

EXPOSURE TO OCCUPATIONAL NOISE AND INFRASOUND AT A UNIVERSITY SPORTS STADIUM

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ABSTRACT

The prevention and control of noise pollution, aimed at safeguarding human health and the well-being of the population, constitutes a fundamental duty of the State, according to the Constitution of the Portuguese Republic and the Basic Environmental Law. Exposure to noise can cause various hearing disorders. Short-term exposure and extremely high sound pressure can cause immediate hearing damage. It is important to note that sound levels are not equally harmful at different frequencies and that individual susceptibility can have very different effects. The Infrasounds with frequencies equal to or lower than 20 Hz, are measured below the threshold of human hearing. They have very specific characteristics and can cause discomfort and long-term consequences, including the spectrum of vibroacoustic diseases. In this context, we aim to understand the exposure to occupational noise and infrasound of workers and users of the University Stadium, as well as their potential for causing hearing damage and vibroacoustic diseases. To assess occupational noise, we used the CESVA DC112 dosimeter, and to assess infrasound noise, we used the CESVA SC420 sound level meter. In addition to collecting sound pressure levels, a questionnaire was administered to the exposed population about their perception of noise exposure. The results indicate that the lower action level for occupational noise is exceeded for a workplace, and in the contexts evaluated for infrasound, the limits recommended by Russian legislation were exceeded at frequencies of 8 and 16 Hz inside buildings (pavilions). This study supports the urgent need to define a national legal framework to protect and safeguard the well-being of workers and users in all contexts, including work and recreation.

Keywords: Occupational Noise, Infrasound, Vibroacoustic Diseases, Perception of Noise Exposure.

1. INTRODUCTION

The term noise is defined as an unpleasant or bothersome sound, which can have different levels of intensity and propagates through the environment in which it occurs (DL No. 182/2006). Noise has increased exponentially in recent decades, and its effects on health have been underestimated (Friedrich *et al.*, 2023).

The sound of public transport in urban and suburban areas, the hum of air conditioning units, domestic refrigerators or ventilation systems, are some of the noises in our daily lives that do not cause hearing loss, but cause discomfort and have other effects on our body (Friedrich *et al.*, 2023).

Noise on roads originates primarily from the interaction between the wheels and the asphalt surface. The noise level depends on the contact gap between the car tires and the road, as well as the roughness of the tread (Berglund *et al.*, 1996).

The portuguese legislation for "noisy" work environments is based on exposures per working day and acoustic amplitude levels, measured in dB(A) Decree-Law 182/2006, aims to measure acoustic phenomena within the audible spectrum (capable of causing hearing loss). Thus, it disregards all acoustic energy outside this spectrum (Friedrich *et al.*, 2023).

Over the past 70 years, several studies have pointed to the manifestation of non-auditory pathologies in workers exposed to noisy environments. One of the most comprehensive, investigated for over three decades, studied the health of some aeronautical technicians in the context of their exposure to infrasounds. It was found that, after four years of occupational exposure to infrasounds, these workers developed several pathologies (bronchitis, oropharyngeal infections, and coughing, in smokers and non-smokers). When simulating occupational exposure (8 hours/day, 5 days/week, weekends in silence) to infrasounds in animal models, it was concluded that there were alterations in their respiratory systems (Alves-Pereira & Branco, 2007). Infrasounds have characteristics that are not shared with higher frequency noises, they suffer less attenuation by infrastructures; they have the ability to make walls and objects shake; they travel great distances with little energy loss and are capable of causing resonance in the human body (Pawlaczyk-Łuszczynska & Dudarewicz, 2022).

Infrasounds can originate from various sources, whether natural, such as earthquakes, volcanic activity, thunderstorms, among others, or anthropogenic, such as railways, roads, rocket launches, military and industrial explosions, geothermal power plants, wind turbines, among others. (Hupe *et al.*, 2022).

