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Vibroacoustic disease: the need for a new attitude towards noise

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ABSTRACT

Background. The importance of information technologies in public awareness of environmental issues is especially clear when a new occupational disease is identified. This is certainly the case with Vibroacoustic Disease (VAD), a whole-body noise-induced pathology, that is not particularly related to the ear. **The Problem**. The social and economic costs of VAD are staggering, and continuously aggravated by the fact that environmental noise assessments pay little attention to the noise that causes VAD - Low Frequency (LF) noise (* 500 Hz), focusing primarily on that which causes hearing impairment. An erroneous assumption justifies these incomplete noise assessment requirements: noise only affects the ear. Thus, all noise protection measures and evaluation procedures focus *exclusively* on the frequencies affecting the auditory system (* 500 Hz). **The Solution**. Physical protection against LF noise is not feasible, given the large wavelength of LF (in meters). Preventing the evolution of VAD to clinically severe stages *is* feasible. The requirements are twofold: a) entry-level and yearly echocardiogram of job-candidates and exposed individuals; b) education of workers, occupational physicians, and management. There is an urgent need to include LF in all noise assessments, and use prevention medicine against this ubiquitous environmental hazard. However, this can only be achieved with active participation of a well-informed public.

THE STATUS QUO

Noise pollution is often considered a contained problem because hearing protection devices are generally efficient, and legislation regarding noise-induced hearing loss is relatively effective. Additionally, common noise assessments are a fairly simple process, normally requiring a hand-held instrument that measures the sound pressure level (SPL) of the acoustic field, in decibels (dB). Permissible exposure levels are primarily based on the dB-level measurements, and are regulated on an hourly basis. Noise pollution is largely regarded as an agent that causes hearing loss and/or minor annoyance and discomfort. The notion that no other harmful organic effects can be attributed to noise exposure is widespread, and exceptions to this are few and far between (Alves-Pereira, 1999).

The human ear captures sound within a specific window of the acoustic spectrum, generally within the 20-20000 Hz range. However, it is most responsive to sounds within the mid-frequencies: 1000-10000 Hz. Noise exposure protection focuses primarily on these frequencies, because its goal is to prevent hearing loss. Acoustic phenomena within the low frequency (LF) range (* 500 Hz) are also audible, but require a higher intensity to be perceived. Infrasound (* 20 Hz) is non-audible to humans; it is therefore considered to have no impact upon hearing loss, and consequently, environmental noise assessments within the infrasonic range are a rarity (Alves-Pereira, 1999). For the remainder of this report, LF noise will refer to acoustic phenomena within the 0-500 Hz range, hence infrasound is also included.

Hearing conservation programs are mandatory in most industrial occupations. Audiograms and tympanograms are commonly used tests to assess degree of hearing impairment and existence of noise intolerance. Professional deafness is normally established when a hearing deficit of 30dB is registered at 4 KHz. Physical, auricle protection devices (such as earplugs) are also employed to prevent professional hearing-loss. To adequately characterize an acoustic environment, both the dB-level and the frequency distribution should be known. With very few exceptions (Alves-Pereira, 1999), environmental noise assessments rarely include a frequency spectra analysis. When they are performed, it is usually for the sole purpose of choosing the best hearing protection device. Again, this established procedure is based on the assumption that noise only affects the auditory system. Thus, protection against noise focuses principally on the hearing function.

Extra-aural, whole-body, noise-induced pathology has been an ignored concept. Over the past decades, scientific investigation into this issue has been infrequent, and existing data is often regarded as inconclusive (Alves-Pereira, 1999). Difficulties arise when reports of noise assessments do not include a frequency spectrum analysis, and only the dB-levels of the acoustic fields are measured. This has led to an accumulation of parallel studies that cannot be compared because the descriptions of the acoustic environments are incomplete. Two environments may have similar dB-levels, but different frequency distributions. One may have the majority of the acoustic power concentrated in the mid-frequency bands, while the other may be predominantly within the LF range (infrasound is not assessed). When studying the effects of noise, it should be considered insufficient to only provide data on the dB-level of the acoustic phenomena. The frequency range to which whole-body organ systems respond is not the same as that for the auditory system. Thus it becomes very relevant whether the acoustic power is predominantly in the LF range or in the mid-frequency range.

In modern society, LF noise is ubiquitous; not only is it found in most industrial environments, but also in nearly all public transportation, numerous leisure activities, and many urban residential areas. The extent to which LF noise exposure is responsible for Public health problems is unknown.

The *status* quo concepts are that
a. noise only produces an organic effect on the auditory system;
b. evidence of noise-induced, extra-aural pathology is inconclusive; and
c. infrasound is non-relevant for noise-induced pathology.
These concepts can no longer be upheld.

