URBAN NOISE: PHYSICAL AND BIOMEDICAL CONSIDERATIONS IN AN EUROPEAN CONTEXT

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Abstract: Urban noise has ancient origins but today many new serious consequences are known. Urbanization, industrialization and transports diffusion transformed the environment. In noisy cities people often suffer from hearing impairment, insomnia and high blood pressure. The young and workers are the groups at risk. Nowadays new clinical techniques allow the early detection of noise-induced diseases and new techniques are used to monitor the environment. With the aid of models we are able to predict the noise levels in many different areas of the city and create 3-D coloured maps (noise mapping). It is mandatory to comply with regulations in order to reduce the urban noise levels under the fixed limits and to protect the people's health. A healthy diet rich in anti-oxidants is recommended in order to protect the inner ear cells from noise injury. Finally, some European projects are briefly reported.

1 INTRODUCTION

Large part of the population is exposed to urban noise and the noise-induced hearing loss (NIHL) is one of the most prominent occupational diseases in Europe (in Italy, INAIL data: 5700 reported cases in 2008 from Istat, 2009); these two observations explain how environmental noise has become a serious social problem in many industrialised countries. It has been estimated that more than 90 million people in the European Union suffer from unacceptable noise levels and a further 180 million live in so-called 'grey areas' where noise can cause serious annoyance. The main contributor to environmental noise, defined as outdoor human-generated sound that can be heard in domestic environments, is transportation, particularly road traffic. Therefore it is important to inform and to protect the population especially the young and workers. Moreover, synergic effects are revealed among environmental noise, noise in work places and ototoxic agents (EU-OSHA, 2009) which may substantially increase the severity of a harmful effect. Hence, the effects of ototoxic substances on ear function can be aggravated by noise, which remains a well-established cause of hearing impairment, and in two expert forecasts published by the European Agency for Safety and Health at Work (EU-OSHA, 2005, 2009) the item "combined effects of chemical hazards with physical hazards" was consistently rated as an emerging risk.

2 PHYSICS ASPECTS

Sound is an alternation of the rarefaction and the condensation of air molecules. The main physical characteristics of sound are pressure level, frequency and its variation in time. Ambient noise level is measured with a sound level meter (microphones or phonogrameter). Individual dosimeters are often used in occupational noise measurements.

It is usually measured in dB above a reference pressure level of 0.00002 Pa, i.e., 20 µPa (micropascals) in SI units(1 pascal is equal to 1 newton per square meter. Most frequently, ambient noise levels are measured using a frequency weighting filter to take into account human ear sensibility, the most common being the A-weighting scale: the resulting measurements are denoted dBA, or decibels on the A-weighting scale, and the noise level is named Leq (see Tab.6).

2.1 From sound to noise

Whether a sound is classified as noise depends in part on the quality of the auditory experience it produces. Noise is unwanted sound and thus implicitly refers to a subjective classification of sound. Noise may adversely affect the health and well being of individuals and populations, and the sound pressure level is the obvious, first parameter under observation to evaluate adverse effects. The following table reports some examples of sound (noise) levels, and the indicative effects they could have on hearing. The noise level which reaches the ear decreases with distance from source.

Table 1 Noise levels

Definition	Noise level (dB)	Effect
Painful	140 dB = firearms, air raid siren, jet engine	
	130 dB = jackhammer	
	120 dB = jet plane take-off, amplified rock music at 4-6 ft., car stereo, band practice	
Extremely Loud	110 dB = rock music, model airplane	
	106 dB = timpani and bass drum rolls	
	100 dB = snowmobile, chain saw, pneumatic drill	
	90 dB = lawnmower, truck traffic, subway	Harmful
Very Loud	80 dB = alarm clock, busy street	
	70 dB = busy traffic, vacuum cleaner	Annoyance
	60 dB = conversation, dishwasher	Disturbance
Moderate	50 dB = moderate rainfall	
	40 dB = quiet room	
Faint	30 dB = whisper, quiet library	
Reference level	0 dB = falling leaf	

The logarithm scale used in Decibel definition aims to compress the very wide range of sound pressure values perceived by the ear