Infrasound exposure can occur at work, while driving, at home, or during leisure activities. Recent animal studies have revealed that exposure during the intrauterine period has teratogenic effects (Friedrich *et al.*, 2023). For biological tissues, it is indifferent whether infrasound exposure is occupational, domestic, or recreational, as all effects depend on the dose (amount of energy received) and duration of exposure (Friedrich *et al.*, 2023). Vibroacoustic disease (VAD) is a systemic disease caused by prolonged exposure (>10 years) to noise propagated below frequencies of 20 Hz, i.e., infrasound.

Infrasound can affect organs and tissues such as the nervous system, the immune system, the cardiovascular system, and the respiratory system, with an emphasis on the latter two (Friedrich *et al.*, 2023). Lesions are caused by mechanotransduction phenomena of sound vibrations as they propagate through tissues. This aggression results in alterations in cell signaling, and one of the characteristic findings is the abnormal proliferation of extracellular matrices (collagen and elastin) (Friedrich *et al.*, 2023). The genotoxic effect of infrasound has also been demonstrated, being associated with a higher incidence of tumors in exposed human populations (Friedrich *et al.*, 2023).

Prolonged exposure to environmental noise is recognized as a risk factor for several health problems, including sleep disorders and cardiovascular diseases (Passchier-Vermeer & Passchier, 2000; World Health Organization [WHO], 2018).

In urban environments, the constant presence of loud sound sources can compromise acoustic comfort, especially in leisure and sports venues (Zannin & Marcon, 2007).

The practice of physical activities in public sports spaces may be associated with intermittent exposure to high levels of noise, coming from both equipment and the movement of people (Guedes *et al.*, 2009; Santos, 2022).

In addition to audible noise, infrasounds with frequencies below 20 Hz have been associated with adverse effects such as feelings of discomfort, irritability and fatigue (Leventhall, 2007).

Suspensions of VAD arise when the patient presents one or more of the following symptoms: Fatigue, changes in sleep quality, disturbances in the gastrointestinal system, increased stress levels (psychological and/or physical symptoms), endocrine system dysfunction, sensation of hyperacusis, hypersensitivity to sound, intolerance to any type of noise, irritability, feelings of anxiety, oppression and heart palpitations, sensation of coughing (complaint in non-smokers),

sudden hoarseness without apparent reason and without improvement with one of the following diagnoses: late epilepsy; balance disorders; respiratory infections and medications, or if the patient already has recurrent oropharyngeal infections; epidermoid tumors of the respiratory system, especially in non-smokers; indication for cardiac revascularization surgery; autoimmune (especially Lupus and Vitiligo) (Friedrich *et al.*, 2023).

In this context, we conducted this study with the objective of evaluating the exposure to noise and infrasound of workers and users of the University Stadium.

2. MATERIALS AND METHODS

Study design

The study is observational, and its nature can be classified as analytical, prospective, and timeline based. The level of knowledge is Level II, Descriptive-Correlational.

Data collection was carried out at the University Stadium and took place over 8 months (from October 2024 to May 2025), with data collection beginning after authorization and approval from the University of Coimbra.

Population and sample

The study population consisted of workers and users of the University Stadium of Coimbra (UC), excluding occasional visitors to these facilities. The sampling method was non-probabilistic, and the techniques used were quota and convenience sampling. The sample size resulted in 152 respondents, 75 sound level meter measurements to assess infrasound in six different locations (inside and outside the three warehouses), and three dosimeter measurements (occupational noise – at three workstations). The workers assigned to the workstations in the pavilions are mobile, both internally and externally, meaning they do not remain stationary.

Instruments and data collection

The measurements were carried out at the U.C. University Stadium, with the intention of evaluating exposure to Infrasound and occupational noise and the questionnaire was applied to workers and users of the U.C. University Stadium.

Before we started data capture, the instrumentation was calibrated using the CB011 calibrator.

