

# NON-AUDITORY EFFECTS OF NOISE AS EMERGING RISK IN WORKPLACES

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In this paper, moving from the new approach and consideration to both the auditory and non-auditory, physiological and psycho-behavioural effects of exposure to noise, a general review of criteria for correctly design the acoustic quality of workplaces with regards to non-auditory effects are shown.

*Keywords: annoyance, non-auditory risk, noise exposure, workplaces*

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## 1. Introduction

In public opinion and policy making, the main indicator for safety outcomes is the number of work accidents and work related diseases. According to statistics there was a strong decrease in fatal accidents and severe occupational disease from mid 1990s until 2010.

Decrease continued after 2010 till 2023 with lower reduction rates for some risks and became stable for others [1].

The main cause of the decrease is the development of prevention (technical and organisational) and the capacity of anticipation of risks. Technology applied to Health and Safety played an important role as well as the decrease of workforce in high-risk sectors like mining and agriculture.

However, the latest estimates of the burden of diseases from the WHO, ILO and ICOH do not show a decline in work and workplace related diseases [2].

An increase in future estimates is expected if the so-called emerging risks (mental diseases, building related illnesses, illness from some physical or biological agents) are considered together with the classical ones.

Besides the consideration of non-auditory effects as emerging risk, there is a conceptual evolution in assessing and planning the acoustic quality of work environments and activities: from one side new approaches to noise assessment in workplaces, in terms of acoustic damage, noise disturbance, acoustic discomfort, are emerging, from the other side, special competences are required for correctly design healthy, safe and comfortable workplaces.

Guidelines for reducing the discomfort and annoyance of workers, making workplaces more comfortable, including design of acoustic correction interventions focused on perceived acoustic quality of places are presented as a result of a research that involved six Italian universities and the Italian National

Institute for Insurance against Accidents at Work. The aim of the research is to determine technical solutions to improve acoustic quality and global comfort, reducing the non-auditory effects of noise exposure in workplaces, school environments in particular, through a study on the source-environment-receiver correlation, developing methods for evaluating non-auditory pathologies.

## 2. Occupational Annoyance as emerging physical risk

As sound (soundscape) is a basic parameter for pleasantness and comfort of places and activities, Noise is considered as a parameter of global discomfort and perceived discomfort in the permanence in working environments, in carrying out work activities, in the worker's living environments and in the performance of extra-work activities that can affect his acoustic health (bad acoustic habits).

There is a new consideration, also in terms of compensation for both auditory and non-auditory (physiological, psycho-behavioural) effects of exposure to noise and a new consideration of the acoustic quality of spaces for speech intelligibility, correct sizing of the safety and alarm signals, reduction of background noise and unnecessary sounds

Noise produces negative impacts on people's health and well-being through auditory and extra-auditory pathological effects, which affect the hearing organ and other organs and systems. For this reason, it is right and necessary that prevention policies consider, or rather reconsider, the non -auditory effects of noise among the emerging physical risks.

### 2.1 Emerging risks

Work and workplaces are constantly changing with the introduction of new technologies, substances and work processes, changes in the structure of the workforce and the labour market, new forms of employment and work organisation.

This generates the so-called emerging risks, that must be studied, anticipated and addressed in order to ensure safe and healthy workplaces in the future [3].

An emerging risk can be defined as a new or unforeseen risk that we haven't yet contemplated in risk anticipation, prevention, assessment, mitigation.

Emerging risks may be linked to (or caused by) technical innovation, social changes, unpredictable events such as a pandemic, new evidences of correlation between new (and old) pathologies and risk factors. For example, the outbreak of the COVID-19 pandemic in 2020-21 required exceptional measures and quick reactions, adapting workplaces and protecting workers, making necessary first of all to deepen scientific knowledge of the problems related to the virus but also those related to the correct way of working to avoid contagion and the spread of the pandemic.

To face emerging risks a good strategy must aim at anticipate the risk using the experience gathered during the emergency following the first appearance of the unknown and unexpected risk to create prevention tools aimed at dealing in the best way with the eventuality that the risk will repeat itself or others with the same nature arise. This approach can prepare workers and population for potential future similar threats.