2.2 Noise and frequency

Noise had to be classified using frequency analysis: it could be composed by a prevalence of pure tones (high, medium o low frequencies) or it could have a uniform distribution (see white noise), or it could be a single pure tone like a whistle, car alarms, etc.. Examples are provided by associating colours to different noise types on the basis of their frequency composition: *White noise* is a signal, named by analogy to white light, with equal energy per cycle (hertz).This produces a flat frequency spectrum in a linear space. In other words, the signal has equal power in any band of a given bandwidth (power spectral density). The frequency spectrum of *pink noise* is flat in a logarithmic space: it has equal power in bands that are proportionally wide. *Grey noise* is random white noise subjected to a psychoacoustic equal loudness curve (such as an inverted A-weighting curve) over a given range of frequencies. This gives the listener the perception that noise is equally loud at all frequencies, in contrast to standard white noise which has equal strength over a logarithmic scale of frequencies but is not perceived as equally loud due to biases in the human equal-loudness contour.

2.3 Noise and time

The duration is a very important parameter to define a noise that can be named as continuous, intermittent or impulsive, the latter being most dangerous. In fact, noise-induced hearing loss (NIHL) can be caused by a one-time exposure to an intense “impulse” sound, such as an explosion, or even by continuous exposure to loud sounds over an extended period of time, such as noise generated in a noisy workplace.

Table 2 Noise Intensity and time

Stationary or continuous noise: intensity variations ≤ 3dB
Fluttuant noise: intensity variations > 3dB
Intermittent noise: the level falls at background level with a period > 1 sec
Impulsive noise: the level falls at background level with a period < 1sec

On the basis of the previous considerations, a rule of thumb is to avoid noises that are “too loud” and “too close” or that last “too long.”

2.4 Sources of urban noise

Generally, there are two kinds of sources of urban noise, indoor and outdoor sounds. The latter ones cannot be controlled in domestic environments and so are the most dangerous. In Italy, outdoor human-generated sounds are caused by transportation, road traffic 53%, neighbours 16%, construction work 7%, airports 6%, industrial and recreational activities 6%, railways 5% and other 7% (Malaguti, 2003; Ispra, 2009).

According to a European Union publication, about 40% of the population in the the European Union is exposed to **road traffic noise** at levels exceeding 55 dBA, and 20% is exposed to levels exceeding 65 dBA during daytime. More than 30% is exposed to levels exceeding 55 dBA during night time.

Table 3 Effects of different noise levels

Level	Effect
More than 85 dBA	Harmful sound levels in case of long exposure
>75 – 85 dBA	Communication is very difficult
>65 – 75 dBA	Mediocre soundscape
>55 – 65 dBA	Acceptable soundscape
>45 – 55 dBA	Good soundscape
Less than 45 dBA	Excellent soundscape

3. HEALTH DAMAGE

Noise level greater than 85 dBA may produce health damages (see Table 3). Besides exposure to intense sounds for long periods of time, several other agents may cause damage to the delicate hearing organ, including ototoxic substances such as some antibiotics, infections, and traumas. The ear is composed of external, middle and inner ear. In the inner ear the cochlea is located, a snail-shell like structure divided into three fluid-filled parts (see Figure 1) and including the Organ of Corti. In mammals, the outer acoustic hair cells (OHCs), together with the inner hair cells (IHCs), the pillar cells, and the tectorial membrane represent a sophisticated apparatus that allows recognition and analysis of the incoming acoustical vibration. The effects of prolonged exposure to intense noise on the OHCs can lead to injury and also to destruction of the cells themselves or of entire sections of the organ of Corti. Without necessarily causing the destruction of cells, exposure to noise may also cause sensory fatigue which leads to a transitory rise of the hearing threshold level, namely to a reduced hearing sensitivity that leads to increased difficulty in verbal communication. All damages that occur without involving the auditory system are named extrauditive (Table 4).