VIBROACOUSTIC DISEASE

Vibroacoustic disease (VAD) is a noise-induced, whole-body pathology, of a systemic nature, caused by excessive and unmonitored exposure to LF noise. It has been identified in aeronautical technicians (GIMOGMA, 1984a), military pilots (Carmo *et* al, 1992 and Canas *et* al, 1993), commercial pilots and cabin crewmembers (Alves-Pereira *et* al, 1999), and disc-jockeys (Castelo Branco, 1999 and Castelo Branco *et* al, 1999). VAD evolves over long-term noise exposure, in years, and can lead to severe medical conditions, such as cardiac infarcts (Castelo Branco, 1999 and Castelo Branco *et* al, 1999), stroke (Castelo Branco, 1999 and Castelo Branco *et* al, 1999), cancer (Silva *et* al, 1996 and Castelo Branco *et* al, 1999), epilepsy (Martinho Pimenta *et* al, 1999a), rage reactions (Castelo Branco *et* al, 1999), and suicide (Castelo Branco *et* al, 1999). When VAD was first identified in professional groups known to be exposed to noise, it was initially thought to be limited to the realm of occupational diseases. However, it has since been diagnosed in individuals exposed to noise in non-occupational settings, or in seemingly non-"noisy" environments (Castelo Branco *et* al, 1999). This rises the issue of LF noise-induced pathology to the domain ofPublic Health issues.

The evolution of VAD is classified by three stages based on years of noise-exposure - mild (1-3 yr), moderate (4-9 yr) and severe (10-15 yr). Please see Table I. This is a departure from current guidelines, which measure noise-exposure on an *hourly* basis. The classification of VAD stages was grounded on a study of 140 aeronautical workers, who had been selected from an initial group of 306 individuals (Castelo Branco, 1999). Selection criteria for this study population are given in Table II. LF noise is a stressor, and, as such, initial exposure causes disorders generally considered as "stress-related", such as gastrointestinal dysfunction or infections of the oropharynx. However, LF noise-specific features of VAD can be identified in the mild stage, such as thickened cardiac structures (Marciniak *et* al, 1999), increased frequency of sister chromatid exchanges (Silva *et* al, 1996), immunological changes (Castro *et* al, 1999), altered values of hemostasis and coagulation parameters (Crespo *et* al, 1988), and specific neurophysiological (Martinho Pimenta *et* al, 1999a, b and c; Pimenta *et* al, 1999) and cognitive (Gomes *et* al, 1999) changes. In the severe stages of VAD, as mentioned above, more serious disorders can develop.

There is an important feature that has prevailed among the many VAD studies performed over the years: a consistent amount of the noise-exposed workers (usually around 30% of the study population) did not develop severe stages of VAD (Castelo Branco, 1999). They exhibited milder symptoms, but never evolved to more critical medical conditions. It is suspected that survivorship bias may play a significant role. Future studies of physiological and homeostatic parameters may provide clues as to what differentiates LF noise-susceptible individuals from the non-susceptible.

VAD is essentially characterized by a proliferation of extra-cellular matrix. This means that blood vessels can become thicker, thus impeding the normal blood flow. Within the cardiac structures, the parietal pericardium and the mitral and aortic valves also become thickened. The most recent VAD studies have been suggesting that infrasound exposure may be crucial to the rate of evolution of VAD. Occupational exposure to infrasound is suspected to cause an increase in the rate of thickening of the pericardium and cardiac valves in commercial airline pilots over that of flight attendants (Alves-Pereira *et* al, 1999).

Among the most serious on-the-job consequences of untreated VAD are rage-reactions, epilepsy, and suicide. VAD patients do not have the usual suicidal profile: after the event, if unsuccessful, they remember nothing, and are confused about the entire episode (Castelo Branco *et a*l, 1999). Similarly, patients who suffer rage-reactions also appear confused and seem to remember nothing (Castelo Branco *et a*l, 1999). These events can have dire consequences if they occur on the job. Not only can other individuals be injured, but also costly sophisticated equipment could become irreparably damaged.

The nefarious effects of VAD in the workplace can be successfully controlled by prevention medicine, and avoided by adequate selection procedures. This can be preliminarily achieved with a relatively simple diagnostic method - the echocardiogram. Other diagnostic tests can confirm a diagnosis of VAD.

Diagnostic Tests for VAD

The echocardiogram is the diagnostic method of choice for a preliminary diagnosis of VAD (Araujo *et* al, 1989; Marciniak *et* al, 1999). Proliferation of extra-cellular matrix can be observed with various imaging techniques. The echocardiogram visualizes thickening of cardiac structures, namely the pericardium and heart valves. In severe cases, echo-Doppler imaging shows thickened carotid arteries, and transcranial Doppler shows abnormal cerebral blood flow (Albuquerque *et* al, 1991). These three diagnostic tools are non-invasive and are based on principles of ultrasound.

