



# Extra-auditory effects from exposure to noise in working environments

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## Abstract

This paper presents the BRIC INAIL 2019 ID 14 project, and it focuses on the specific actions aiming at investigating the onset of auditory and extra-auditory effects from exposure to noise in animals and humans. In working environments, the definition of precautions to prevent risks correlated to noise exposure is particularly relevant. The work involves the systematic review of scientific literature, taking into account the consequences of exposure to noise and the damages reported to various apparatus. This is the first part of a wider study which intends to analyse school environments, the effects of noise on health of teachers and students and the correlation between acoustic quality and extra-auditory disease. Main results emerging from the first year of activity are shown.

**Keywords:** noise exposure, extra-auditory effects, acoustic analysis.

## 1 Introduction

### 1.1 The consequences of exposure to noise

Noise is a source of harm to people, and it is defined as a stressful environmental factor. A prolonged or particularly intense exposure to noise can generate increased blood pressure, vasoconstriction and increased heart rate. Moreover, it may accelerate and intensify the development of latent mental disorders. Noise exposure and related annoyance for the population turns out to be a public health problem [1]. According to the World Health Organisation, noise can cause a range of symptoms such as anxiety, stress, nausea, headaches and instability. In particular, in occupational and educational environments, noise affects performance on cognitive tasks.

In humans, prolonged exposure to noise can cause damage both to the hearing, with the onset of perceptual hearing loss, and to the extra-auditory system, with alterations mainly to the cardiovascular, gastrointestinal and nervous-psychological systems. Besides the auditory effects that generate hearing loss impairment, the most common response to chronic noise exposure is annoyance [2] [3] [4] [5], defined as a feeling of displeasure, disturbance or irritation caused by a specific sound [6]. In general, the disturbance may result from the interference of noise with normal daily activities and may be accompanied by negative reactions and stress-related symptoms. Neurobehavioral disorders including anxiety, emotional distress, nausea, headaches, instability, sexual impotence, mood changes, increased social conflicts, as well as general disorders such as neurosis, psychosis, hysteria are reported [7].

The auditory damage is represented by pathologies of the auditory system. On the other hand, the assessment of non-auditory damage - physiological or psychological damage - deriving from exposure to noise, is more complex to identify, since the causes of acoustic discomfort could also be linked to different factors and depend on the subjectivity of sound perception.

Mostly, extra-auditory effects are temporary and removing the cause, the previous state is restored.

The psycho-physiological effects of noise exposure can occur at noise levels of 60 dB, and there is no possibility of adaptation.

The link between noise and extra-auditory effects is not easy to be determined. For this reason, medical analysis plays a fundamental role in identifying auditory and extra-auditory damage caused by noise exposure. The definition of a cause-and-effect relationship is particularly necessary in legal matters.

## **1.2 BRIC INAIL 2019 ID 14 Project**

The research work presented in this paper is part of the BRIC INAIL 2019 ID 14 project. The latter aims at identifying the types of extra-auditory damage from exposure to noise, with particular attention to school environments. In the first phase of the project, a cataloguing of the typologies of extra-auditory damages caused by noise exposure was carried out starting from the evidence in scientific literature. The study lays the foundations for the acoustic analysis to be carried out in selected work environments, as well as to study the correlation between acoustic quality and behavioural reactions. Specifically, this part of the study has reported a review of the scientific literature on noise damage among animal models and humans.

## **2 Methods**

### **2.1 Literature review of extra-auditory effects from exposure to noise in animals**

The review included articles published in the last 10 years, from 2010 to 15 September 2020, on the main online databases (PubMed, Cochrane Library, Scopus, Embase, Google Scholar). The search strategy used a combination of keywords, in combination with each other: noise, loud, sound, exposure, environment, neurobehavioral, psychological, mental, neural. The search string used was “((noise) OR (sound)) OR (sound level)) OR (loud)) AND ((exposure) OR (environmental) OR (environment)) AND ((neurobehavioral) OR (behavioral) OR (behavioral) OR (neurobehavioral) OR (psychological) OR (mental) OR (neural))”.

