis being carried out using Bayesian Networks. These networks have been validated under the criterion of the Receiver Operating Characteristic (ROC) curve and specifically by means of the Area Under the ROC Curve (AUC) whose value is between 0.5 and 1, depending on whether it is a random assumption or it represents a perfect fit (Fawcett, 2006; Hanley & McNeil, 1982). Our model is robust, as the three mentioned indices have obtained very good results for all their hearing impairment classification groups (all of them with values above 0.90).

With regard to the hearing status of the workers, considering the vast diversity of the sample, made up of individuals from all economic sectors and jobs of very different natures, we generally found good health from a hearing point of view on the basis of the three indices mentioned. Likewise, the results obtained in the two indices calculated for both ears, the ELI scale and the Hearing Loss Percentage Index, support the phenomenon of laterality or difference in hearing levels between both ears found by other researchers (Axelsson et al., 1987; Kannan & Lipscomb, 1974; Rudin et al., 1998; Ruiz, 1997), in favor of the right ear as the ear with the better hearing of the two for the majority of people.

With this said, we can compare the results for the three hearing assessment methods. When we evaluated the hearing status of the individuals in the sample under the SAL Index, we found that the majority of people had a hearing grade A or B, that is, normal (68.55% of the sample) or almost normal (29.55%). Only three people had hearing impairments and no individual in the sample was graded SAL F or G, which in practice are related respectively to profoundly worsening and total deafness. This contrasts, for example, with the results obtained with the ELI scale where many more people were rated as having poor hearing. These findings seem to support the criticisms made by several researchers of the SAL Index, when they state that it only takes into consideration the hearing of the better ear of the two and ignores the evolution of the worse ear and that it does not make an early diagnosis as it only assesses the frequencies of 500, 1,000, and 2,000 Hz (Vilanova, 2016). Its use may be limited to the most advanced cases of deafness (Marqués et al., 1988; i.e., when the loss affects conversational frequencies), and even then, in these cases it may present deficiencies by excluding some of these frequencies, such as 3,000 Hz (Pérez et al., 2010). In the next step we use the multifactorial model obtained in our Bayesian network to predict how likely an individual is to be included in the different groups of the SAL Index based on the noise level of their job and their job seniority. The noise level seems to have a logical influence on the SAL Index only when the noise level is classified as low noise, so our results are in line with the opinion of several researchers who report that this method is not able to detect high percentages of individuals with noise-induced pathology (Vilanova, 2016). On the other hand, our results clearly show that the probability of good hearing in workers decreases as their seniority increases, being increasingly lower as the years of continuity in a job increase in practically all cases, regardless of the level of noise associated with the job; so it could be a useful method in the assessment of deafness when it is influenced by temporal aspects (e.g., the age of the individuals or the time of exposure to agents that are harmful to the hearing system).

In the analysis carried out under the ELI scale, we found that for both ears, most of the individuals presented a hearing grade of type A (Normal Excellent), B (Normal Good), or C (Normal). However, in the ELI index, unlike the SAL index, we found individuals with the worst possible score, ELI E (clear indication of deafness). Specifically, 15% of individuals have this grade of deafness in their right ear and 19% in their left ear. When we use our model to predict how likely an individual is to belong to the different groups of the ELI scale based on the work factors selected in this research, our results show that neither of the two variables (i.e., neither noise level nor, above all, seniority in the job) seem to have a significant influence on this index. The low influence of the noise level in the workplace seems to confirm some of the criticisms that this index has received from other researchers who describe it as a method that is not preventive, and which fails to detect 79% of individuals with noise-induced hearing pathology (Vilanova, 2016). One of its limitations is that it only uses the 4,000 Hz frequency, when in fact noise is usually present at a much higher frequency range. On the other hand, the almost null influence on this method of seniority in the job that we have found in our research could be closely related to the individual's own age. Our findings would confirm the main criticism of this method, which is that it makes corrections based on the age of the individual, assuming that people will develop hearing loss over time, regardless of exposure to other factors that may exacerbate it. These types of corrections are not technically adequate, as they are, in short, corrections on a statistical population value (Vilanova, 2016; Pérez et al., 2010) and could mask the detrimental influence of other factors.

If we look at the Hearing Loss Percentage Index, we observe that the vast majority of the individuals sampled do not present any hearing loss. Specifically, the percentage of individuals with 0% hearing loss is 91.61% for the right ear, 88.58% for the left ear, and 86.11% binaurally. In general, this index detects fewer cases of people with hearing difficulties than the other indices (such as the ELI scale), so our results seem to support the criticisms made by other researchers who find that in this type of assessment the better ear is favored, and that hearing impairment is only detected when cases are advanced (Vilanova, 2016).

7. Conclusion

In our multifactorial predictive analysis, we found that the Hearing Loss Percentage Index is clearly related to seniority in the workplace, thus hearing loss increases with length of service, but is not so clearly related to the level of noise in the workplace, especially when we found noise levels ranging from moderate to high. On the other hand, it has been proven that the ELI scale is the least restrictive of the three methods, therefore it does not qualify virtually the entire population with good hearing levels. However, the use of a single frequency band (4KHz) in this index and its weighting system, which assumes presbycusis as a disease that all individuals will develop, means that this scale is practically incapable of discriminating hearing problems caused by exposure to noise, both in terms of its intensity level and the time of exposure to it, thus its use in the field of occupational risk prevention is very limited. These arguments could help explain the high specificity, but low sensitivity found by several researchers, especially the SAL and ELI indices (López, 1999; Pastrana-González et al., 2013; Pérez et al., 2010), which does not make them advisable for use in epidemiological monitoring programs. Thus, we can conclude that all three methods are deficient in detecting noise-related hearing problems in most workplaces, and especially in doing so in a preventive way. It is logical to think about the use of other hearing assessment methods such as modified Larsen, NIOSH, or the Klockhoff scale, but these assessment systems also have significant limitations (Pastrana-González et al., 2013) that have led to their scarce use by occupational medicine specialists. For all the above reasons, it seems reasonable to consider the need to build new scales, or even to work on improving the existing ones. In the meantime, occupational health monitoring professionals are advised to use several methods simultaneously in order to obtain a better assessment of the hearing status of patients.

Conflict of interest

The authors declare that there is no conflict of interest in the publication of this paper.

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