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Public health and noise exposure: the importance of low frequency noise

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ABSTRACT

Noise exposure is known to cause hearing loss and a variety of disturbances, such as annoyance, hypertension and loss of sleep. It is generally accepted that these situations are caused by the acoustical events processed by the auditory system. However, there are acoustical events that are not necessarily processed by the auditory system, but that nevertheless cause harm. Infrasound and low frequency noise (ILFN, <500Hz) are acoustical phenomena that can impact the human body causing irreversible organic damage to the organism, but that do not cause classical hearing impairment. Acoustical environments are normally composed of all types of acoustical events: those that are processed by the auditory system, and those that are not. It is generally assumed that acoustical phenomena not captured by the human auditory system are not harmful. This is reflected by current noise assessment procedures that merely require the quantification of the acoustical phenomena that are audible to human hearing (hence the dBA unit). Thus, studies investigating the effects of noise exposure on public health that do not take into account the entire spectrum of acoustical energy are misleading and may, in fact, be scientifically unsound. Two cases of in-home ILFN are described.

1 INTRODUCTION

If noise is to be taken seriously as a Public Health issue, then it must be recognized that acoustical phenomena does not impinge only on (or via) the auditory system alone. Acknowledging this fact brings several issues into question, such as a) what type of acoustical event is being taken into account when the effects of noise on Public Health are under study, and b) what type of pathology is being evaluated in study populations. When the description of any acoustical event is coarsely classified as *either* audible or non-audible, then a substantial bias is introduced into research designs that are geared toward investigating the relationships between noise and Public Health. Obviously, if it is only acknowledged that acoustical phenomena impacts Public Health through the auditory system, then non-audible acoustical events are irrelevant, as is non-auditory pathology. By non-auditory pathology it is meant pathology that is not induced exclusively *via* the auditory system.

The goal of this report is to expand on the prevalent bias in studies associating noise exposure to Public Health issues, showing how this bias leads to misleading and/or invalid scientific studies. It will also be shown how this bias is allowed to persist, confronted with the lack of alternative viewpoints. Two cases of in-home Infrasound and low frequency noise (ILFN, <500Hz) will be described.

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2 ACOUSTICAL CONSIDERATIONS

2.1 The dBA-level

This parameter is a standard measure in international noise-related legislation. It measures the overall average acoustical amplitude as if it were being *heard* by humans. It matches the variable human auditory sensitivity to the different acoustical frequencies, effectively eliminating all acoustical energy at frequencies that are inaudible and less-audible to humans. Hence, the dBA-level provides information on the overall average amplitude of the *audible* acoustical environment, and not of the entire (real) acoustical environment (1-3). It is possible to obtain the overall average amplitude of the acoustical environment, but only if measurements are taken in dB, and not in dBA.

2.2 The Acoustical Spectrum

The acoustical spectrum ranges from 0 Hz to megahertz ranges and higher. The audible portion is between 20 Hz and 20 kHz. All other frequencies are considered non-audible. The lower section of the non-audible portion is called infrasound, while higher frequencies in the megahertz range and above are called ultrasound. This is the rudimentary manner in which science has divided the acoustical spectrum. In the electromagnetic spectrum, the visible portion is the minute section between 0.42-0.75 $\times 10^{15}$ Hz, and the ultraviolet (UV) portion (0.75-3.0 $\times 10^{15}$ Hz) is, itself, divided into 3 distinct segments: UV-A, UV-B and UV-C. No such refined segmentation exists for the acoustical spectrum. This topic has been the object of other studies (4,5).

2.3 Frequency Distribution Analyses

It is not standard procedure to obtain a frequency distribution analysis during routine noise assessments. Moreover, it has become common practice to compare acoustical environments merely based on dBA-level measurements. While this might be a valid methodology when the classical hearing impairment/skills are under study, it is entirely unsound if one seeks knowledge on the association between noise exposure and Public Health. In this report, infrasound and low frequency noise (ILFN) refers to all acoustical phenomena that occur at frequencies equal to, or below, 500 Hz.