Table 4. Noise derived health damage

Extrauditive damages
Insomnia
High breathing rate
Disturbs digestion, ulcer
High blood pressure
Stress
Intensifies the effects of factors like drugs, alcohol, aging and carbon monoxide
Uditive damages
Temporary hearing impairment with a recovery of sensibility after a night rest in a quite environment
Hearing fatigue with a reduction of sensibility and audibility of human voice for 10 days
Chronic impairment acoustic trauma with a reduction of intelligibility of 50%

Figure 1: Cross section of one turn of the cochlea showing the scala vestibuli (SV), scala media (SM) and scala tympani (ST). Reissner's membrane separates the SM and SV, while the basilar membrane (BM) and organ of Corti separate SM and ST.

The auditory deficit is observable as a deep or notch at 4kHz and, as previous mentioned, it depends on the interaction of noise parameters such as frequency, intensity, duration of exposure (acute vs chronic), nature of the noise (e.g. continuous, impulsive, intermittent), distance from noisy sources, and individual factors such as individual sensitivity, age, etc. Auditory threshold shifts may be reversible or irrreversible (temporary threshold shifts, TTS, or permanent threshold shifts , PTS). TTS or auditory fatigue is due to glutamatergic excitotoxicity underneath the cochlear hair cells and/or to an energetic exhaustion of the hair cells. Recovery is possible, depending on the post-exposure rest. Residual auditory threshold shift lasting four weeks after exposure, are considered permanent. PTS results from irreversible lesions which predominantly occur within the organ of Corti. Two distinct mechanisms of PTS may take place in the organ of Corti, i.e. mechanical and metabolic damage.

Mechanical damage: Impulsive occupational noise, as those produced by pneumatic drills, can induce mechanical damage such as: i) broken, collapsed, fused or floppy stereociliae in the cochlear hair cells (see Figure 2 from Fetoni et al 2008a); ii) micro-lesions of the plasma membrane of cochlear hair cells and iii) tears in Reissner's or the reticular membrane.

Metabolic damage: Prolonged exposure to noise can cause metabolic damage due to i) the excitotoxic phenomenon leading to acute swellings (Puel et al., 1995) and ii) the generation of reactive oxygen species at the level of the sensory cells of the organ of Corti (Henderson et al., 2006; Fetoni et al 2009).

4. CLINICAL AND EXPERIMENTAL APPLICATIONS

4.1 Clinical tools

To explore human hearing, several tools are available:

Table 5 Tests for hearing funcionality

Subjective tests:
Pure tone Audiometry (PTA)
High frequency Audiometry
Speech Audiometry
Objective tests:
Otoacoustic emissions (OAE)
Brain auditory responses (ABR)

The most widespread in the evaluation of hearing is the pure tone audiogram (PTA). Although the human auditory range is from 20 to 20,000 Hz, the PTA in a strict sense only covers the speech spectrum: 250, 500, 1,000, 2,000, 3,000, 4,000, 6,000 and 8,000 Hz. The PTA is set out with frequency in hertz (Hz) on the horizontal axis and a dB hearing level (HL) scale on the vertical axis (Figure 2) representing in a standard way a person's hearing threshold (lowest hearing level at which a tone is heard compared to the average threshold of hearing registered as 0 dB in the audiometer). The audiogram is a plot of the threshold value corresponding to different frequencies. In Figure 2 it should be observed the typical differences between normal hearing (left side) and noise trauma (right side). PTA is useful in calculating hearing acuity, detecting significant threshold shifts and differentiating conductive hearing impairment from sensorineural. Objective tests are useful in monitoring temporary or permanent changes in the cochlea (auditory fatigue; ototoxic effect; cochlear dysfunction) and in particular, new methods are being developed to study Otoacoustic Emissions (OAEs). In fact, exposure to environmental noise may cause injuries to the inner ear, and Transient Evoked (TEOAEs) Otoacoustic Emissions and Distortion Product (DPOAEs) may identify these cochlear alterations by evaluating the integrity of outer hair cells. Otoacoustic emissions are sounds generated from the activity of the outer hair cells (OHCs) of the inner ear (Kemp, 1978). They can be recorded from all normal subjects when the auditory periphery is solicited by external acoustic stimuli and, from most subjects, even in the absence of stimulation (Zimatore et al. 2000). The measurements of OAEs provides a non invasive and sensitive method for the objective functional evaluation of the outer hair cells (OHCs), which are the primary target of noise-induced hearing loss (NIHL).

