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# Mitigating the impact of occupational noise exposure for elderly workers: setting the functional requirements for an ANC system

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**Abstract**

Noise affects people in very different aspects and in almost every aspect of our daily life. The most prominent impact of noise exposure is hearing loss. However, it can also impair people at their work settings due to other effects rather than hearing loss. Older works tend to be more susceptible to noise exposure effects at work, firstly because most of them already have some 'natural' hearing loss, as a results of the ageing process, and secondly because they also tend to be more susceptible at an psychological level. The current study is an attempt to describe the potential problem and to make a survey to identify the available active noise cancelation systems, as well as to specific the main requirements of this type of systems to be applied in such contexts. Several aspects of characteristics of the ANC systems were identified and are presented in this study. From the obtained results it was possible to have a clearer idea about the potential of this technology, and to confirm that this type of solution can be extremely important as a component of an active ageing program, as the preservation of hearing will also impact on the social life of the exposed workers.


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## 1. Introduction

Literature on the demographic implications of ageing populations has extensively demonstrated that there are many societal changes that can, may, and should occur worldwide to support the growing portion of the global population that is over 65. In Europe and North America, where more data is available and published, one can already see changes taking place in workforce demographics, as traditional retirement age is challenged due to personal or national financial situations, as well as changes in cultural norms. The changes in demographics have begun to affect just about every market sector including healthcare, finance, insurance, food, durable goods, electronics, and the automotive industry [1] Although most of the analysis about these changes effects have been centered in the market, for example, in terms of buying and consumptions habits, less attention has been given to how demographic shifts will impact the future of the workforce and workplaces.

Companies and other employers need to address an ageing workforce and place themselves in a strong position to tackle the challenges this "new" reality may impose. Employers need to capitalize on their changing workforce in order to stay on the edge of their market and prevent lost knowledge due to massive retirement departures. Although ageing is often presented as a risk factor from the human factors and ergonomics point of view[2], it could alternatively be seen as an advantage, as older employees tend to have other interesting characteristics for employers, such as a greater experience, knowledge about the field, and relevant "know-how".

The main physiological effect of noise exposure is hearing loss, which mainly affects workers that are continuously exposed to high noise levels. There are also other well-demonstrated effects at a psychological level, such as lack of attention, interferences with memory, and sleep impairment. Some of these effects are clearly related to the performance that workers will have at their workplaces.

Older workers are a group of workers with an increasing susceptibility to noise, mainly because they already have a deficit in their performance due to the ageing process, also called presbycusis. This phenomenonis presumedto begin after the age of 35 but becomes more pronounced with advancing age and is experienced by older adults [3] Hearing loss can include a loss of sensitivity to high frequency tones, difficulty understanding speech, problems localizing sounds, and increased sensitivity to loud noises. According to Yeomans [4], this can cause safety concerns, for example if they do not hear hearing safety alarms, or understand some oral instructions and, in extreme cases, may lead to vertigo and an increase in the risk of falling [5, 6]. Therefore, and assuming also that this deterioration of hearing will be more pronounced as age increases, working noisy environments will also affect the safety of older workers, as they will be more prone to have communication difficulties and that can lead them to experience more occupational safety implications and

The deterioration of hearing with age can also be aggravated by being exposed in work noisy environments. Insuch environments, the hearing loss may also lead to communication difficulties,whichmay results in occupational safety implications and lead to social isolation [7].

According to Mitzner et al. [8], presbycusis is a condition associated with decreased sensitivity to higher frequency sounds (over 6000 Hz), which can also be added to the hearing loss that may results from the exposure to work at noise, typically in the mid-frequencies. Because of that, and according to the same authors, older workers may demonstrate decreased sensitivity to a large part of the entire auditory spectrum. These accumulated hearing deficits may lead older adults to experience difficulties in processing auditory information and demonstrate a reduced ability to filter out background noise [9]. Another example given by Barr and Giambra [10] is that older adults tend to miss information from multiple noise sources in a noisy environment because they have to selectively attend to pertinent information received by the left or the right ear.Therefore, these factors associated with age-related auditory impairments may interact in the work environment to reduce older adults' abilities to meetjob-related demands[8]

Nichols et al. [11] also emphasize that safe and efficient systeminteraction can depend on the user's ability to hearnormally and that older adults can be affected by that as their hearing ability show declines over time. The authors also refer specific characteristics of hearing that may play an important role on impairments caused by noise exposure. For example, they refer the auditory acuity that occurred more in older workers. According to the authors, high frequency sounds are used as an alert or alarm in several devices or machines, but older adults are sometimes unable to perceived these stimuli. Accordingly, they suggested that the high-frequency sounds should be avoidedin any system or product that older adults might use.