3 BIOLOGICAL CONSIDERATIONS

3.1 Hearing Impairment

In general, hearing impairment means that larger amplitudes of acoustical energy are required in order to be heard. Hearing impairment is the most recognized consequence of excessive exposure to audible acoustical phenomena. This is the main reason why most international legislation regarding noise protection is based of the dBA parameter –one which simulates the characteristic frequency response of the human ear.

Hearing loss can be assessed and/or monitored through audiograms – a hearing test which measures the dB’s required to make a tone audible to the subject. The higher the dB-level, the larger the amount of hearing loss.

3.2 Noise Annoyance

Noise annoyance is a distressing feeling that can be felt by noise-exposed individuals. It is a subjective parameter. The European Commission’s Noise Team maintains: *Annoyance is the scientific expression for the non-specific disturbance by noise, as reported in a structured field survey. Nearly every person that reports to be annoyed by noise in and around its home will also experience one or more of the following specific effects: Reduced enjoyment of balcony or garden; When inside the home with windows open: interference with sleep, communication, reading, watching television, listening to music and radio; Closing of* *bedroom windows in order to avoid sleep disturbance. Some of the persons that are annoyed by noise also experience one or more of the following effects: Sleep disturbance when windows and doors are closed; Interference with communication and other indoor activities when windows and doors are closed; Mental health effects; Noise-induced hearing impairment; Hypertension; Ischemic heart disease* (6).

The position of these authors regarding annoyance differs somewhat from what is generally accepted by mainstream scientists. For this team of researchers, complaints of noise annoyance are given the importance of a clinical symptom, and indicate the possibility of cumulative excessive exposures to ILFN. It has been postulated by this team that the symptom of annoyance is justified by underlying organic lesions. Although already described in previous papers (4, 7-10), briefly, it has been proposed that the solidity of fused cochlear cilia, both amongst themselves, as well as to the upper tectorial membrane (a consequence of ILFN-exposure in rats), will cause discomfort (i.e., annoyance) when the basal membrane moves in response to the presence of an acoustical stimulus.

3.3 Structural Damage

When solids vibrate, their structural integrity may be threatened. Structural reinforcement is often the counter-measure applied to structures that must be able to exist in a vibrating environment. When airborne ILFN impacts on biological (viscoelastic) tissue, this triggers a vibratory motion of sheets of cells, an event that can be empirically established in any dance-club of the world. As a non-inflammatory response, the organism reacts by producing collagen. Collagen is a protein which imparts mechanical strength to the tissue and, for that reason, it is often considered the “steel” of the human body. The increased production of collagen in the presence of ILFN can be interpreted as an attempt, on behalf of the biological structure, to reinforce its structural integrity. Numerous studies on ILFN-exposed humans and animals demonstrate and corroborate this position (8, 11-17).

3.4 Cardiovascular Disease

The commonly held notion is that excessive noise causes annoyance which, in turn, triggers the standard generalized stress symptoms that, if sustained, can lead to cardiovascular disease. While this may be true, it is also a fact that cardiovascular disease can equally be the consequence of atherosclerotic plaque formation in blood vessels, constricting the lumen and, subsequently, restricting blood flow, potentially causing ischemia.

In ILFN-exposed blood vessels (of both animal and human models (8,12,13,18,19)), the media layer of blood vessel walls is greatly thickened by the increased amount of collagen (explained above). Hence, the same effect of lumen constriction and blood flow restriction is achieved, albeit through a different process. This thickening of cardiovascular structures can be readily observed through echocardiography (20,21).

Both large and small ILFN-exposed vessels appear with thickened walls (8,12,13,18,19) and this can lead, directly, to coronary heart disease. In many cases, cardiac bypass surgeries are recommended for these ILFN-exposed individuals (11). Indeed, cardiovascular disease and ILFN exposure are correlated but, as with annoyance, there is a more morphological explanation for this pathology than the classical, stress-triggered chemical cascade alone.

