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How activity type, time on the job and noise level on the job affect the hearing of the working population. Using Bayesian networks to predict the development of hypoacusia

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A B S T R A C T

In this research we identify the main factors believed to trigger occupational hypoacusia in an effort to increase our knowledge of how this occupational disease occurs and develops. With this goal in mind, we have gathered various demographic/personal, occupational and non-occupational data from a heterogeneous sample of 1418 workers. The data selected include the noise levels to which the individuals in the sample are exposed. This entailed taking measurements at their respective jobs, as well as doing an objective assessment of their hearing ability, which required administering medical hearing tests. Lastly, the workers completed a survey on various habits and other factors deemed to be influential, and on the respondents' own perception of their hearing.

Bayesian networks were used to obtain the conditioned probability of developing hypoacusia based on the data collected from the sample. Specifically, for this study we used the general network created by the relationships between all of the factors associated with developing hypoacusia in order to analyze the influence individually and by grouping three specific variables: activity sector, noise level and time on the job.

This work yielded a considerable database that can be used to conduct a multitude of analyses intended to study and predict the hearing acuity of the working population under different scenarios. Specifically, in the case at hand, the Bayesian network obtained indicates that the three factors analyzed influence the hearing of the individuals, though to different extents. The least influential factor involves the sector of activity, followed by the noise level on the job, which varies noticeably in favor of better hearing for workers in jobs whose noise levels are rated as low. Finally, we deemed time on the job (which is also related to age), as the most influential factor as it exhibits the largest differences among its potential states, with workers whose time on the job is rated as low or medium exhibiting the best likelihood of having good hearing.

1. Introduction

Some 360 million people around the world are affected by hypoacusia to varying extents, with the effects ranging from physical to social and psychological (Díaz et al., 2016). Deafness can cause problems involving spoken communication, cognitive deterioration and mental health (Lin et al., 2013; Mohr et al., 2000; Pascolini and Smith, 2009; Van Vliet, 2005). It can even entail a higher risk of mortality (Hallam et al., 2006; Yueh et al., 2003). When we speak of the factors that determine the risk of developing hypoacusia as an occupational disease, the most typical trigger for this disease is noise (Fernando Pablo, 1996), although other majors factors include the sound pressure level, the type of noise, the noise exposure time and age, as well as the characteristics of the worker, the working environment, the distance and position relative to the sound source, gender, diseases, osteoclerosis and deafness due to cranial trauma, among others (Fernando Pablo, 1996). This study focuses on noise, the duration of the noise exposure and the nature of the activities carried out by the individuals as factors in the development of hypoacusia.

In terms of noise, some 80 million Europeans are routinely exposed to noise levels in excess of the tolerance limit (65 dB) specified by the World Health Organization (WHO) (Sanz López, 2013). Direct and indirect exposure to this physical phenomenon accounts for 11% of workplace accidents. As concerns work-related diseases, it is calculated that hypoacusia caused by noise ranks third among occupational diseases (Bartosińska and Ejsmont, 2002). It shares this place with pathologies involving years lived with disability (YLD), behind depression and unintentional injuries (Díaz et al., 2016)

The development of legislation and technical reference documentation on noise intensified in the second half of the 20th century, following the end of the Second World War. In the 1950s, and with the publication of the book *The Effects of Noise on Man* in 1970, Kryter (2013) related noise exposure time and noise intensity to the probability that workers exposed to different noise levels would suffer hearing damage. In 1975, the International Organization for Standardization drafted the ISO 1999 standard, on determining the hearing risk

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from noise exposure. This was also done by means of conventions of the International Labour Organization, such as convention number 155 of 1981 (OIT 155, 1981), on occupational safety and health and the working environment, ratified by Spain in 1985. This regulation laid the foundations for Spain's national law, and in 1989 led to Royal Decree 1316/1989 (RD 1316, 1989), which was updated fifteen years later to create the current law in Royal Decree 286/2006 (RD 286, 2006), on protecting the health and safety of workers against risks related to noise exposure.

In 2006, Royal Decree 1299/2006 (RD 1299, 2006) was published in Spain, which approved the new listing of occupational diseases in the Social Security system, and laid down criteria for reporting and recording them. This regulation includes noise-related hypoacusia or deafness in group 2 of the occupational diseases, cataloguing it as neurosensory, bilateral and irreversible occupational deafness for frequencies 3–6 KHz related to jobs that expose workers to constant noises whose equivalent daily sound level is equal to or higher than 80 dB. The latest publications from the Observatory for Occupational Diseases and Diseases Caused or Aggravated by Work (Observatorio de Enfermedades Profesionales, 2017), created by the Spanish government, show that in Spain, of all the occupational diseases recognized in 2016, 3.08% involved hypoacusia, and of all the diseases deemed to have been caused by work, 0.51% were associated with the ear.