All research fields were considered. In particular, we conducted a research strategy in the databases on the effects of noise ‘exposure on animals by applying the PICO’s statement. The study included all animals, with no difference in species, habitat or geolocation. The intervention concerned any kind of noise exposure (pollution caused by humans and not), in any terrestrial environment. The health outcomes considered were those related to neurobehavioral changes in according to recent studies. In particular, we included short term and medium-long term effects, such as changes in swimming direction and speed, burrow building, foraging for food and reproduction, irritability, agitation, anger, changes in neurobehavioral skills. If found, hormone excretion level or alterations in instrumental diagnostic tests, were included. In addition, we have carried out a manual search of the selected articles and reviews for a more accurate analysis. Two independent reviewers read the titles and abstracts of the various reports identified by the search strategy. Reviewers selected studies based on inclusion and exclusion criteria. Doubts or disagreements were resolved by discussing them with a third researcher.

Subsequently, the authors independently reviewed the complete texts to decide on final admissibility. Finally, the authors eliminated duplicate studies and articles without the full texts.

Tabulated data were obtained mainly from published results but also from any other supplementary source, when available. In particular, the authors selected the date and country of publication, the animal species examined, and the type of disorders reported. We included studies on the main neurobehavioral consequences of this exposure, in particular aggression, adaptation systems, nutrition, reproduction and anti-predatory behaviours. All types of study designs were included, without linguistic restrictions. Publications relating only to the human species were excluded; furthermore, we excluded articles not reporting

neurobehavioral alterations, reports of lesser academic relevance, editorial articles, individual contributions and purely descriptive studies published in scientific conferences, without any quantitative and qualitative scientific contribution.

## **2.2 Literature review of extra-auditory effects from exposure to noise in workplaces**

The research included articles published in the last 10 years, from 2010 to 15 September 2020, on the major online databases (PubMed, Cochrane Library, Scopus, Embase, Google Scholar). The search strategy used a combination of controlled vocabulary and free text terms based on the following keywords: work, job, task, workplace, noise, loud, sound, occupational, environment, neurobehavioral, psychological, mental, neural. All research fields were considered. The search string used was the following: (((((noise) OR (sound)) OR (sound level)) OR (loud)) AND (((((((workplace) OR (work)) OR (job)) OR (job task)) OR (occupation)) OR (occupational)) OR (environmental)) OR (environment))) AND (((((((neurobehavioral) OR (behavioral)) OR (behavioural)) OR (neurobehavioural)) OR (psychological)) OR (mental)) OR (neural)).

In particular, we conducted a research strategy in the databases on the effects of noise ‘exposure on workers’ health by applying the PICO statement. The studied population was composed of workers, with no difference in age, gender or type of job. The type of intervention concerned any noise exposure in the workplace. The considered health outcomes were related to neurobehavioral changes in according to the most recent studies. We included short term effects and medium-long term effects, such as insomnia, sleep disturbance, fatigue, impaired concentration and memory, changes in work performance, errors, mood changes with irritability, anxiety, aggression, depression, annoyance. If found, physiological measures and work-life balance, such as hormone excretion level or changes in management of social and family life, were included. Additionally, we practiced a hand search on reference lists of the selected articles and reviews to carry out a wider analysis. Two independent reviewers read titles and abstracts of the reports identified by the search strategy. They selected relevant reports according to inclusion and exclusion criteria. Doubts or disagreements were solved by discussion with a third researcher. Subsequently, they independently screened the corresponding full text to decide on final eligibility. Finally, the authors eliminated duplicate studies and articles without full texts. Data was mainly obtained from the published results but also from any other supplementary sources when these were available. In particular, the authors have selected date and country of publication, sample size, involved noise ‘source, exposure decibel and kind of reported disorders. In addition, the authors have highlighted the number of studies included for all reviews and the length of the study, in case of trials or cohort studies. We included studies on principal neuro-behavioral consequences to this exposure, in particular annoyance, sleep disorders, short memory, poor concentrations and working performance. All types of study designs were included, and no linguistic restrictions were applied. We have excluded reports related only environmental exposure or noise pollution, not specifically conducted in a workplace setting, publications on programmatic interventions and studies not considering diseases or disturbances linked to noises; we have excluded reports of less academic significance, editorial articles, individual contributions and purely descriptive studies published in scientific conferences, without any quantitative and qualitative inferences.