Anticipating the new and emerging risks is crucial for bringing them under control. Among the most diffused examples of emerging risks, besides risks connected to digitalization and solitary remote work, there are the non-auditory effects of noise exposure.

## 2.2 Annoyance

Annoyance is defined as the reversible alteration of the psycho-physical conditions of subjects exposed to a specific cause or to a set of causes present in a given environment (examples: work-related stress, sick building syndrome and building related illness) [4]. Noise Annoyance is the feeling of displeasure, nuisance, disturbance or irritation caused by a specific sound.

According to WHO collection of scientific evidences reported in the most recent edition of the Environmental Noise Guidelines [6], The critical health effects considered in the evidence-based review are: hearing damage (hearing loss, tinnitus, ...), cardiovascular diseases, metabolic problems, sleep disturbance, cognitive impairments, mental health and limitation of well-being, complications to pregnancy (adverse birth outcomes).

Occupational annoyance is one of the emerging physical risk in workplaces. It can be defined as alteration of the psycho-physical conditions of subjects exposed to a specific cause or to a set of causes present in a given environment. The mentioned work-related stress, sick building syndrome and building related illness are connected to noise annoyance in noisy workplaces and in doing noisy activities [7].

## 2.3 Auditory and non-auditory effects of noise

The effects of noise on health are being redefined at a scientific and application level, including besides the auditory effects, problems related to the multisensory perception of discomfort, which fall into the categories of noise disturbance and annoyance.

The auditory occupational diseases deal with existing laws, rules and regulations for consolidated definitions and quantifications of auditory hearing damage (including hypoacusis, tinnitus and other complex pathologies of the auditory system).

The ISO 9612:2011 defines a method for the determination of occupational noise exposure, indicating the chronological sequence for the risk assessment articulated in five steps: job analysis, choice of measurement strategy, measurements, calculations and presentation of results. Neither this fundamental standard nor other regarding noise exposure describe in detail methodologies and limits for noise that determines non-auditory effects.

At the same time international and national legislative and regulatory systems show a poor or null consideration of the non-auditory effects produced by exposure to noise and poor acoustic quality of workplaces.

In terms of cause-effect relationships considering both scientific literature and international standards and guidelines, noise has been usually included in the group of physical agents that surely may cause occupational disease in terms of bilateral hearing loss. At a lower level (diseases whose origin is possible at work) some extra-auditory effects are mentioned, diseases of the cardiovascular, digestive, endocrine and neuropsychic systems.

Only at the third level, (diseases whose origin is of limited probability) we may find the prolonged efforts of the vocal cords which generate the appearance of nodules in the vocal cords as an occupational disease.

Nevertheless, critical health effects are considered in various reviews of evidences, besides the classical hearing damages. Noise produces negative impacts on health and well-being through auditory and non-auditory effects, influencing health condition of workers and the perception of comfort and discomfort of work activities and workplaces.

A huge number of disability-adjusted life years (DALYs), depends on noise exposure [8]. The presence of noise in the workplace is not only a possible source of pathologies of the hearing system but also potentially responsible for damage to other systems and, more generally, for psychological conditions of stress and perceived discomfort.

Hearing damage results from the adaptation mechanism (shift of the hearing threshold) which can be temporary (hearing fatigue) or permanent (hearing loss). The threshold of 80.0 dBA, is generally considered as the lower action level threshold of risk for auditory effects, as it represents the minimum level where temporary threshold shift (TTS) of hearing capacity due to noise exposure may become permanent threshold shift (PTS), generating pathologic hearing impairment.

According to WHO guidelines [6] significant non-auditory effects of noise exposure can generate pathologies at levels lower than this threshold in particular harmful effects like sleep disturbances, cardiovascular diseases, cognitive problems may arise when the daily exposure reach and overcome levels of 50 dBA.

