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A RELAÇÃO DOSE-RESPOSTA NA EXPOSIÇÃO A RUÍDO OCUPACIONAL: A DISTORÇÃO NA QUANTIFICAÇÃO DA DOSE QUE INDUZ A COMUNIDADE MÉDICA EM ERRO

DOSE-RESPONSE RELATIONSHIP IN OCCUPATIONAL NOISE EXPOSURES: THE DISTORTED QUANTIFICATION OF DOSE THAT MISINFORMS THE MEDICAL COMMUNITY

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Abstract
Background: One of the foundational principles of Medical Sciences is the Dose-Response relationship. When occupational noise is measured, this corresponds to quantifying the Dose. In Portugal, noise is regulated by DL 9/2006 (RGR) which describes the methodologies to be used when quantifying noise levels. **Objective:** To demonstrate how RGR-imposed methodologies are misleading the medical community as to the amount of Dose received and, consequently, compromising the investigation and evaluation of clinical Responses. **Methods:** High resolution noise measurements were continuously acquired during 7 days in a workplace. Data was analysed with RGR methodologies and compared to more modern and scientifically robust methodologies. **Results:** A total of 2022 10-minute recordings were collected, two of which were selected for presentation herein. As per the RGR-imposed methodologies, these two samples reflect similar acoustic environments since both exhibit an overall, audible noise level of 28 dBA. Physical reality, however, demonstrates that these two samples have significantly different acoustic environments, one of 89 dB and the other 47 dB. **Conclusion:** The medical community is being misinformed by the RGR regarding the amount of Dose that workers receive. Consequently, the investigation into potential clinical Responses (health complaints) is frequently deemed (erroneously) to be unnecessary.

Keywords: Infrasound, Low frequency noise, A-weighting, Noise-induced pathology, Health complaints.

Resumo
Introdução: Um dos princípios fundamentais das Ciências Médicas é a relação Dose-Resposta. A medição do ruído ocupacional corresponde à quantificação da Dose. Em Portugal, o ruído é legislado pelo DL 9/2006 (RGR) que descreve as metodologias para a quantificação do ruído. **Objetivo:** Demonstrar como as metodologias impostas pelo RGR estão a induzir a comunidade médica em erro quanto à quantidade de Dose recebida e, consequentemente, comprometendo a investigação e avaliação da Resposta clínica. **Métodos:** Foram efetuadas medições contínuas de ruído em alta resolução durante 7 dias num local de trabalho. Os dados foram analisados com as metodologias RGR e comparados com metodologias cientificamente mais robustas. **Resultados:** Das 2022 gravações de 10-minutos recolhidas, duas foram selecionadas para apresentação. De acordo com as metodologias impostas pela RGR, os dois ambientes acústicos são iguais porque ambos apresentam um nível de ruído global audível de 28 dBA. A realidade física, no entanto, demonstra que estes ambientes acústicos são significativamente diferentes, apresentando um 89 dB e o outro 47 dB. **Conclusão:** A comunidade médica está a ser mal informada pelo RGR relativamente à quantidade de Dose que os trabalhadores recebem. Como consequência, a investigação da potencial Resposta clínica (queixas de saúde) é frequentemente considerada desnecessária.

Palavras-Chave: Infrassons, Ruído de baixa frequência, Ponderação A, Patologia, Queixas de saúde.

Introduction

Within Medical Sciences, noise is classified as a *physical* agent of disease, in contrast to biological, chemical or psychosocial agents of disease. As such, noise exposures are comparable to exposures to other physical agents of disease, such as vibration and electromagnetic radiation. The Dose-Response relationship in Medical Sciences is of foundational importance, applicable to exposures to poisons, medications and any type of agent