To assess occupational noise, the CESVA dosimeter, model DC112, was used, complying with the assumptions of decree-law no. 182/2006, used in 3 workplaces for a period representative of the workers' exposure to occupational noise.

To evaluate noise, in relation to Infrasounds, we used the CESVA SC420 sound level meter, according the specifications of the international standard IEC 61672 for class 1.

The CESVA SC420 sound level meter was used inside and outside the 3 warehouses, in 6 different locations, at a distance of 4 meters from the walls at a height of 1.50 meters from the ground, at different reference times (morning, afternoon, late afternoon and night).

From the 75 measurements carried out, 225 values were obtained, distributed across the infrasound frequencies of 2Hz, 4Hz, 6Hz, 8Hz and 16Hz, but only the frequencies of 2, 4, 8 and 16 Hz were considered for evaluation and statistical processing purposes, since the Russian standard only covers these frequencies.

Russian standard

Sound pressure levels dB in octave bands of geometric mean frequencies Hz

	2 Hz	4 Hz	8Hz	16Hz	Overall value
Housing and public places	75	70	65	60	75

The climatic conditions during the measurement periods remained stable with an average maximum temperature of 20.7°C and an average minimum temperature of 9.9°C. The air speed was 15 km/h, for an average relative humidity of 63.3%, varying between values of 8.5% and 100%.

In addition to collecting sound pressure levels using instrumentation, a questionnaire was conducted with the population exposed at our study site, which was active from March 1 to April 15, 2025.

Statistical analysis

After the measurements, the data collected by the sound level meter were extracted to a computer using CesvaLab software version 5.6 and the data collected by the dosimeter were analyzed using Cesva Capture Studio software version 9.1.4, thus allowing their numerical and graphical visualization.

The data obtained were integrated and analyzed statistically, with the construction of several databases, using specialized software for this purpose - IBM SPSS Statistics version 30.

The statistics applied were descriptive and inferential. In descriptive statistics, we used frequency analysis (absolute and relative), measures of central tendency (simple arithmetic mean), and measures of dispersion (standard deviation).

We used the Chi-Square Test of Independence with Yates' Continuity Correction or Fisher's Exact Test to assess whether the predisposition to vibro-acoustic diseases varies depending on the type of user, worker or user of the U.C. University Stadium, and to assess whether exposure to infrasounds differs according to the location, inside and outside of pavilions 1, 2, and 3 of the U.C. university stadium, and to assess whether the infrasound exposure limit values established by this criterion of the Russian Federation standard were exceeded.

For statistical inference, we use a 95% confidence level for a random error less than or equal to 5%.

3. RESULTS

Of the 152 participants surveyed, we considered only 132 valid responses; the remaining 20 did not complete the questionnaire. Those who completed the questionnaire are between 18 and 74 years old, have a health status that meets the medical requirements for sports practice and fitness for work. They are sports students and athletes from various sports sections, and employees of the University of Coimbra's003A 64 are male and 64 are female; four preferred not to answer. Valid respondents are linked to various occupations: 25 are workers, 44 are students, 35 are users, and 28 are visitors, whose health status we cannot determine.

Occupational noise exposure

To assess occupational noise exposure among workers at the University Stadium of Coimbra, we used a CESVA DC 112 dosimeter for sampling. After calibration, we installed the dosimeters on

three workers representing exposure in the following work contexts: secretary; the worker spends 8 hours a day sitting at a desk and confined to the office space, with a measurement time of 30 minutes; and in Pavilions 1 and 2, although the workers have a small office where they perform bureaucratic tasks, most of their work time, which is 6 hours continuous, involves constant movement inside and outside the pavilions. The total measurement time was distributed among the two pavilion workers, approximately 12 hours of continuous measurement.

The sampling data in the table below, particularizing the value of $L_{EX,8h}$ for workers in Pavilion 2, with daily noise exposure exceeding 80 dB(A):

Table 1: Result of data obtained by using dosimeters per worker in different locations.