As non-auditory effect of noise is an emerging risk, designers of workplaces are required to consider the global comfort approach and new parameters like speech intelligibility, correct sizing of the safety and alarm signals, reduction of background noise and unnecessary sounds.

In conclusion, non-auditory effects of exposure to noise are one of the emerging physical risks in the workplace, strictly connected to the emerging occupational global comfort approach.

### **3. Occupational comfort and acoustic design of workplaces**

The aim of occupational comfort approach is to consider human comfort in workplaces, using for environmental comfort a multi-domain approach (simultaneously evaluating thermal, visual, acoustic, and air quality) and considering also social variables in a multi-disciplinary approach.

Perception of comfort and discomfort is multisensory: human beings may have different sensitivities in each of the five senses and in the combined effects that generate sensations and feelings.

Feeling of well-being and perception of comfort (or discomfort) are both linked to the characteristics of the outdoor and built environments, which interact with individual neurophysiological aspects.

#### **3.1 Comfort of workplaces and non-auditory effects of noise**

In recent years, also driven by the new evidence of acoustic damage and cause-effect correlations between levels of exposure and related pathologies [6], new approaches to noise assessment have been developed in the workplace, including the categories of acoustic damage, acoustic disturbance, and acoustic discomfort [9], distinguishing sub-categories corresponding to auditory and extra-auditory damages are catalogued.

Acoustic quality of workplaces within the risk assessment procedures represents the new frontier of occupational health and safety improvement, according to the occupational hygiene and health promotion principles.

Acoustic quality, as well as global comfort level, can be considered by means of objective variables.

First, noise must be considered as a parameter of perceived global discomfort in the following situations:

- staying in certain work environments,
- carrying out certain work activities in the worker's living environments,
- carrying out extra-work activities that can affect acoustic health (bad acoustic habits).

A new consideration can derive from this, also in compensatory term of non-auditory damages from exposure to noise, distinguishing between risks with physiological nature and risks with psycho-behavioral nature.

A new consideration of the acoustic quality of all the spaces within the work environments is required.

Appropriate acoustic-architectural characteristics must allow, or not hinder:

- intelligibility of speech,

- listening to safety signals and alarm,
- any other form of acoustic communication connected to the activity.

Each scheme of composition of variables that contribute to global comfort should consider objective acoustic and non-acoustic variables, combined with subjective variables representing pleasantness and social benefits for workers.

### 3.2 Assessing the risk of non-auditory damages

The presence of noise in the workplace is not only a possible source of pathologies to the hearing system but also potentially responsible for damage to other systems and, more generally, for psychological conditions of stress and perceived discomfort.

A possible list of non-auditory effects that can become damages is the following:

- physiological effects,
- effects on communication,
- effects on sleep,
- effects on learning,
- acute effects,
- psychological effects.

The physiological non-auditory effects of noise exposure concerns some specific pathologies as well as the interference of noise with attention capacity, memory and ability to deal with complex problems.

Among the pathologies connected to adaptation strategies of human body are:

- increase in blood pressure, high blood levels of stress-related hormones,
- weakened immune defenses,
- gastrointestinal problems,
- cardiovascular problems with hypertension and increased risk of heart attack.

There is extensive and documented evidence in the literature of the relationship between exposure to noise and the onset of ischemic heart disease and hypertension, starting from daily exposure levels between 65.0 and 70.0 dBA.

Among the effects on communication there is the interference of background noise with:

- ability to concentrate,
- memory,
- level of intelligibility of sounds.

In places intended for speech and listening, or where clear and timely receipt of audible warnings is important, SPL of background noise should be at least 10 dB(A) lower than speaker's voice or signal to be heard.

In some workplaces unnecessary noise can be source of accident. Risk assessment must consider possible interactions between noise and warning signals: high background noise levels, masking signal and voices, could cause a potential danger for the safety of workers.

For some workers overprotection of PPE can cause an excessive isolation. The evaluation of the effectiveness of acoustic personal protective equipment must consider that hearing protectors can mask fundamental signals such as warnings, alarms and communications among colleagues.