## **3 Results**

### **3.1 Evidence of extra-auditory effects on animals from noise exposure**

The online search yielded 1119 studies: PubMed (256), Scopus (19), Cochrane Library (648), Embase (132), and Google Scholar (64). Of these, 1082 studies were excluded because they were deemed unrelated to alterations associated with noise exposure. Of the remaining, three publications were deleted because the full text was not available and another three due to exclusion criteria. Finally, 31 studies were included in this literature review (Figure 1). Of these, 2 were systematic reviews, 12 were narrative reviews, 1 were a meta-

analysis, and 16 were original articles. Among these original articles, 9 were experimental studies, 2 observational studies, 4 case-control studies, and 1 cohort study (Table 1).

The United States of America is the country where most of the studies were published (8 articles; 25.8%). Most of the articles were published in 2020 (9 studies; 29%), followed by 2016 (7 articles; 22.5%).

The main neurobehavioral disorders found in the groups of animals examined are alterations in movement or swimming, with changes in nutrition or anti-predator adaptations (12 articles; 38.7), aggression and overt anxiety (10 articles; 32.2%) and finally, alteration of autonomic reflexes and memory abilities (5 articles; 16.1%). The main groups of animals examined belong to marine fauna (fish, whales, dolphins, cephalopods) with 13 articles (41.9%), followed by rats and mice with 8 studies (25.8%), finally other mammals of various sizes (such as dogs, zebras, elephants) with 6 articles (19.3%).