Another important aspect is auditory localization. Abel et al. [12], for example, have also suggested that some older adults are less capable to localize sounds in a specific room. High frequency hearing impairment tend to turn localization harder, particularly in the elevation dimension (high or lower)rather than in the lateral (right or left) [13].Furthermore, higher-frequency stimuli are harder tolocalize for all ages because high-frequency stimulireach both ears at the same time [14].According to Nichols et al. [11],this reduced ability to localize high-frequency sounds justifies again the need to avoid this type of stimuli. When designing auditory stimuli for older adults it should be acknowledge that the stimuli should be presented between 5000 and 8000 Hz.This problem of designing auditory alarms or signals is particularly useful when designing such alarms for workplaces or other scenarios where the user islikely to remain in the same space.

Finally, there is also the problem of the degradation of the stimulus environment. This is a difficulty that highlights the need to think about alternative ways to present information other than the auditory way when the background noise is relevant. It is quite likely that speech perception can be affected in high-noise environments and for older adults [11].

Recently, several advances in noise reduction and control systems have been developed as consequence of the increasing awareness and scientific evidences of the health problems arising from noise exposure and also due to more strict legislation. There are plenty of solutions available to minimize occupational noise exposure, but it is possible to mention that, at a technical level, there are two main types of solutions in the market, the passive and active solutions.

Passive noise control solutions, also called classical solutions, include several types of solution that are mostly based on their mechanical properties or the acoustical behavior of the applied materials and can include solutions such as insulation, silencers, vibration mounts, damping treatments, absorptive treatments such as ceiling tiles, and conventional mufflers (automotive industry). However, passive solutions do not always provide effective sound attenuation and additionally they can be bulky, heavy and expensive and, therefore, not viable to implementation in specific and more difficult cases.

On the other side, active solutions, also called active noise cancelation (ANC) systems is a promising technology that have been used in the acoustics area with some success. Currently, the state-of-the-art ANC based devices are usually headsets, which do not work in large rooms and do not address, at least so efficiently, the high-frequency noise. However, more recently there have been some attempts to develop new technologies addressing personal zones, such as car seats.

Within this emergent ANC based devices, there is a few companies trying to develop and selling these productscommercially, such as the most prominent case of Silentium[15], which is offering a varied range of solutions. Two good examples of these solution include the *Quiet Buble*$^{TM}$ *family* –QB1TM- which is an active noise reduction headset, or the QB2TM, which is a noise reduction solution introducing a personal quiet zone around passenger's head in a car. They also develop the *S-Cube development kit* (SCDK$^{TM}$), which is a solution that reduces low/medium frequency noise more than 10dB(A). Applications of this model include noise reduction for server/networking equipment, HVAC equipment for both residential and automotive markets.

Particularly the automotive industry has pushed advances in this area. Honda, for example, offers an ANC technology that reduces low frequency noise in the interior of the car, specifically, in the frequency range below 100 hertz, ANC results in a 10 dB reduction in noise level[16].

Nevertheless, the ultimate goal of this study is to define functional characteristics for a new product, a one with a technology that has unique specific features that can make this new product advanced when compared to the competing technologies.

The idea of this functional analysis is to be focused on professionally active older adults as primary end-users of its technology. The target audience and the potential buyers of this systems will be companies and public organizations in which older adults are employed and performing indoor work in an office, a factory or any other kind of noisy workstation. Eliminating or reducing excessive noise at work is not simply a legal responsibility for employers; it is also in an organization's commercial interests. The safer and healthier the working environment, the lower the probability of costly absenteeism, accidents and under-performance and early retirement.

Accordingly, This study aims at analyzing the functional needs for the introduction of an emergent technology that is based on the use of an Active Noise Cancelation (ANC) system, especially designed for elderly people that work in noisy environments. The goal of the study is to define a set of defined specifications for the ANC solution.

## 2. Methods

The main methodology adopted for this functional specifications definition was a review of the scientific and Technical literature about the impact of noise for individual performance and in particular for older workers, as well as a preliminary survey about the technological characteristics of the ANC systems currently available.

According to the specifications of the target-users, the solutions to be implemented and tested should be assessed not only at a technology level, but also at the end-users level, as they will be the main beneficiaries of the developed solution. Accordingly, the solution should be developed considering an user-centered methodology, i.e., developed based on human factors and ergonomics principles and focused on the users' needs and abilities, considering their feedback at all the stages of the solution development.