Among the effects on learning, deficits in the ability to concentrate and psycho-physical stress, as well as negative effects on reading and speaking skills are considered. Among the effects on sleep all aspects of the correlation between noise exposure and sleep disturbances: difficulty falling asleep, reduced deep

sleep phase, increased awakenings and adverse effects after awakening, such as fatigue and impaired performance, are included.

Among the emerging risks connected to non-auditory effects of noise also the study of acute effects deserves great attention and new and widespread epidemiological and clinical research are running.

Serious tympanic lesions and inner ear structures in the event of sound wave traumas have historically been considered in this area, but in recent years some studies have begun to systematically address the contexts that gave rise to exposure risks, complicated by acute events: these are mainly airports, city traffic, some manufacturing workplaces, shipbuilding.

Considering background noise and sound masking, we notice that in environments characterized by high levels of background noise, the need to communicate raises voice, increasing the background noise (Lombard effect) and can induce aggressive behavior as an extreme effect. A category of psychological and behavioral effects has to be considered, concerning the aspects of degeneration of annoyance and discomfort feelings caused by noise: not only the mentioned aggressive behavior but also a reduction of instinctive reflexes in response to dangerous situations, with potential repercussions in terms of safety.

### 3.3 Designing comfortable workplaces

As the assessment of the risk related to the exposure to noise of workers should take into consideration the possible hearing damage for workers but also the need to provide workers with comfortable and ergonomic working environments, a new paradigm for designing workplaces, according should be defined according to the principles of global comfort.

Workplaces must be provided with effective acoustic insulation, considering the type of building and the activities done by workers in respect of ergonomic principles in the conception and design of workplaces in order to achieve the acoustic comfort objectives.

In fact, there are a series of technical standards and reference parameters, to be applied to different work environments (e.g. school environments, analysis laboratories, offices), to design work environments that not only protect workers from potential hearing damage according to law and regulation but which can also guarantee other requirements such as speech intelligibility, non-interference with the maintenance of concentration: if the working environment does not meet the minimum requirements prescribed by the law, the risk of onset of effects cannot be excluded inaudible noise.

The acoustic design of work environments is the aim of Project BRIC INAIL ID 26 (2018-2019) [10] where a new classification of the main categories of work environment is based also on the most recent typologies of work, including "smart" and "remote" working, defining the acoustic parameters for each type of work. The project regards the following workplaces: industries, schools, hospitals, offices, restaurants, entertainment, extreme work environments subject to high sound pressures.

Based on data obtained from relevant experiences of acoustic analysis and design of work environments, an updated cataloguing of work environments is proposed.

Starting from the relevance of acoustics for structural and functional quality, levels of quality and well-being that can be assessed through objective acoustic descriptors. Values of descriptors are closely linked to the perception of occupational well-being and can be translated into variables and indicators typical of the algorithms for calculating the Global Comfort of work environments.

The non-auditory effects of noise exposure in non-comfortable workplaces is the aim Project BRIC INAIL ID 19 (2020-2022) [11]. This research determined technical solutions to improve acoustic quality and global comfort, reducing the non-auditory effects of noise exposure in workplaces, school environments in particular, through a study on the source-environment-receiver correlation, developing methods for evaluating non-auditory pathologies.

Both projects, involving nine Italian universities are funded by INAIL, the Italian the National Institute for Insurance against Accidents at Work, a public non-profit entity safeguarding workers against physical injuries and occupational diseases, provided guidelines for reducing the discomfort and annoyance of workers, making workplaces more comfortable, including design of acoustic correction interventions focused on perceived acoustic quality of places.

In particular the second project systematically investigated the extra-auditory effects of exposure to noise in schools, starting from an objective and subjective (instrumental and perceived) evaluation of the acoustic climate and the annoyance caused by the high noise levels to which teachers and students are subjected. In addition to a large series of SPL measurements and evaluations of environmental and architectural acoustic parameters, three different questionnaires were prepared and distributed to users of the environments (teachers and students), aimed at investigating the acoustic perception of the environments in which educational and non-educational activities take place. On-field case study was conducted in nine schools located in the Italian cities of Florence, Perugia and Rome, selected with criteria of maximum representativeness of the national universe of school buildings, represented the application places (case studies) of the research [12].