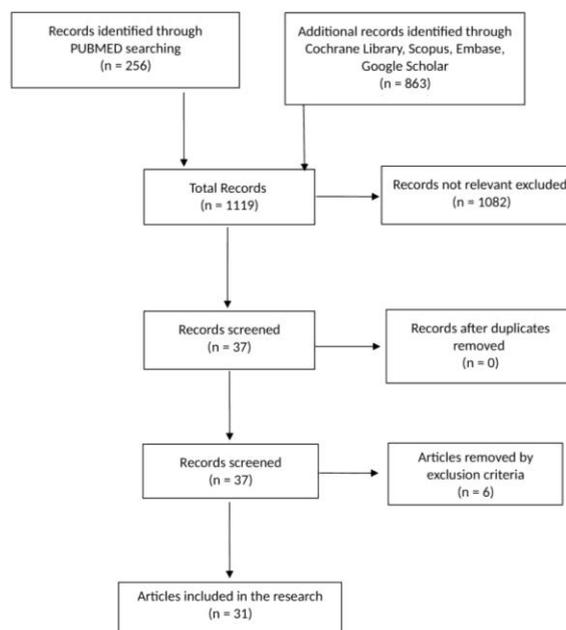


Figure 1 – Flow-Chart of bibliographic research

Table 1 – Included studies in this article, in alphabetical order

First author	Year	Country	Type of study	Species	Alterations
Abdullah	2020	Indonesia	observational study	Elephants	altered anti-predatory reaction
Akefe	2020	Nigeria	experimental study	Rats	learning, short-term memory, sensorimotor reflex
Baltzer	2020	Wadden sea	experimental study	marine mammals, fishes	altered movements, swimming speed, anti-predatory reaction
Blanchett	2020	USA	observational study	birds	aggression, pacing, nesting etc
Codocedo	2016	Australia/Chile	narrative review	mice, rats	anhedonia, anxiety, social-avoidance behaviors
Cox	2017	Canada	meta-analysis	fishes	complex movements and swimming abilities
Criddle	2018	USA	experimental study	Hamsters	hyperactivity
De soto	2016	Spain	narrative review	marine invertebrates	altered movements, swimming speed, metabolic parameters
Di franco	2020	Italy/France	systematic review	marine invertebrates, fishes	altered movements, swimming speed, anti-predatory reaction
Frouin	2020	Mexico	experimental study	whales	resting, interaction mother-calf
Heinrichs	2010	USA	narrative review	rodents	anxiety, hyperactivity
Hubert	2020	North sea	experimental study	fishes	changed swimming
Kight	2011	USA	narrative review	rats, zebra	cognition, sleep
Koorpivaara	2017	USA	experimental study	dogs	anxiety, fear
Kunc	2016	UK	narrative review	marine species	aggression, hunting, movements, anti-predatory reaction
Landsberg	2015	Canada	case-control	dogs	anxiety, fear
Li	2018	Indo-Pacific sea	narrative review	dolphins	altered movements and vocals
Longenecker	2016	USA	cohort study	mice	hyperactivity
Mandel	2016	Israel, UK	narrative review	cows, calves	various
Manukyan	2020	Armenia	case-control	rats	anxiety, memory
Mikolajczak	2013	Poland	experimental study	geese	movements, stress
Mills	2020	Polynesia	experimental study	fishes	hiding, distance, aggression
Mulders	2013	Australia	case-control	pig	hyperactivity
Nabi	2018	China/USA	narrative review	marine mammals	masking, altered reproduction
Peng	2015	China	narrative review	marine species	nesting, aggression, anti-predatory reaction
Pienkowski	2011	Canada	narrative review	rats, cats	cortical plasticity
Pirotta	2012	USA	case-control	whales	foraging, movements
Popper	2019	USA/UK	narrative review	fishes	impairment of spawning, interference with foraging, disruption in migration-habitat selection
Samson	2016	USA/Netherlands	narrative review	cephalopods	escape, inking, altered speed
Shannon	2016	USA	systematic review	wildlife	vocals, movements, foraging, escape, vigilance, mating
Uran	2012	Argentina	experimental study	rats	recognition, memory

### 3.2 Evidence of extra-auditory effects on humans from occupational noise exposure

The online search yielded 4485 studies: PubMed (3056), Scopus (21), Cochrane Library (13), Embase (115), Google Scholar (1280). Of these, 4434 studies were excluded because they were deemed unrelated to noise-related problems. Of the remainder, 4 articles were also excluded because they were duplicates. Duplicate publications were carefully eliminated in order not to introduce bias, by comparing the names of the authors, the topics addressed, the workers examined, and the results obtained. Another 6 publications were deleted because the full text was not available. In conclusion, 41 studies were finally included in this analysis (Figure 2). Of these, 4 are literature reviews (2 systematic; 2 narrative) and 37 are original articles. Among the latter, 16 are cross-sectional studies, 2 cohort studies, 5 case-control studies, 2 pilot studies, 1 observational study, 10 experimental studies and 1 mixed (cross / experimental) study (Table 2).

Sweden is the country where most of the studies were published (6/41; 14.6%). Most of the articles were published in 2018 (9/41; 21.9%), followed by 2019 (6/41; 14.6%). Selected articles examine various symptoms related to psychological distress and reported by the samples, such as annoyance (11/41; 26.8%), sleep disturbances (9/41; 21.9%), reduced work / cognitive performance (14/41; 34.1%). Taking into consideration the tasks examined, it was found that the most frequent analyses concern school staff (10/41; 24.3%), followed by employees from various industrial sectors (9/41; 21.9%) and office workers (6/41; 14.6%).