## 3. Results and discussion

### *3.1. Impact of occupational noise on elderly workers*

Noise-induced hearing loss (NIHL) is the most common occupational disease in Europe, accounting for about one third of all work-related diseases. It is estimated to affect around 16% of the adult population [17]. Its prevalence increases significantly with age, with almost 35% of the 50+ population and 50% of 85+ population suffering from hearing problems [18]. NIHL is usually caused by prolonged exposure to loud noise. The first symptom is normally the inability to hear high-pitched sounds. Unless the problem of excessive noise is addressed, a person's hearing will deteriorate further, including difficulties detecting lower-pitched sounds.

Hearing problems affect the ability to communicate and, as such, it impacts not only the hearing impaired individual but also his or her family, colleagues, and social surroundings, and depending on the severity of the disability, can result in feelings of frustration, anxiety, low self-esteem, and social isolation from work colleagues, family and others [19, 20, 21]. Equally important, high surrounding noise greatly impacts communication, as a speech level at the ear of the listener that is at least 10 dB higher than the surrounding noise level is required for effective communication. Exposure to high noise can also cause irritation, stress and circulatory disorders. In fact, occupational noise, even when it is not at a level that requires action to prevent hearing loss, can be a stressor (e.g. the frequent ringing of a telephone or the persistent noise of an air-conditioning unit). Finally, loud noise can also be instrumental cause of accidents, since it reduces the attention and makes it difficult to hear warning sounds [22]

High surrounding noises and resulting hearing impairment can therefore profoundly impact the individual's social, psychological and physical well-being not only in the private sphere but also at work, where having a hearing impairment can result in a loss of job function, lowered job satisfaction, and lowered labor market participation [23] The prevalence of workplace difficulties caused by hearing problems is well documented: research indicates that people with hearing impairments are more likely to be unemployed or take early retirement when compared to people without such problems[24, 25, 18]. In fact, the decline in overall health, such as developing cardiovascular disease and increasing hearing problems, can result in working limitations that intimidate and discourage both the employer and the older employee. A recent report showed that a major reason for early retirement from the job market was due to unconsciously age-related hearing problems and that hearing problems in the 50-64 age group cause productivity losses of EUR 360 million on an annual basis in Denmark alone [24]. Noise is a problem for all, but it affects particularly older adults. Nevertheless, senior adults are starting to experience hearing problems at a younger age. According to a recent study [26], 20 years ago the age-related hearing-loss started normally around the age of 58-60, whereas today the problem of distinguishing sounds already starts at the age of 50.

Today´s older adults have a positive self-image and bright expectations for their future. Satisfactory employment can help people avoiding sickness and physical or mental deterioration, secure good cognitive and physical capacity, and promote positive and active attitudes towards life. Good work also promotes cooperation between young, middle-aged and older generations. Overall, the quality of working life has a big impact on all workers, due to the

long time spent at work. However, the increasing hearing problems significantly hamper a good and satisfactory working life, especially for older adults. There is thus a fundamental need to develop new solutions to preserve cognitive and physical capabilities of older adults to continue managing their occupation. As demonstrated, there is a huge need to help senior workers to combat the noise problem at work and help them filter the background noise from what is important, as well as to keep an acceptable level of noise, so the elderly can concentrate on their tasks, which is also a growing problem with age.

The development of solutions must be end-user driven taking into careful consideration their different needs and indispensable input. Therefore, end-users must be involved throughout design processes, working very closely with engineering and research staff, in order to develop an intuitive, user-friendly and essentially very advanced State-of-the-Art noise control system platform to support and ease the adaption of the environment noise and sound to each type of working environment (large office or industry) and according to their special needs. As the group is most severely disadvantaged by occupational noise, the primary end-users targeted by the solution are elderly people that work in noisy environments.

As a first step, a further and detailed characterization of the workers, as primary end-users, must be carried out in order to identify and classify their specific exposure profiles. These exposure profiles include all the socio-demographic data of the subjects (age, gender, seniority, etc.), plus other relevant noise-related features, such as: 1) the individual audiometric profile, which will allow the detection of potential existing hearing losses and identifying their nature, for example, the contribution from presbycusis and from noise-induced hearing losses; 2) task requirements regarding oral communication, existent barriers to intelligibility and/or auditory signals identification needs; 3) use of personal protection, such as hearing protection devices, and use of personal listening devices (headphones and/or hearing aids). From the initial stages, end-user partners should provide requirements and specifications for the novel solution, which will help guiding the research and technological development in further stages of the work.

The end-users can provide feedback loops validating and verifying the progress of the development work. Workshops and interviews and other participatory design methods will identify the employee's personal experience of the soundscape. The goal is through a participatory process to empower the employees to help identify and describe the soundscape in which they work in order to find solutions of how to reduce the noise problems and improve their working environment. In addition to input requirements and feedback, end-users should play a key role in testing and demonstrating the prototypes at end-users' facilities. Some leading indicators of performance and productivity, audiometric profiles can be used among employers and end-users in the analysis and comparison of worker's performance before and after the use of the novel technology. Additionally, other aspects such as usability and acceptance must be evaluated. Finally, end-users should be involved in the business case development by providing input about customer behavior and attitude, also define terms of price sensitivity.