3.5 Cumulative Exposures

ILFN is prevalent in all urban areas, in many suburban areas, in some rural areas, in numerous occupational settings, and in a wide variety of recreational activities. Hence, an individual’s exposure to ILFN can occur in a variety of venues, not the least common of which is the automobile. Levels of ILFN inside ordinary cars are higher than in cockpits of commercial airliners (2). Cockpit workers (i.e., commercial airline pilots) are one of the professional groups with the highest risk of developing ILFN-induced pathology, because they work in ILFN-rich environments (21,22). The same can be said of commercial airline cabin crewmembers, i.e., flight attendants (21,22).

ILFN exposure can occur on-the-job *and/or* in the home *and/or* during leisurely activities. Biological structures do not discriminate between occupational, residential or recreational exposures of the organism to ILFN; they respond to the frequency *and* amplitude of the acoustical event(s), and not to different social settings of ILFN exposure.

Hence, when noise as a Public Health issue is considered, it is not scientifically sound to merely gather data on populations' residential areas (for example). Professional, recreational and even fetal exposures must also be taken into account, if *bona fide* data on the relationship between noise exposure and Public Health is genuinely sought.

3.6 Vibroacoustic Disease: ILFN-Induced Pathology

The clinical pathology developed by persons who are excessively exposed to ILFN is called vibroacoustic disease (VAD) (23,24). On March 8th, 2007, and for the first time, the Portuguese Ministry of Labor, through its National Center for Occupational Diseases, attributed 100% professional disability to a 40-year-old flight attendant, who had been diagnosed with VAD since 2001. Acknowledging that an ILFN-induced pathology exists categorically implies the recognition of ILFN as an agent of disease. Although the most thoroughly documented cases of VAD have been due to occupational exposures (21,24,25), several reports have already been produced regarding individual cases of VAD caused by environmental exposure to ILFN, usually within the home (26,27).

Dose-responses for ILFN and, consequently, for assessing the risk for developing VAD are non-existent. This situation is partially a consequence of the inadequate segmentation of the acoustical spectrum, as explained above (Section 2) and elsewhere (4,5). Large-scale epidemiological studies are non-existent, partially because ILFN has not yet been acknowledged as an agent of disease. For the same reason, protection, prevention, and zoning areas for ILFN-rich activities have not been and, to these authors' knowledge, are not being considered. Pharmacological therapeutic pathways for VAD-related pathology have also not been and, to these authors' knowledge, are not being explored.

Nevertheless, VAD can be readily diagnosed through echocardiography and/or through bronchoscopic examinations (21,22,26,28,29). Although bronchoscopy provides strong forensic evidence for the existence of VAD, because of its invasive nature it is only performed when legal proceedings are involved.

4 VIBROACOUSTIC DISEASE AND PUBLIC HEALTH – CASE REPORTS

At this juncture, the authors would like to clarify that they are not party to anti-technology sentiments, and that they welcome large industrial plants, such as grain terminals, as well as alternative forms of renewable energy, such as wind turbines. The authors further clarify that these data have not be scrutinized under any agenda other than that of scientific inquiry.

Two cases of in-home exposure to ILFN will be described.

Case 1 (Family F.) was first documented in 2004 (27). Family F. consists of mother (forestry engineer), father (architect) and 10-year-old son who have been exposed to ILFN generated by a deep water grain terminal (TDWT), located in Trafaria, District of Almada, Portugal (Figs. 1,2). The TDWT is across the Tagus River from Family F.'s home (Fig. 2), and is operated by the Lisbon Port Authority.

Figure 1. Trafaria Deep Water Terminal (TDWT).

Figure 2. View from the home of Family F., located in Lisbon. Across the Tagus River is the TDWT.