Taking into account the widest type of article selected (i.e. the 37 "original articles"), the main disorders examined include cognitive performance, attention and motivation in the workplace (15/37; 40.5%), followed by annoyance (4/37; 10.8%), stress (3/37; 8.1%), mood changes with depression and / or aggression (2/37; 5.4%), sleep disorders (1/37; 2.7%). Finally, 6 articles (6/37; 16.2%) analyse mixed disorders. With regard to the questionnaires administered to workers, we have identified a wide variability (such as, for example, the General Health Questionnaire (GHQ), the Patient Health Questionnaire (PHQ), the Copenhagen Psychosocial Questionnaire (COPSOQ), the Stroop Test (ST), the Reaction Time (RT), the Memory Test and the Sustained Attention to Response Test (SART)). As for cognitive functions or various logical and memory skills, most authors agree that their quality decreases with exposure to noisy sources.

Another disorder frequently encountered in the selected articles is annoyance, that is, a feeling of annoyance, malaise, constant tension. Some authors have sought a correlation between this reported disorder and some individual or work-related factors, such as individual sensitivity, gender differences or some characteristics related to workstations. Finally, we have identified other alterations that could be related to occupational noise, such as states of agitation, tension, nervousness, tendency to develop aggressive behaviors or addictions. On the other hand, with regard to the professions among the original articles, school staff is the main category of workers analysed (11/37; 29.7%), followed by various employees (industry, farmers, manufacturing, etc.) and administrative-employees (7/37; 18.9%), military (4/37; 10.8%) and health workers (2/37; 5.40%).

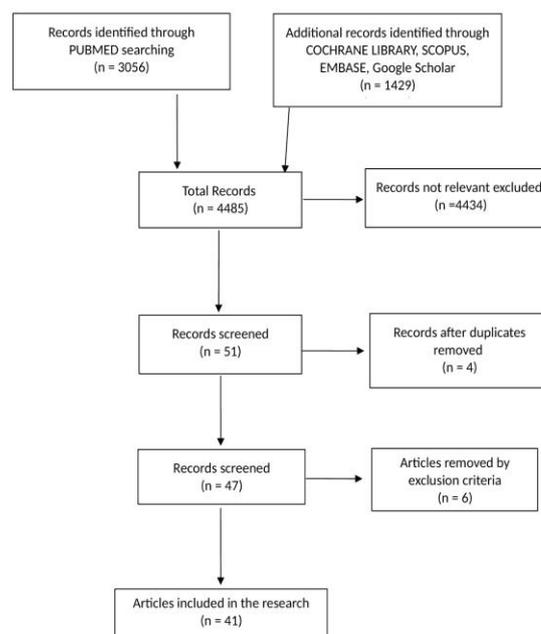


Figure 2 – Flow-Chart of bibliographic research

Table 2 – Included studies in this article, in alphabetical order.

First Author	Year	Country	Study	Categories Workers	Diseases
Abbasi	2015	Iran	pilot study	wind farmers	general health, sleep disorders, annoyance
Alimohammadi	2019	Iran	case control	automotive workers	cognitive performance, annoyance

Alimohammadi	2018	Iran	cross sectional	automotive workers	aggressive behavior
Alimohammadi	2010	Iran	cross sectional	white collar employees	annoyance
Azuma	2017	Japan	cross sectional	office workers	psychological distress
Burns	2019	Usa	cross sectional	electronic waste workers	perceived stress
Cheng	2019	China	case control	military	working memory performance
Clausen	2013	Denmark	cohort study	office workers	long term sickness absence
Deng	2019	China	cross sectional	not specified	depression
Di Blasio	2019	Italy	cross sectional	office workers	annoyance, mental health, well being
Eysel-Gosepath	2012	Germany	cross sectional	teachers	annoyance, sleep disorders, fatigue
Fredriksson	2015	Sweden	cross sectional	obstetrics	annoyance, work-related stress
Fredriksson	2019	Sweden	cohort study	teachers	work-related stress
Freiberg	2018	Germany	systematic review	wind industries	annoyance, sleep disorders
Habibi	2013	Iran	experimental study	university personnel	speed of work, annoyance
Horsten	2018	Netherlands	systematic review	healthcare workers	sleep disorders
Hua	2014	Sweden	case control	employees	cognitive skills
Irgens-Hansen	2015	Norway	experimental study	navy personnel	cognitive performance
Jahncke	2011	Sweden	experimental study	open plan offices	cognitive performance
Keller	2017	Usa	experimental study	military	cognitive performance
Keller	2018	Switzerland	observational study	healthcare workers	cognitive performance
Kim	2016	Korea	cross sectional	office work, sales, manufacturing	smoking intensity
Kristiansen	2014	Denmark	cross sectional	teachers	mental health, fatigue
Mahendra Prashanth	2011	India	narrative review	industrial workers	sleep disorders, cognitive performance
Mapuranga	2020	Zimbabwe	cross sectional	manufacturing workers	job performance
Milenovic	2018	Serbia	case control	manual/administrative workers	aggressiveness
Molesworth	2015	Australia	experimental study	aircraft personnel	recognition memory, working memory, reaction time
Monteiro	2018	Portugal	pilot study	students/fast food employees	working memory performance