In Fig. 1 the workflow of the project is summarized.

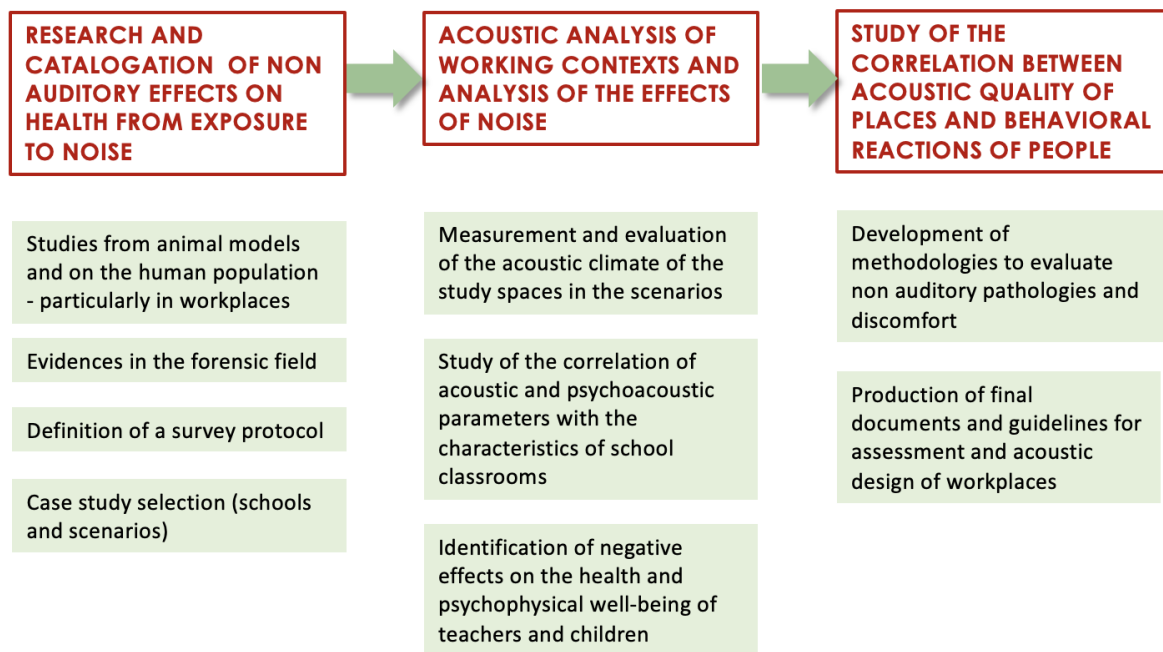


Figure 1: Workflow of project on non-auditory effects of noise exposure in non-comfortable workplaces

#### 4. Conclusions

The classical approach to occupational health and safety management and control, based only on measuring and reducing risk levels does not seem to be effective in improving quality of workplaces and quality of life of workers.

It should be integrated with models and actions that consider objective comfort variables and the subjective perception of wellbeing during worktime.

The acoustic quality variables should be considered as components of the global comfort design of workplaces with special attention to reducing the risk of non-auditory effects on workers' health. It is necessary that prevention policies consider emerging risks, assessing and quantifying them with proper variables. It is necessary to design or re-design workplaces (and living places) according to the holistic principles of global comfort.

Digital technologies in the workplaces can be safe and beneficial for workers if the potential risks are properly assessed and managed. The reduction of occupational noise to levels below action limit values established by law or regulations as is no longer enough as it is no longer sufficient to guarantee the acoustic quality of a working environment.

Occupational hygiene criteria, combined with those that consider the promotion of workers' health, must be considered in risk assessment and planning of mitigation interventions, as well as in the design of new working environments.

In this context, environmental, building and architectural acoustics represent an important contribution and cannot be overlooked.

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