4.2 Animal models

Many studies have shown that the generation of reactive oxygen species (ROS) and free radicals is involved in the cascade of cochlear events that induces acoustic trauma (Le Prell et al., 2006, Fetoni et al., 2009). The mammalian cochlea does not have regenerative properties, leading to irreversible hearing loss. However, there is a synaptic repair mechanism occurring within the first few days post-exposure that is partially responsible for the recovery of acute hearing loss (temporary threshold shifts, TTS) (Puel et al., 1998). The generation of ROS leads to mitochondrial damage, membrane lipide peroxidation and release of pro-apoptotic factors inducing apoptotic cell death (Handerson 2006). Apoptotic cells can be evidenciated by confocal images of surface preparations of a damaged area in which are Tunel-positive fluorescent nuclei (see Fig.2 panel b in Fetoni et al. 2008a). Different approaches have been used to prevent noise induced hearing loss, such as antioxidant drugs (Sergi et al., 2006, Fetoni et al., 2008a; Fetoni et al., 2008b). Animal models are useful to quantify and observe the location of inner ear damage and to test antioxidant agents.

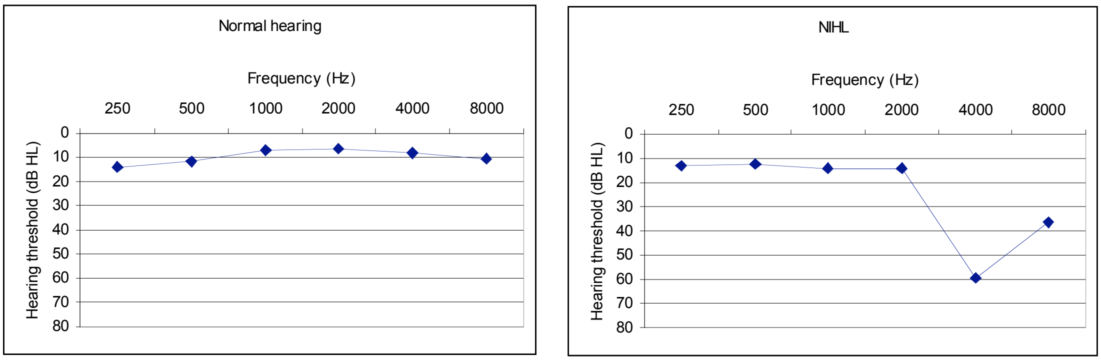

Figure 2: Pure tone audiograms for normal (left) and a "typical" noise-induced hearing loss (right)

4.3 Experimental tools

Several new techiniques have been developed in order to obtained morpho-anatomical and physiological information of damaged area and of apoptotic cells at different levels of detail.

1. **Immunohistochemistry. Tunel assay.** Visualising an antibody-antigen interaction can be accomplished in a number of ways. In the most common instance, an antibody is conjugated to an enzyme; alternatively, the antibody can also be tagged by a fluorophore (immunofluorescence). Tunel assay is a method for detecting DNA fragmentation by labeling the terminal end of nucleic acids. The method has subsequently been much improved and, if performed correctly, it should only identify cells in the last phase of apoptosis.
2. **Scanning electron microscope (SEM)** To obtain high-resolution imaging on damage areas with the possibility to observe *morfology* and *localization* of apoptotic cells.
3. **Western blot** or protein immunoblot, is an analytical technique to detect specific proteins in a given sample of tissue homogenate or extract; it is useful in quantification of proteins expression) **.**
4. **Signal analysis.** Recurrence Quantification Analysis (RQA) and Principal Component Analysis (PCA) have been carried on TEOAE waveforms (Zimatore et al.2000, 2002, 2003) to extract new descriptors that could facilitate an early diagnosis of acoustic trauma.
5. **Biophysical models.** An electronic model of human peripherical uditive system is useful to test and improve new hypothesis of cochlear mechanisms and to anatomically distinguish different contributions to hearing deseases (Zimatore at al.2008).

5 EUROPEAN STRATEGIES

WHO/Europe has carried out an assessment study to provide guidance about the estimation of the burden of disease related to environmental noise and preliminary estimates of health impact for the European Region, which is expected to be published in 2010.