that can impact human health. For noise exposures, the Dose-Response relationship was defined many decades ago, to prevent hearing impairment and deafness in noise-exposed workers (for example, OSHA, 2025 and EASHW, 2025). Today, occupational noise exposures are limited by values expressed in dBA (A-weighted decibels).
The dBA is a measure of the audible noise in the environment that can potentially cause hearing impairment, depending on exposure time. The "A" refers to the application of the A frequency-weighting filter, or A-weighting, which is used because it simulates the variability of human hearing. When noise is measured linearly (i.e., with no filter or unweighted), noise levels are expressed in dB. The dBA metric has since expanded into the realm of Public Health, within the context of environmental noise exposures, such as from urban, recreational or industrial sources. In occupational settings, the act of measuring noise is equivalent to quantifying the Dose of the agent of disease. The corresponding clinical Response is usually assessed through audiograms which evaluate the auditory function in noise-exposed workers. Professional deafness is legally established at the 4000 Hz band (or notch) of the audiogram.
In Portugal, the legislative document DL 9/2007 (Ministério do Ambiente, 2007), also known as the *Regulamento Geral do Ruído* (RGR) stipulates the methodologies that must be used when measuring noise levels, in both occupational and environmental settings. The stipulations in this legislative document are similar to those found in most other EU and non-EU countries. For example, in New Zealand the document is called SR1995/167 (Ministry of Labour of New Zealand, 1995); in the United Kingdom it is known as UKSI 1989 No. 1790 (HSE, 1989); and in Estonia it is the RTI, 05.12.2018, 12 (Ministry of Social Affairs of Estonia, 2007). These methodologies, which are predominantly based on the dBA metric, effectively exclude the large portion of the acoustic environment that does not cause classical hearing impairment (as measured through audiograms). This excluded portion of the acoustic environment is mostly composed of infrasonic (below 20 Hz) and lower-frequency components (below 200 Hz) that are believed (erroneously—see Stepanov (2000), for example) to have no impact on human health.
The goal of this paper is to demonstrate that the noise measurement methodologies imposed by the RGR are, within the context of Medical Sciences, insufficient to properly characterize the Dose of noise to which workers are exposed. This will be achieved by contrasting the legislation-imposed, A-weighted methodology with a more updated and scientific-grade methodology that uses unweighted values and increased temporal and spectral resolutions.

Materials and Methods

Within the context of a research project, high-resolution acoustic measurements are being conducted in several occupational environments. The methodology and protocols applied to this research project have been previously used in the quantification of infrasound and low frequency noise within environmental settings (Bakker *et al.*, 2022; IARO 2024). Only one prior study in an occupational environment was performed using this methodology (Stefuryn *et al*., 2024).
In July 2024, Mrs. S (a member of the general public residing in Lisbon, Portugal) contacted these authors and explained that she and her husband were working remotely from home for the past 2 years. They felt they were being exposed to excessive amounts of low frequency noise, emanating from a large supermarket located beneath their apartment building. She expressed concern for their deteriorating health, and she appeared particularly worried about the symptomatology identified in their 3-year-old daughter. Acoustic recordings were conducted within the S Family workplace/residence for 7 continuous days, from 12 July (18:47) until 19 July (19:04).
Acoustic recordings were obtained with the SAM Scribe FS (Full Spectrum) (Model Mk2, Soundscape Analytics, Palmerston North, New Zealand) (Atkinson & Rapley Consulting, 2016; Bakker *et al.*, 2017) which allows for continuous data acquisition of sound down to 0.1 Hz for days, weeks or months. This system comes equipped with two channels (blue and red microphones) and provides sound data via USB to a Windows computer, with a sampling frequency of up to 44.1 kHz. Recordings are saved on a hard drive in non-compressed

.wav file format. GPS information on location is also recorded in the file metadata with a corresponding digital signature. The frequency response curve of the microphone is practically linear in the 1–1000 Hz range (0.5–1000 Hz: ± 0.5 dB, 1–10 kHz: ± 2dB; 10–20 kHz: ± 4dB) (Primo, 2016).

Data was processed by Matlab (The MathWorks, USA) using a Class 0, narrow band filter bank in accordance with ANSI® S1.11-2004 and IEC 61260:1995. Data was acquired with a sampling rate of 11.025 kHz including the calibration signal for reference (Calibrator Type I, 1000 Hz/94 dB tone). Calibration was performed at the beginning and end of each recording. Both microphones were installed on tripods approximately 1.5 m above the ground and were fitted with wind shields throughout the entire recording period. The blue microphone was placed in the child's bedroom and red in the workspace/lounge.

After data acquisition, scientific-grade, high-resolution analyses were performed with:

- A temporal resolution of 1-second,
- A spectral resolution of 1/36th of an octave, and
- Sound pressure level (SPL) expressed in dB unweighted.

The methodology described in the RGR was also informally applied for the purposes of comparison and clarification, using:

- A temporal resolution of 10 minutes,
- A spectral resolution of 1/3rd of an octave, and
- SPL expressed in dBA.

Results

A total of 169 hours of data were acquired, corresponding to 2022 10-minute recordings (both microphones). Table 1 summarizes the number of samples obtained per SPL range, expressed in dBA.

Table 1. *Number and percentage of Samples, per microphone, within specific SPL ranges, expressed in dBA.*

	Blue	%	Red	%
<30 dBA	524	52	611	60
30 - 40 dBA	375	37	254	25
40 - 50 dBA	70	7	110	11
>50 dBA	42	4	36	4

Table 2 shows the same data but for SPLs expressed in dB.