The second case is more recent. Family R. lives on a horse- and bull-breeding farm, located in a zoned, rural agricultural area, 1 hour north of Lisbon. Family R. consists of mother, father, 12-year-old son, and 8-year-old daughter. In November 2006, 4 wind turbines (2MW each) were installed around Family R.'s farm, at approximately 322m, 540m, 580m and 643m from the residential home. The distance to the stables is less than to the residential house (See Fig. 3).

Figure 3. Farm of Family R. isolated on upper left (arrow) with the four wind turbines.

Figure 4. Farm of Family R., with the two of the turbines at approximately 322m and 643m from the home.

The detail and \accuracy of acoustical measurements greatly depends on the type of equipment available. Both noise assessments were obtained in 1/3 octave bands and in linear dB (not dBA), and all equipment was duly calibrated.

Acoustical measurements at the Family F. home were conducted with one Bruel&Kjaer 2260 sound level meter, equipped with a ½" microphone (B&K, model 4189). Measurements were obtained in periods of 15-min, for 3 hours, starting at 9 p.m. (evening period) on Feb 4th, 2004 (27). The lower limiting frequency was 6.3 Hz.

Those conducted at the Family R.'s home used two 01dB Symphonie sound level meters, equipped with ½" microphone (GRAS, model 23606). Measurements were obtained in periods of 30-min, continuously for 12 days, between Apr 5th-16th, 2007. The lower limiting frequency was 1 Hz. Simultaneous and synchronized accelerometer and wind speed data were also acquired.

4.1 Vibroacoustic Disease in Family F.: Documented in 2004

Mr. F. is apparently asymptomatic. He complains of a lack of concentration and overall irritation, and has severe bouts of rosacea. He has always lived the suburbs of the city of

Lisbon, and has been working in the centre of Lisbon for the past 10 years. Mrs. F. has been diagnosed with hepatitis A, mononucleosis and allergic rhinitis. While still a student in university, she was once diagnosed with a late-onset epileptic seizure, for which she is currently unmedicated. She complains of body aches, particularly in the right shoulder, left knee, back and neck. X-rays have not revealed any abnormalities. She has always had headaches, mostly irradiating along the back of the neck. Approximately 4 or 5 years ago, while in a shopping mall supermarket, Mrs. F. suffered a violent tachycardia, with feelings of faintness. She was taken to the hospital where a subsequent EKG did not disclose abnormalities. Mrs. F. has worked in governmental administrative offices, in the centre of Lisbon for the past 16 years. Ten-year-old P. suffered from asthma until the age of 1 year. At the 5–8 months of age, he was medicated for reflux, and then again until he was 1 year old. At 8 months he suffered pneumonia. After the age of 1, he began to develop repeated ear infections that were not responsive to antibiotics. At age 3 he underwent ear surgery. At the age of 5, at school, he suddenly lost his vision, and was taken to the hospital where the EEG revealed a late onset epileptic seizure. Nose bleeds without an apparent cause used to be frequent, but have subsided with age. There is no history of rheumatic fever, radiation or asbestos exposure (27). Through echocardiography, all disclosed characteristic thickening of cardiovascular structures normally seen in VAD patients, namely the pericardium and mitral valve. The most severe cardiovascular condition was observed in 10-year-old P., most probably because the mother spent the pregnancy gestation months in that same ILFN-rich home. For a more detailed description of echocardiography findings in this family, see (27).

Late-onset epilepsy (24,29), nose bleeds (23,24), tachycardia (23,24), muscular and joint pain with no imaging corroboration despite sustained patient complaints (23,24), are common in VAD patients (23,24). Respiratory pathology has already been closely linked to ILFN exposure, both by this team (26,28,30-32), and by other authors (33-36). This family continues to be followed by this team, and has chosen to remain in the ILFN-rich home, but have relocated their bedrooms to the back of the house.