5.1 European Environmental Noise Directive 2002/49

In the Green Paper on Future Noise Policy, the Commission addressed "noise in the environment" as one of the main environmental problems in Europe. In May 2002, the Council of Ministers formally approved the EU Environmental Noise Directive (2002/49/EC).

The main target is an integrated noise management system. In the first phase the competent authorities in the European member states had to produce strategic noise maps for major roads, railways, airports and agglomerations. The second phase is to inform and to consult the public. The third phase is to implement local action plans to reduce noise.

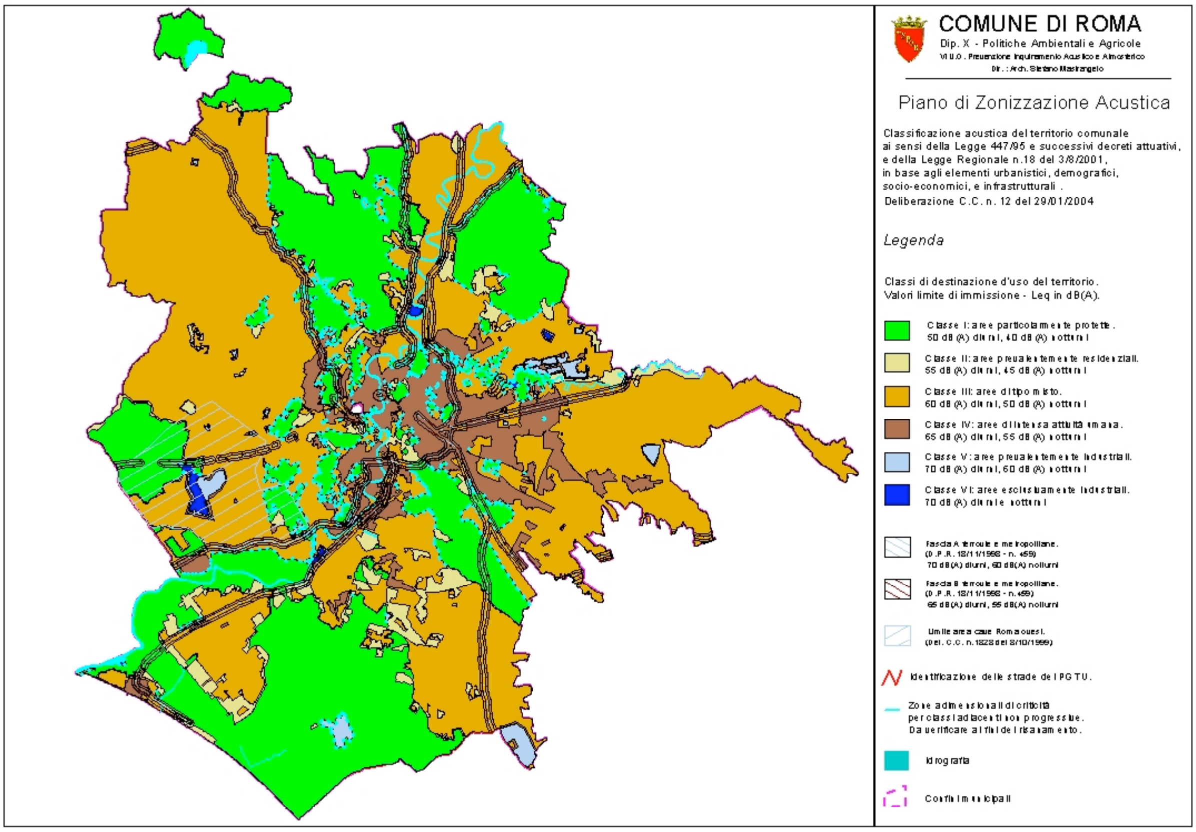

Figure 3 Zoning of Rome from Comune di Roma webpage , 2006

5.2 Zoning

Zoning is a device of land-use planning used by governments in most developed countries. The word is derived from the practice of designating permitted uses of land based on mapped zones separating one set of land uses from another. Zoning may be use-based (regulating the uses to which land may be devoted), or it may regulate building height, lot coverage, and similar characteristics, or some combination of these. Similar urban planning methods have dictated the use of various areas for particular purposes in many cities from ancient times. (See Figure 4). A "strategic noise map" is defined as a map designed for the global assessment of noise exposure in a given area due to different noise sources or for overall predictions for such an area (EU Directive 2002/49/EC);

Table 6: Noise exposure: Land-use planning and limits.