Table 2. *Number and percentage of Samples, per microphone, within specific SPL ranges, expressed in dB.*

	Blue	%	Red	%
<40 dB	0	0	0	0
40 - 50 dB	31	3	24	2
50 - 60 dB	195	19	186	18
60 - 70 dB	254	25	252	25
70 - 80 dB	372	37	372	37
>80 dB	159	16	177	18

Two 10-minute Samples, representative of these recordings, have been selected for presentation herein, both captured with the blue microphone in the child's bedroom at different times of day: Sample 1 starting at 22:28 and Sample 2 at 05:50. These Samples are shown in Figure 1, partially in accordance with RGR methodologies: 10-minute average, spectral resolution of 1/3rd of an octave, SPLs expressed in dBA (red bars), and with the A-weighting ensuring that frequencies below 20 Hz will not measurably change the SPL value. Greatly exceeding RGR requirements, Figure 1 also shows the SPLs expressed in unweighted dB (pink bars), with a lower limiting frequency of 0.1 Hz. These values reflect physical reality, i.e., both the audible and inaudible portions of the spectrum.

As per the methodology imposed by the RGR, both Samples registered SPLs of 28 dBA. This means that, according to the RGR methodology, the acoustic environment is the same in both Samples. As a result, the RGR methodology stipulates that these two samples reflect equal environments. Consequently, the medical community is informed that there is no acoustical difference in these environments and, therefore, the clinical Response of workers (due to their noise exposure) from these two environments is expected to be similar.

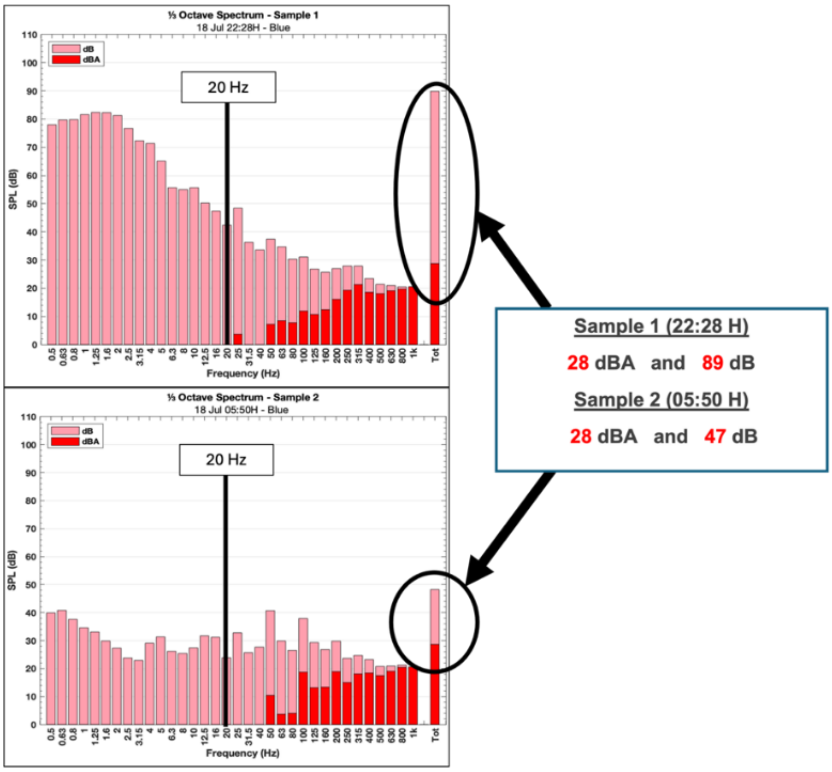

Figure 1*. Frequency distribution analyses of two acoustic environments, represented as 10-minute average, with a spectral resolution of 1/3rd octave. Red bars are SPL expressed in dBA while pink bars are expressed in dB. The bars in black circles represent the overall noise level as expressed in dBA (red) and in dB unweighted (pink).*

However, when the entirety of the physical soundscape (pink bars in Figure 1) is considered through the removal of the A-weighting (which means non-compliance with RGR methodologies), Sample 1 registers a noise level of 89 dB, while Sample 2 registers 47 dB. Scientifically, then, these acoustic environments are significantly different. The Dose is not the same. The clinical Response of workers in these two environments, due solely to their distinct noise exposures, could reasonably be expected to be substantially different.

Increasing the spectral resolution from 1/3rd to 1/36th of an octave, and expressing all SPLs in unweighted dB, Figure 2 shows additional acoustic information contained in these two Samples, including the harmonic series analysis.