### *3.2. Currently available ANC technologies*

Active noise control (ANC), also known as noise cancellation, or active noise reduction (ANR), is a method for reducing unwanted sound by the addition of a second sound specifically designed to cancel the first. Currently, three main applications of the basic principles are commercially available or described in the literature. First, the well-known SNC headsets, which have found their way into mainstream consumer electronics, secondly device or sound source specific devices, which are technology add-ons aimed at reducing or manipulating the actual or perceived nose of a particular source, for instance an engine or an HVAC system. Finally, and most recently, space-specific technologies, which are aimed at creating particular sound characteristics for defined, personal spaces are emerging. It is this latter category, which has relevance for a workspace ANC for elderly workers.

Soundscaping and sound design of defined spaces to combat the noise level exists in very limited applications. These are still costly and their implementation limited to basically car cabins and flight cabins, where interaction and space variables are easily controlled. However, there are currently no solutions for large rooms (>100 m2) nor solutions addressing high frequencies.

### *3.3. Brief discussion*

According to the obtained preliminary results it waspossible to define that some important functional needs include the ability to reduce noise in large rooms and providing up to 10 dB of reduction for specific frequency ranges. Similarly with other ANC systems, it is expect that this one can be based on a sound system creating a comfortable soundscape according to user's input. It is also important that it provides an user-friendly software, specially designed for elderly people, preferably as a standardized and plug & play solution. Among other relevant identified needs, it also possible to mention the need of filtering background noise in work environments.

Considering the identified impact of noise exposure in workers' performance, the requirements will also include other factors, mainly related with the specific characteristics of the workplace, in particular the physical and cognitive requirements for the considered jobs. Based on this assumption, the system specifications can also be differentiated for different end-users, i.e., considering end-users working at industrial workplaces (with higher noise exposure and more physical demand tasks), clerical workers (with less noise exposure but with highly cognitive demands) and mixed workplaces.

Due to the nature of the target-users, the solutions to be developed should consider an user-centered methodology, i.e., developed based on human factors and ergonomics principles and focused on the users' needs and abilities, considering their feedback at all the stages of the development. Therefore, it should include the potential improvements in the intelligibility on oral communication, aiming at minimizing errors due to a misunderstanding communication, which ultimately may result in the occurrence of work accidents. Additionally, it should enhance end-users' cognitive abilities or skills, which is particularly important for elderly workers.

Considering the obtained results and the prospective characteristics expected for the system functional requirements, it is expected that such a system may be able to affect and improve the quality of life for the targeted end-users:

- By improving intelligibility between oral communication, which will minimize errors due to a misunderstanding communication, which ultimately may result in more severe effects such as the occurrence of work accidents
- By enhancing end users' cognitive abilities or skills, which is particularly important for elderly workers, who have already some cognitive impairments due to the ageing process
- The preservation of hearing will also impact on the social life of the exposed workers, as hearing loss is recognized to be one of the most obstacles to a regular social life, inhibiting the normal interaction with other people and contribute to an isolation of the person affected by hearing loss.
- The impact on social life should also be considered in the after-retirement period. It is likely that the most relevant impact of hearing loss will be observed at this stage of life, where the inhibition of a social interaction will have the highest impact for these people and will affect negatively their quality of life
- Social well fare systems of the countries will also benefit with this solution, considering that a reduction of hearing loss, as an occupational disease, will also result in a reduction of potential litigation and damage/injury indemnification costs
- If companies are considered as secondary end-users, they will also benefit from the proposed solution, as they will improve the quality of the workplaces and, consequently, improve the workers' satisfaction at work.

The new solution should produce ANC (up to 10 dB noise reduction) in large rooms (e.g., with area higher than 100 m^2) targeting high frequencies (up to 8000 Hz) and, concomitantly, create an ambient sound. The ANC solution would need to be flexible and a self-adaptable solution based on improved adaptive signal processing algorithms that can deal with variations in the physical parameters. The soundscape solution will be reactive to the input from users. Moreover, this solution will be specifically designed for elderly people that work in noisy environments, such as offices or factories. High quality and user-friendly software will bring an added value to this product.

## 4. Conclusions

After the definition of the functional requirement for the technology to be applied to this case, it was possible to conclude that this type of solution can be extremely important as a component of an active ageing program, as the preservation of hearing will also impact on the social life of the exposed workers. Hearing loss is recognized to be one of the most obstacles to a regular social life, inhibiting the normal interaction with other people and contribute to an isolation of the person affected by hearing loss.

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