Land-use planning	Leq dBA day	Leq dBA night
Noise sensitive or protected	50	40
Residential area	55	45
Mixed residential area	60	50
Commercial area	65	55
Industrial area	70	60
Exclusivelly industrial area	70	70

5.3 European Projects

Following the previous directive above mentioned, several projects have been supported by EU community, for examples:

- QCITY.
- Quiet city transport is a new EU-funded project focusing on noise propagation and reception in urban areas. Taking a medium-term approach, the project aims to provide local communities with powerful tools for more effective policy making on reducing the harmful effects of sound due to road and railway transportation. The project has developed noise maps and action plans as envisaged by EU Directive 2002/49.
- SILENCE.
  The EU-funded SILENCE project (Quieter surface transport in urban areas) is addressing urban noise issues from first principles, taking a longer-term scientific perspective. Partners aim to develop integrated methodologies and technologies for improving the control and coordination of surface transport and to reduce human-generated noise in urban areas. Issues to be covered include: Control of noise at the source; Noise propagation; Noise emission; The human perception of noise. The Silence project aims at helping local authorities to tackle urban noise which is perceived by citizens as a major source of annoyance, such as sleep disturbance or the effects on health. A first phase, recently concluded, had the task to map current noise abatement policies and tools, as well as, the necessary solutions to deal with urban transport noise problems in different European cities (Barcelona, Bristol, Brussels, Copenhagen, Genoa, London, Paris and Stockholm). The next step will see the development of a guidance framework for implementing noise action plans.
- HARMONOISE. The project intends to develop and validate methods for the assessment and management of noise from road and rail traffic. The project will build on the most recent scientific achievements in all member states and will also provide consensus amongst future users throughout the EC. For this purpose the consortium has a wide international and scientific background. The methods to be provided will be implemented as obligatory under the Directive and will thus find a wide use for purposes of noise planning, mapping, zoning, noise abatement measures and strategies .

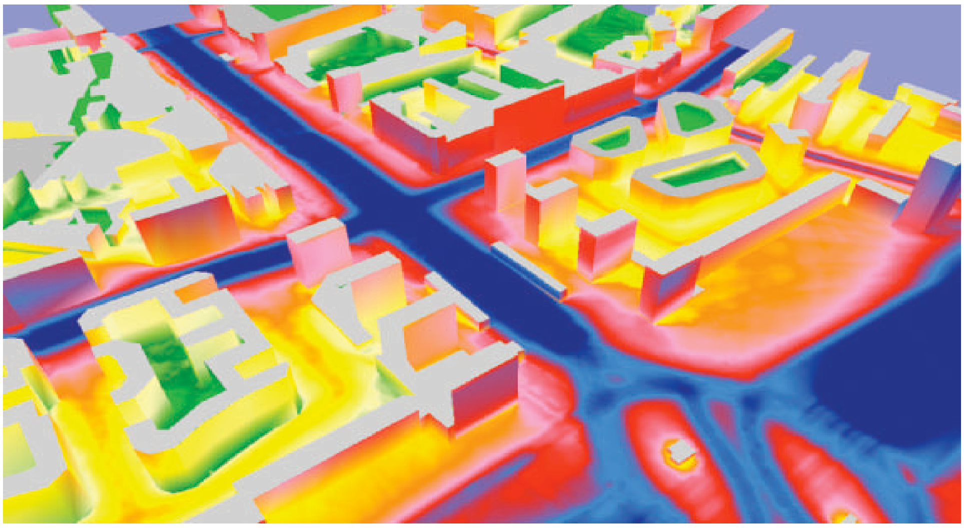

Figure 4: "*You can fly through Paris in full surround sound*": Paris noise mapping from Butler 2004

5.4 Noise mapping

The "noise mapping" is defined as the presentation of data on an existing or predicted noise situation in terms of a noise indicator, showing breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator in a certain area (EU Directive 2002/49/EC). In order to calculate real human exposure to noise, several simulation models have been realized and with this map it is possible to see what we hear. A noise map is a graphic representation of the sound level distribution existing in a given region, for a defined period. Different colours correspond to different levels of sound pressure (See Figure 4; Butler, 2004). As an example the 3D Paris map has virtual microphones every 10 metres horizontally and 3-meter interval vertically: in total, 26 million virtual microphones. Test measurements give an error rate of ± 1 decibel. In figure 5, the sound propagation in a valley in Val d'Aosta, Italy, is shown.