If the echocardiogram shows thickening of cardiac structures then other diagnostic tests are in order. Brainstem auditory evoked potentials (BAEP) measure the reaction time of the brain to auditory stimuli. In VAD patients, these recordings are altered in terms of amplitude and latency values (GIMOGMA, 1984b; Pimenta *et* al, 1999). BAEP are also a non-invasive medical procedure. A thorough neurological examination is useful to investigate whether other VAD-related signs or symptoms exist, such as balance disorders (Martinho Pimenta *et* al, 1999b), palmo-mental reflex (Martinho Pimenta *et* al, 1999c) or epilepsy (Martinho Pimenta *et* al, 1999a). The existence of brain lesions can be confirmed through magnetic resonance imaging (Cruz-Maurício *et* al, 1991 and Pimenta *et* al, 1999).

A blood test can provide information on the genotoxic (Silva *et* al, 1996), immune (Castro *et* al, 1999), and blood coagulation parameters (Crespo *et* al, 1988), all of which are altered in VAD patients. Lastly, CT scan of the lungs can identify lung focal fibrosis which has been seen in both non-smoker, LF noise-exposed workers (Reis Ferreira *et* al, 1999), and in LF noise-exposed animal models (Grande *et* al, 1999). The respiratory tract of small rodents, exposed to LF noise on an occupationally-simulated schedule (8 hours/day, weekends in silence), seems to be one of the main targets (Sousa Pereira *et* al, 1999a and b, and Oliveira *et* al, 1999), as well as the immune system (Águas *et* al, 1999a and b)

The audiogram measures the amount of hearing loss at specific frequencies. In VAD patients, losses in the lower frequencies are observed (Castelo Branco, 1999). Alone, losses in the LF ranges could be caused by a variety of LF noise-exposure patterns, for example, excessive use of portable cassette-players ("walkmans"). The audiogram does not assess whole-body effects of LF noise exposure, thus it is ineffective as a method to diagnose VAD.

THE PROBLEM

Noise is thought to only affect the auditory system. Thus, noise protection is focused principally on the frequencies of acoustic phenomena that are audible to humans. Consequently, infrasound is not considered.

Legislation for workers in "noisy" environments are based on hourly exposures and acoustic amplitude levels. For example, according to the United States Occupational Safety and Health Administration, a worker can be exposed to a 90 dB-level acoustic environment for 8 hours per day (OHSA, 1995). No mention is made to the frequency bands that, together, compose the 90 dB level. Are they predominantly in the 20-500Hz range, or in the 1000-5000 Hz range? This is highly relevant information since different organ systems are susceptible to different acoustic frequencies. Within the 20-500Hz range, 8 hours a day of an acoustic field at a 90 dB amplitude can cause irreversible damage to several organ systems. However, frequency distribution analyses of the environment are generally only performed to determine the best hearing protection device. There seems to be no legislation for infrasound.

If this were a situation with light instead of sound, it would be like ignoring x-rays (merely a different frequency of visible light), simply because they can't be seen. Current LF noise protection is analogous to wearing dark glasses against these x-rays.

The long-term effects of LF noise on living systems is still a wide-open field of unknowns, and VAD is, as yet, unrecognized by current labor legislation. The primary reason is the lack of large-scale epidemiological studies. Past VAD studies have been limited to animal models, and small samples of 30, 45, 60, and 485 LF noise-exposed workers. The results obtained urgently warrant that large-scale epidemiological studies be undertaken, and medical communities, noise-exposed workers, and the public at large be promptly informed. The extent of LF noise-induced disease in the general population is unknown. Among noise-exposed workers it continues to be a mis-diagnosed pathology.
Current problems regarding noise-pollution can be summarized as follows:

a. The steadfast but erroneous concept that noise only causes damage to the ear;
b. Lack of legislation regarding LF noise exposure;
c. A workforce with increasing absenteeism, lowered productivity, and increased risk in the workplace;
d. Widespread effects of LF noise exposure among the general population are unknown;
e. Public awareness of the danger of LF noise exposure is close to non-existent.

THE SOLUTION

Recognition of a previously unacknowledged environmental stressor is always a traumatic event. Classifying LF noise as an agent of disease, and VAD an occupational pathology, will certainly cause some upheaval, especially since physical protection against LF noise is not a feasible option. The dimensions of acoustic barriers are directly related to the wave length of the acoustic phenomenon. Within the low frequency range, wave lengths can be on the order of meters. Hence, acoustic barriers would be too large to be practical. At present, the most successful way to avoid VAD is through methods of prevention medicine and employee selection procedures.