Sampling Results - Dosimeter											
N.º	Sampling Station	$L_{EX,8h}$	L_{Cpico}	63	125	250	500	1	2	4	8
		dB(A)	dB(C)	Hz	Hz	Hz	Hz	KHz	KHz	KHz	KHz
1	Secretary	55.3	118.1	34.1	49.7	58.4	65.2	59.5	54.5	50.9	47.3
2	Pavilion 1	77.0	128.2	41.9	54.8	64.5	75.6	74.0	67.6	63.6	53.1
3	Pavilion 2	81.5	131.9	45.7	62.9	71.2	79.8	75.6	68.3	60.2	54.4

Table 1 shows the exposure data for workers in the different positions evaluated. The workstations—the secretariat and Pavilion 1—are acoustically located in a risk-free environment, as recommended by law. The situation is different for workers in Pavilion 2, as confirmed by the value of $L_{EX,8h} = 81.5$ dB(A) above the lower action level $L_{EX,8h} = 80$ dB (A), in accordance with Decree-Law 182/2006.

Infrasound

Table 2 presents general data related to exposure to infrasounds, in frequencies, namely: 2 Hz, 4 Hz, 8 Hz and 16 Hz. For each frequency, the observed mean values (accompanied by the standard deviation), the reference limit values and the mean difference between the observed values and the established limits are provided.

Table 2: General data related to exposure to infrasounds with statistical treatment

Frequencies	Mean +/- Standard Deviation	Limit Value	P, Value
2HZ	57,493 +/- 7,3125	75	<.001
4Hz	54,600 +/- 6,2801	70	<.001
8Hz	50,729 +/- 5,6227	65	-14,2707 <,001
16HZ	51,549 +/- 5,4437	60	-8,4507 <,001

The data analyzed in the table 1 show that, if we particularize at the frequency of 2 Hz, the largest negative difference has an average value of 57.493 ± 7.3125 , resulting in an average difference

of -17.5067 in relation to the limit of 75 dB. At the frequency of 4 Hz, the average value was 54.600 ± 6.2801 dB, also below the limit of 70 dB, with an average difference of -15.4. At 8 Hz, the average levels were 50.729 ± 5.6227 dB, resulting in an average difference of 14.2707 dB in relation to the limit of 65 dB. Finally, at the frequency of 16 Hz, the smallest difference was observed, with an average of 51.549 ± 5.4437 dB and a difference of -8.4507 in relation to the limit value of 60 dB. These average values of exposure to infrasounds are considerably below the threshold considered critical for these frequencies, in light of the above.

Table 3 presents the results of sound pressure measurements obtained with the sound level meter, for the frequencies of 2 Hz, 4 Hz, 8 Hz and 16 Hz, carried out indoors and outdoors. These data were compared with the limits established by the Russian standard for exposure to infrasound.

Table 3: Sound level meter data indoors and outdoors, with reference and comparison to the limit value for each infrasound frequency listed in the Russian standard.

Local	Frequencies	Mean +/- Standard Deviation	Limit Value	Average Difference	P. value
Interior	2Hz	56,550 +/- 7,2817	75	-18,4500	<.001
	4Hz	55,156 +/- 6,5736	70	-14,8444	<.001
	8Hz	53,036 +/- 6,0219	65	-11,9639	<.001
	16Hz	53,892 +/- 5,8273	60	-6,1083	<.001
Exterior	2Hz	58,364 +/- 7,3261	75	-16,6359	<.001
	4Hz	54,087 +/- 6,0366	70	-15,9128	<.001
	8Hz	48,600 +/- 4,2978	65	-16,4000	<.001
	16Hz	49,387 +/- 4,0542	60	-10,6128	<.001