6 CONCLUSIONS

The cochlea is a fascinating and high-resolution acoustic sensor which needs protection. Taking advantage from personal experiences, it cannot be overestimated the importance of researches and studies focusing on the knowledge of cochlear mechanisms, not yet completely explained, and on testing new strategies to reduce noise damage. In this frame some antioxidants can be suggested as protective agents after appropriate testing in animal models. In a different context, some interesting examples of current european projects aiming to reduce noise emission and to limit its propagation, especially regarding road traffic, are illustrated and their foreseeable positive impact on the urban living condition underlined.

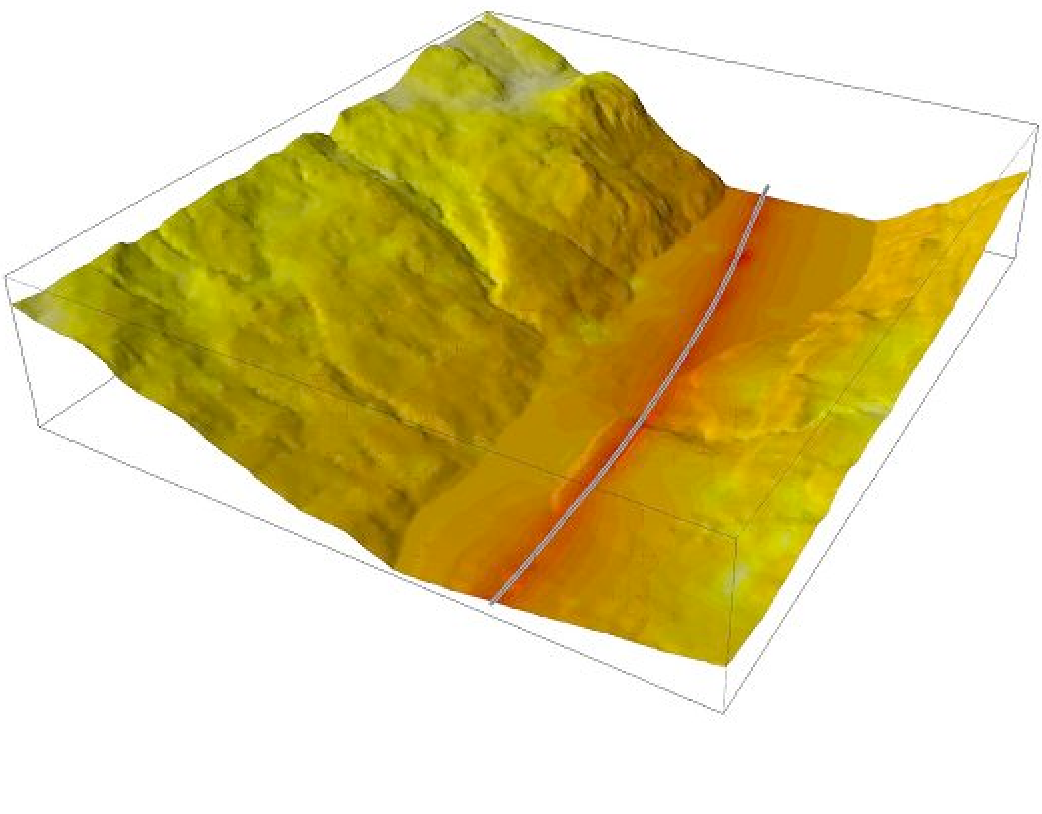

Figure 5: Example of simulation of noise propagation from auto route A5 by ARPA_Val d'Aosta

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LINKS:

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