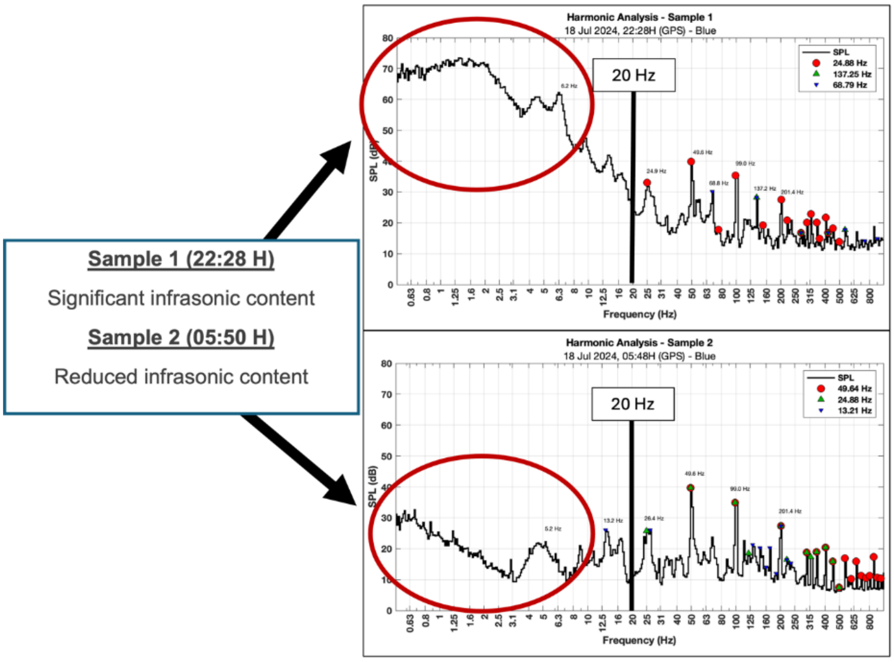

Figure 2. *Frequency distribution analyses of the same two acoustic environments shown in Figure 1, represented as 10-minute averages, with a spectral resolution of 1/36th of an octave, and SPLs all expressed in dB unweighted. The legend in the upper right-hand square indicate the fundamental frequencies of the three most prominent harmonic series identified in each Sample.*

Figure 3 shows the sonograms corresponding to each of the Samples. Here, spectral resolution is 1/36th of an octave, temporal resolution is 1 second and SPLs are expressed in dB (as seen in the colour scale).

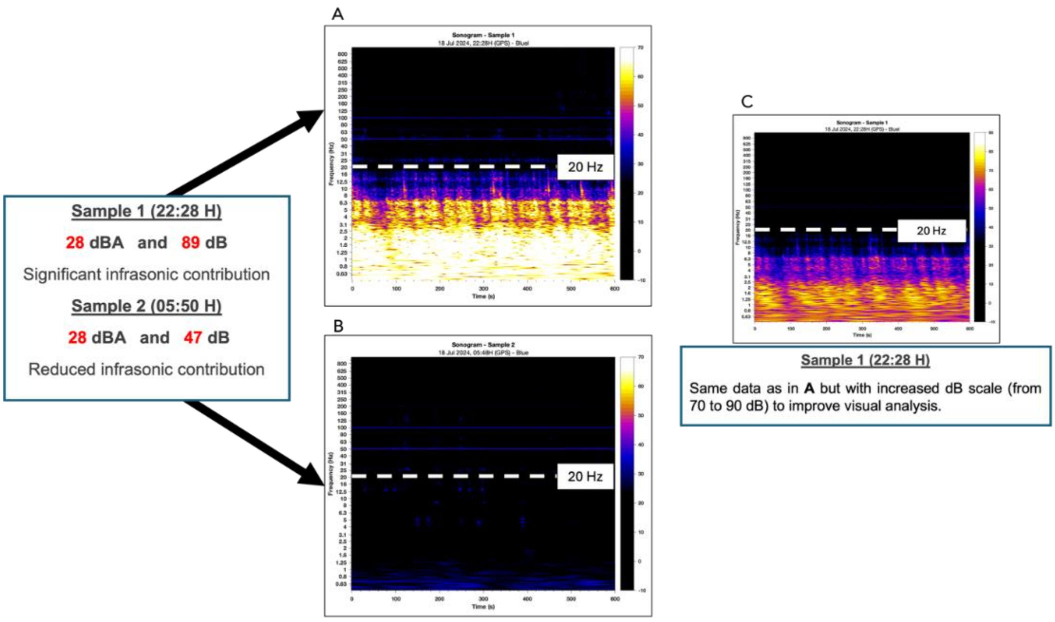

Figure 3. *Sonograms corresponding to Sample 1 (**A**) and Sample 2 (**B**) and Sample 1 (**C**) enlarged.*

As expected, the bulk of the acoustic disturbance is occurring below the 20-hertz band. Sample 1 exhibits colour saturation and therefore, a second sonogram is provided (C) where the scale has been increased to improve visual detail.