4.2 Acoustical Measurements at the Home of Family F.: 2004 Data

Several years ago, this team adopted a method whereby the levels ILFN could be adequately compared to each other. As explained above (Section 3.5),

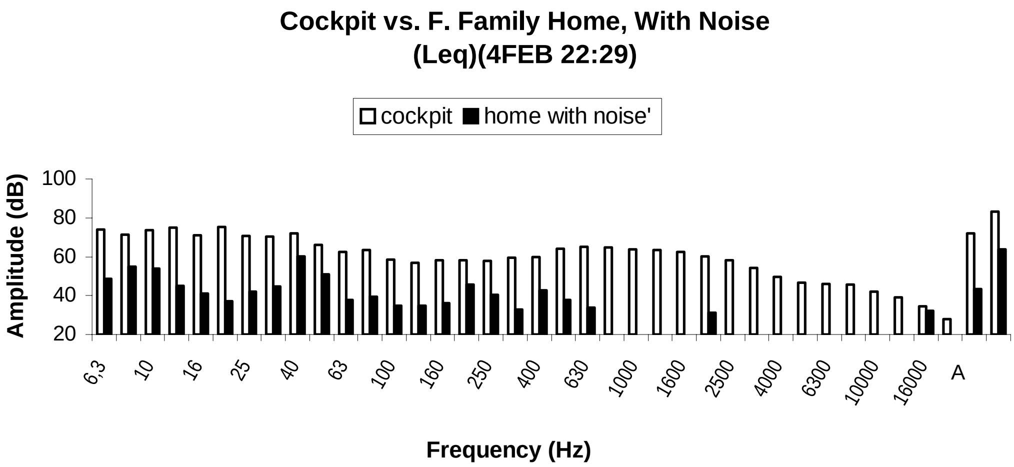

Figure 4 - Comparison of the frequency distribution obtained in the cockpit of the Airbus-340 (see text) with that obtained in the home of Family F., when the acoustical phenomena was present (L_{eq} values in dB). Reproduced from (27).

the acoustical environment of commercial airline cockpit is conducive to VAD. Since no standards for ILFN exist, this team has been using the acoustical levels obtained in the cockpit as a standard. Hence, Fig. 4 compares the ILFN obtained in the cockpit to that obtained in Family F.'s home. This was the first documented case of environmentally-induced VAD (27).

4.3 Acoustical Measurements at the Home of Family R.

Here, the measurements were conducted by an accredited firm (37), as a paid service provided to Family R. Data were made available to this team, within legal terms and with written consent on behalf of Family R., as well as the accredited firm. To date, and given the wealth of data, only the infrasound bands from 6.3-20 Hz have been analyzed by this team and, hence, only these are reported herein.

This time, data need not be compared with the cockpit. Instead, logic dictates that they must be compared to the acoustical measurements obtained in the house of Family F., since the acoustical environment in the home of Family F. has already been demonstrated to be conducive to the development of VAD. Figure 8 clearly shows that the levels in the home surrounded by wind turbines are larger than in the home that is being impacted by the TDWT.

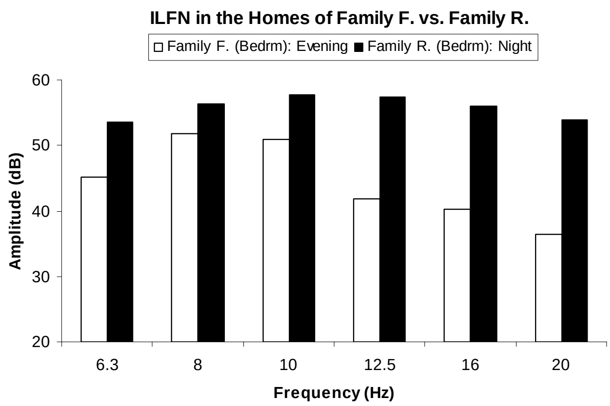

Figure 8 - Comparison of the frequency distribution within the infrasound bands (<20 Hz), obtained in the home of Family F. during Evening hours (8-11 pm), with that obtained in the home of Family R. during Night hours (11 pm-7 am) (L_{eq} values in dB).