In order to model and analyze the influence of the potential factors affecting hearing loss, we consider a representative sample of 1418 workers and use data-driven Bayesian networks for probabilistic modeling and inference (Castillo et al., 1997). Bayesian networks are increasingly popular machine learning tools that are widely applied in health studies – e.g. in healthcare (Friedman et al., 2000; Lucas et al., 2004; Mani et al., 2005) or disease transmission (Lau et al., 2017) – particularly in problems involving discrete variables. Bayesian networks provide a sound methodology to define parsimonious joint probabilistic models for the variables of interest (hearing loss and influential factors in this study) by considering only the relevant marginal and conditional dependence relationships among the variables (García-Herrero et al., 2017; Pittavino et al., 2017), as learned from the available data using efficient learning algorithms (Acciardi, 2008). This provides users with efficient modeling and analysis tools for probabilistic data analysis (Koller and Friedman, 2009) as an alternative to more complex techniques, such as neural networks or the analysis of hierarchical multilevel trajectories (Peter et al., 2016; Shipley, 2009).

This research focuses on the working population and utilizes Bayesian networks to analyze the probability of developing hypoacusia based on multiple variables, which in our case are grouped as demographic and personal factors (meaning those that characterize a specific population), occupational factors (those related to the working conditions in different companies) and non-occupational factors (those that are manifested outside the work environment). This study considers the hypothesis that the combination of these factors affects the hearing health of people, which is why the sensitivity analyses generated with the Bayesian network proposed consider all of the model's variables, such that every factor is involved in each analysis.

Finally, it should be noted that this study was designed for the purpose of answering the basic questions of how and why some workers develop hypoacusia. How do the main occupational factors influence this? In what proportion? To answer this, one of the main lines of this research focuses on studying the noise level and time on the job variables in the primary sectors of activity.

2. Framework. Relationship between hypoacusia and occupational factors

We define occupational factors as those related to the working conditions that could in some way have an effect on the development of hypoacusia.

There are many papers and studies that relate the noise that is produced in the workplace to the hypoacusia suffered by part of the population. Occupational noise, therefore, is a contaminant of great interest that can negatively influence the health of workers who are exposed to it at their work center (Hernández Díaz and González Méndez, 2007). As concerns the characteristics of the noise to which a worker is exposed, the consequences that the noise exposure has on hearing function vary depending on several factors, including the type of noise, its intensity, and the individual's chronicity and susceptibility (Nowak and Bilski, 2003). Fernando Pablo (1996) regards the noise type as a basic factor in terms of the frequency spectrum it exhibits, as well as of its stable, intermittent, fluctuating or impacting nature. This author concludes that it is generally accepted that constant noise is more tolerable than intermittent noise. As concerns the frequency of the noise, it is generally considered that noise that is mostly distributed at frequencies above 500 Hz is more harmful than noise with predominantly low frequencies. As for hearing thresholds, it is important to note that a typical drop was identified in the hearing tests at 4000 Hz, which has long been considered to be indicative of noise-induced hypoacusia (Rytzner and Rytzner, 1981). Narrow-band noises are also considered more dangerous than broadband noises. Impact noises, when very loud, can cause immediate injury due to acoustic trauma (Fernando Pablo, 1996). According to Sanz López (2013), as concerns the intensity, time and intermittency, hearing loss induced by an average noise in a group of workers increases with noise intensity and exposure time almost linearly. In a workplace with a constant noise intensity, the rise in noise-induced hearing loss over time approaches an exponential function. Likewise, according to Fernando Pablo (1996), the importance of the level to the development of hypoacusia is essential: "Even if no exact relationship can be established between the sound pressure level and hearing damage, it is obvious that the higher the sound pressure, the greater the hearing damage (loss of hearing), but the relationship between the two is not linear". Given current regulations and the studies presented to date, the limit for preventing hypoacusia if exposed to a constant noise over 40 h a week is considered to be 80 dB.

Another vitally important factor is noise exposure time, which is typically considered from two aspects, according to authors like Fernando Pablo (1996). One is the hours/day or hours/week of exposure, and the other is the time on the job, or the number of years that the worker has been in a job with a given noise level. If the exposure is interrupted, the damage is reduced as the ear can recover from listening fatigue. Apparently the ear can withstand more energy if the exposure is intermittent instead of constant when faced with a single impulse of short, intense noise (Ward, 1995). According to Borg (2001), most noise-induced hearing loss occurs in the first five years of exposure. Thus, the damage rises quickly at first, but then slows gradually. López González (1981), who conducted a study with 88 workers at the "Desembarco del Granma" textile plant who had been on the job more than eight months, concluded that the noise pollution present had a negative effect on the health of the personnel exposed, despite the short exposure time, leading to hearing problems. There is also research, like that by Talbott et al. (1990), who did a study of 245 individuals ranging in age from 56 to 68 who retired after 30 years of work, and found, by way of hearing tests, severe hearing damage in 67% of the oldest workers (from 64 to 68 years of age). Other studies also agree and predict that occupational hypoacusia will more often be present in old individuals than in young ones (Delgado, 1991; Mcshane et al., 1991). There are likewise studies that propose that the harmful effect of noise is proportional to the duration of the exposure (Clemente Ibáñez, 1991), with many authors agreeing with this conclusion, including Sataloff (1953), Howell (1978), Burns and Robinson (1970) and Dobie (1995). We can state that there is a direct relationship between the length of the noise exposure and the presence of hearing loss, especially at 4000 Hz and nearby frequencies (Burns and Robinson, 1970; Dobie, 1995; Howell, 1978; Sataloff, 1953). As for the form in which deafness or hypoacusia occurs, there is evidence that over the long term, noise-induced hearing