The sources responsible for these acoustic disturbances have not yet been identified within the context of this ongoing research project.

Discussion

Using high-resolution analysis of acoustic recordings from occupational environments as a comparison, it is shown that the methodologies imposed by the RGR are insufficient to quantify the Dose of the agent of disease to which individuals are exposed. In fact, RGR methodologies deem two very distinct, and significantly different, acoustic environments as *the same*. The Medical Community is then informed of this scientific fallacy and will expect to see *the same* Response in workers from these significantly different environments.

More egregious is the specific situation shown here: A Dose of 28 dBA would not raise any suspicion of excessive noise-exposure, nor would it raise any concern regarding the risk for hearing impairment. Therefore, the medical community would not see any need to clinically investigate the reported health complaints in association with excessive exposures to the acoustically aggressive environments, as represented by Sample 1. In fact, most scientists in this area are still grounded in the scientific fallacy that “what you can’t hear can’t hurt you.” Indeed, the RGR methodologies are based on this exact, false premise.

Many legislative documents have tried to ‘deal with’ the issue of infrasonic and lower frequency exposures (for example, Ministry for the Environment of Denmark, 2019; Noise Working Group (UK), 1997; Ministry for Social Affairs of Estonia, 2002), although to date, and to these authors’ knowledge, only the Russian Federation has properly legislated permissible exposure levels for infrasonic exposures, in both occupational and environmental settings (Stepanov, 2000). The dBC-dBA measure (SPL in dBC minus the SPL in dBA) was devised to evaluate the extent of these lower frequency components that may be present in the environment. However the C-weighting only maintains a zero weighting down to 100 Hz. Below that range, the C-weighting also introduces an increasing de-weighting of the SPLs (ISO, 2007). Another attempt to ‘deal with’ this type of acoustic pollution was the implementation of the G-weighting. This filter only provides unweighted SPL values at two discreet points of the spectrum: at 10 Hz and at 31.5 Hz (ISO, 1995). Many, if not all, of the frequency-weighting filters are based on the (erroneous) notion that the acoustical environment has to be ‘heard,’ or ‘perceived,’ for it to be harmful. Their ultimate purpose is to reduce the importance of the numerical values for SPLs, as per human perception. When no weighting of any kind is applied to the acoustical data, then a more realistic understanding of the physical environment can be achieved—numerical values of SPL are taken as they exist in the soundscape, and are not altered, or distorted, by weighting systems.

Increasing the spectral resolution from 1/3rd of an octave to 1/36th of an octave allows for a more in-depth understanding of the soundscape. This is akin to dividing the meter stick from decimetres into millimetres which, in turn, allows for the measurement of smaller objects. The same is achieved when the segmentation of the spectrum is increased to 1/36th of an octave. Without the coarse segmentation of 1/3rd octave, a more detailed analysis of the environment is possible and, as a result, a truer picture of acoustical events is attained. Acousticians would resort to using (Fast) Fourier Transforms (FFTs) to provide detailed analysis when tonality is suspected but, even here, the spectral resolution is rarely chosen to match that of 1/36th octave, narrow-band filtering at the lowest frequencies, as shown in the analyses herein.

In addition to considering the unweighted SPL values with increased spectral resolution—from 1/3rd to 1/36th of an octave—the temporal resolution of these measurements was also increased. The sonograms capture 1-second averages instead of the 10-minute averages shown in the 1/3rd-octave spectra. The increased spectral resolution and temporal resolution allows for the identification of harmonic series whose fundamental frequency can often be contained within the infrasonic ranges. These would be excluded from capture if the A- C- or G-filters were used. They would be diluted by the temporal resolution of 10-minute averages, and they would be invisible if the 1/3rd-octave resolution were used.

Conclusions

The methodologies imposed by the RGR in Portugal (and other similar legislation in other countries) correspond to specifications that were well defined by the limits of the technology almost a century ago. Today, far more sophisticated, scientific-grade characterization of acoustic environments is possible. It is time for these new advances to be incorporated into legislation that is chartered to protect human populations from excessive acoustical aggressors. These authors urge the medical community to re-evaluate their position on accepting noise levels (i.e., quantification of the Dose) obtained through methodologies that are many decades out of date and do not comply with the Scientific Method.

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