4.4 Vibroacoustic Disease in Family R.

The wind turbines installed around Family R.'s home began operation in November 2006. In March 2007, the parents received a letter from the school inquiring about the reason for the sharp decrease in the memory and attention skills of the 12-year-old child, and the overwhelming tiredness he exhibited during physical education classes. The school questioned the parents if the boy was getting enough hours of sleep during the night.

The entire family has already received the typical VAD diagnostic tests, including echocardiograms which did not disclose any significant thickening of cardiovascular structures. Tissue fragments have been removed from the farm animals that have been scheduled for slaughter, and will be submitted to the light and electron microscopy analyses that this team usually conducts on ILFN-exposed tissue fragments. These procedures will be repeated every 6 months, and follow-up reports will ensue.

5 DISCUSSION

5.1 Some Problems…

In a perfect world, designed for the most efficient and accurate scientific studies, all noise assessments ought to be conducted with the same equipment and with the same procedures. This is not feasible. So, despite on-site and factory calibrations, a legitimate question will always remain: can the differences between the ILFN levels in the homes of Family F. and Family R. be due to differences in the noise measuring equipment and procedures alone?

Maybe, if and when VAD-related symptoms are documented in Family R., this question can be put to rest. But, it must be recognized that this course of action lacks an ethical basis. Given what has already been put forth to date by this team, regarding the dangers of excessive ILFN exposure and the risk of developing VAD in ILFN-rich environments, it would seem that these data are sufficient for some sort of precautionary measure.

5.2 Active and Effective Zoning of ILFN-Producing Facilities

The apparent dichotomy between economic development *or* healthy populations is a hindrance to real problem-solving. In this particular case, there is a third solution that could amicably combine the existence of ILFN-producing facilities and human populations: effective zooming laws. In urban areas, residential neighborhoods *could* be located behind large office buildings, instead of next to high-volume highways. Large industrial complexes *could* only be authorized within industrial parks, away from residential areas. And wind turbines *could* be confined to wind parks, located at safe (yet to be determined) distances from homes. Given what is known to date about the long-term effects of ILFN exposure on human health, these are neither unreasonable nor unfeasible propositions.

5.3 In Defense of ILFN-Producing Facilities

Scientists are not oblivious to the social and economical advantages of deep water grain terminals and wind turbines. Nor are they indifferent to the requirements of an ever-increasing technological society. *In no way can or should this report be construed as a document arguing against wind turbines and/or against grain terminals.* ILFN-generating facilities are inextricably linked with modern societies, even in a vast number of recreational activities.

Nevertheless, human life must always be at the highest exponent of importance, and the field of Public Health attests to the concerns that societies have had with the health of their populations. In humankind's recent history, other agents of disease associated with industrial activities were once also a problem (e.g., toxic odors or air- and water-borne chemical substances), and most of them have been dealt with through zoning laws. There is a reason why one can no longer set up a pig farm in downtown Manhattan: industry zoning laws.

6 CONCLUSIONS

Regarding noise exposure and Public Health:

- Studies must take ILFN into account if useful and accurate data are, indeed, desired;
- The acoustical spectrum should be further segmented and the dBA unit should be abolished from ILFN assessments;
- VAD, i.e., ILFN-induced pathology, is not restricted to occupational exposures and has been documented as a result of in-home ILFN contamination.

Regarding in-home ILFN exposure:

- ILFN levels inside the home near wind turbines, Family R., are larger than those inside the home near a grain terminal – Family F.;
- Family F., living near the grain terminal developed VAD;
- Family R. will also develop VAD should they choose to remain in their home.

If the effects of noise on Public Health are truly a concern then common sense, scientific data and logical thought processes dictate that a) acoustical phenomena is capable of inducing irreversible pathology unrelated to the classical hearing impairment; b) acoustical energy distributed across the frequency spectrum must be routinely and correctly assessed; and c) valid pathological signs and symptoms must be correctly identified and objectively evaluated.

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