Among LF noise-exposed workers, VAD can be successfully prevented from reaching the severe stages if a yearly echocardiogram is administered to the noise-exposed workforce. Evolution of VAD can thus be followed, and severe stages of VAD can be avoided. When the effects of VAD-associated pathologies (See Table I) begin to accumulate, the employee should be removed from the noise environment and reassigned to a non-"noisy" worksite. Simultaneously, job applicants for "noisy" jobs should be screened for pre-existing LF noise exposure and/or VAD. Many popular leisure activities can impose large amounts of LF noise on the individual, such as rock concerts, dance clubs and motorized sports. If the echocardiogram reveals some thickening of cardiac structures, the applicant should be re-evaluated for the position. This is not discrimination. Selection of individuals to work a particular job has been a common practice among many professions. For example, aircraft pilots must have 20/20 vision; sky-scraper window-washers and some construction workers cannot suffer from vertigo; pregnant women do not work with x-rays.

The consequences of the above paragraph are fully recognized. Disruption to established employer-employee practices will be significant. However, the undesirable alternative is an increasingly ill society and workforce. The development of disabilities requiring early retirement, or a change of career, can shatter the lives of many individuals. For example, to initiate a career path within a noise-environment job, only to be removed and possibly demoted within a few years is costly both to a company and to the employee, often instigating problems within the human resources and management departments, and with the individual's social and family life. Similarly, if a company spends time and resources to train individuals for certain noise-environment positions, the investment return might be null if the individual is only capable to work for a few years.

Moreover, according to Portuguese labor law, the employer is responsible for any pre-existing medical condition that is aggravated on-the-job. Since VAD is not legislated as an occupational disease, and LF noise is not recognized as an agent of disease, the burden of the medical costs of VAD patients is currently upon the governmental healthcare system. Furthermore, workers on sick leave, or who were forced into early retirement due to VAD-associated disorders are not eligible for any workers' compensation. Clearly, recognizing VAD as an occupational disease will bring some mayhem, but ignoring it will have disastrous consequences.

Proposed short-term solutions:

a. All environmental and/or occupational noise assessments should include a frequency distribution analysis, and evaluation of infrasound levels should be included in the acoustic evaluation;
b. General physicians should inquire about the individual's workplace as part of the initial interview;
c. Noise exposed workers should be made aware of the possible dangers of LF noise exposure, and should mention to their primary care physicians that they work in "noisy" environments.

Proposed long-term solutions:

a. Establishment of legislation requiring that all environmental and occupational noise assessments include a frequency distribution analysis, and infrasound evaluation;
b. Establishment of the echocardiogram as a mandatory yearly examination of all noise-exposed workers, and as a pre-requisite for applicants to jobs within "noisy" environments;
c. Establishment of LF noise as an agent of disease, and VAD as an occupational disease, so that appropriate compensation can be awarded to the many disabled workers.

THE NEED FOR PUBLIC INFORMATION

All the above information must be made public. It is no longer acceptable that individuals have their lives destroyed because of excessive LF noise exposure. Worse than undesirable, it is unethical to keep workers within "noisy" environments, and ignore the potentially devastating, whole-body, acoustic trauma.

LF noise environments abound in modern leisure activities; specifically, rock concerts, dance clubs and powerful car audio equipment, not to mention the ever so popular water jet skis and motorcycles. Just how widespread are the LF noise-induced disorders is unknown. The public must be informed immediately that excessive exposure to these "noisy" activities may limit their professional future.

An Anecdotal Story

In one of the VAD studies among employees of an aeronautical industry, one of the subjects initially chosen for the control group worked in the Technical Drawing Division certainly a quiet environment! As the VAD diagnostic tests progressed, his came up positive for the LF noise-induced disease. His mode of transportation to and from work, his current residential area, and his hobbies were all investigated, and, strangely enough, none suggested exposure to a LF noise source. Finally, during the last physical examination, in which he presented all the neurological signs of VAD, the baffled physician explained the situation to him. With a grin, the man said: "Noise?! I was exposed to a lot of noise when I was growing up. My parents owned and operated a water mill, and our house was right above it. I lived there until I was 26 years old." Unfortunately, the mill has since been deactivated, so noise assessments are no longer possible. Nevertheless, this 34 year old man was already manifesting signs and symptoms of a moderate stage of VAD (See Table I) (Castelo Branco *et* al, 1999). Luckily, he did not decide to become an airline pilot, an astronaut, a disc-jockey, nor a sound or aircraft technician or a shipmaster, for example. Had he done so, his condition at 34 years of age may have been much more serious, or even fatal.

Education of the public is crucial. Non-scientific literature on VAD is also important, and a feeble attempt has been made to fill this void (Paiva *et* al, 1998). Management and executive officers must be educated on the health implications of LF noise exposure on their workers. According to VAD studies mentioned above, approximately 70% of the population is susceptible to LF noise. This is all the more alarming since "noisy" environments do not seem to be having a tendency to decrease much on the contrary.

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