Nari	2020	Korea	cross sectional	employees	sleep disorders
Oenning	2018	Brazil	cross sectional	various (public, private, domestic, farmworkers, technicians, manager)	depressive disorders
Onchang	2018	Thailand	case control	university personnel	annoyance
Realyvásquez	2016	Spain	experimental study	manufacturing workers	working performance, job satisfaction, aggressivity
Schlittmeier	2013	Germany	cross/experimental study	office workers	cognitive performance, annoyance
Sjodin	2012	Sweden	cross sectional	preschool personnel	work-related stress, sleep disorders
Sloof	2010	Netherlands	experimental study	university personnel	work motivation
Smith	2010	Uk	experimental study	university personnel	working memory performance
Tomic	2018	Sweden	experimental study	not specified	working memory performance
Wassermann	2013	Usa	case control	university personnel	attention
Wright	2016	Uk	experimental study	university personnel	cognitive performance, psychological disorders
Yoon	2014	Korea	cross sectional	white, pink, blue collars	depressive disorders, suicidal ideation, annoyance
Yuen	2014	Malaysia	narrative review	manufacturing workers	annoyance, sleep disorders

### 3.3 Future outlook

Starting from the bibliographical research, which showed different typologies of auditory and extra-auditory effects due to noise exposure, the Project carries out acoustic analyses of schools, which are peculiar work environments. The aim is to study the correlation between acoustic quality of schools, in terms of insulation from noise produced outside the classrooms and acoustic comfort derived by room acoustics and building acoustics design, and the extra-auditory effects on students and teachers. The activities planned in the following phase consist in the selection of an adequate number of case studies to carry out analyses in. It is therefore planned also to assess the acoustic climate of the school environments and to define the strategies and solutions for the control of noise and the creation of working environments with a low risk of extra-auditory damage. At the same time, some global comfort design rules will be applied for making more comfortable the classrooms and other noisy areas in the school buildings. Specific guidelines for acoustic design and noise mitigation will be developed.

Another further activity of the project could be the definition, in the frame of the guidelines, of some rules and procedures for quantification of damage done and attribution of responsibilities where and when an extra-auditory effect of noise exposure is identified and associated with a cause-effect relationship to a workplace or work activity.

This aspect is particularly important, given the scarcity of references based on forensic evidence and judgments of the labour courts.

## 4 Discussion and Conclusions

The study shows that prolonged exposure to noise can cause damage both to the hearing system - with the onset of perceptual hearing loss - and to other extra-auditory systems - mainly affecting the cardiovascular, gastrointestinal, and nervous-psychological systems -.

Although the correlation between extra-auditory damage and exposure to noise is widely supported by scientific literature, it has been observed that it is difficult to determine the causes of extra-auditory effects from noise exposure not considering other influencing factors.

In the frame of the BRIC INAIL 2019 ID 14 project, the identification of the typologies of extra-auditory damages caused by exposure to noise is the starting point for the development of the next objectives of the Project.

## Acknowledgements

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