The results found in the table 4 show that, for both the interior and exterior of the three pavilions, the average sound pressure values are below the limits established by the Russian standard for all frequencies. This is indicated by the negative mean differences (column "Mean Difference"). Regarding statistical significance, a P-value < 0.001 for all cases indicates that the differences between the measured values and the limits are statistically significant. In other words, the probability of these differences occurring by chance is extremely low. Comparing indoors and outdoors, in general, the values indoors are slightly higher than outdoors. Example: 2 Hz: Indoor = 56.550 dB / Outdoor = 58.364 dB, 16 Hz: Indoor = 53.892 dB / Outdoor = 49.887 dB An exception occurs at 2 Hz, where the value outdoors (58.364 dB) is slightly greater than that indoors (56.550 dB). The frequency with the smallest mean difference indoors, the smallest mean difference from the limit, occurs at 16 Hz (-6.1083), indicating that this frequency is closer to the allowable limit. Outdoors, the smallest mean difference also occurs at 16 Hz (-10.6128). The frequency with the largest mean difference indoors occurs at 2 Hz (-18.4500). Outdoors, the largest mean difference is at 8 Hz (-16.4000).

Infrasound by Pavilion vs. Reference Criteria

Table 4: Sound level meter data from the 3 pavilions with integrated v. and comparison with the overall value of the Russian Standard

Global maximum value	Pavilion 1	Pavilion 2	Pavilion 3	P. value
75 dB	57.284 +/- 7.3668	61.236 +/- 6.2174	57.576 +/- 5.1158	.053

Table 4 shows that the three pavilions under study have average infrasound values below the 75 dB limit established by the Russian standard (Russian Federation, 2004). Pavilion 2 has the highest average value (61.236 dB), yet still has a safe margin of approximately 13.76 dB below the limit. Pavilion 1 and Pavilion 3 have very similar values (approximately 57.3 dB and 57.6 dB).

The deviations indicate the variability in measurements within each pavilion. Pavilion 1 presents the greatest variability (7.3668), while Pavilion 3 is the most stable (5.1158).

The p-value of 0.053 suggests no statistically significant difference between the three sites at the traditional 0.05 (or 5%) significance level. However, it is very close to the threshold, indicating a tendency toward a difference, especially if the sample size increases.

Perception of workers and users of the U.C. University Stadium regarding the audible sounds of this location.

The data presented in table 5, obtained from a questionnaire, relate to the period in which the interviewees work or attend the U.C. sports complex and their perception of the noise level there.

Table 5: Perception of exposure to noise levels at the U.C. sports complex.

		Sound level perception				
		Very low	Low	Moderate	High	Very high
How long have you worked at or attended the sports complex?	Less than 6 months	1 33,3%	6 22,2%	8 13,6%	3 27,3%	1 33,3%
	Between 6 months and 2 years	0 0,0%	1 3,7%	13 22,0%	5 45,5%	0 0,0%
	Between 3 and 5 years	2 66,7%	8 29,6%	12 20,3%	1 9,1%	0 0,0%
	More than 5 years	0 0,0%	12 44,4%	26 44,1%	2 18,2%	2 66,7%

First, less than 6 months ago we have a total of 19 participants who responded as follows: Very Low: 1 (33.3%), Low: 6 (22.2%), Moderate: 8 (13.6%), High: 3 (27.3%), Very High: 1 (33.3%). There are extreme perceptions (Very Low or Very High) in over 66% of cases. This suggests varying sensitivity or inexperience with the environment. Secondly, between 6 months and 2 years, a total of 19 respondents perceived the sound mostly as moderate (22%) or loud (45.5%). No one marked "Very Loud", and only 1 person (3.7%) marked "Low". This shows a tendency to perceive the sound as present, but not extreme. Thirdly, between 3 and 5 years, 23 respondents responded in which the majority perception is Very Low (66.7%), followed by "Low" (29.6%). Finally, over 5 years, 42 responses were obtained, over 88% perceived the sound as Low or

Moderate, only 66.7% (2 people) said "Very Loud". Indicating significant habituation to the noise over time.

Table 6: Relationship between symptoms, factors, interference in performance and need for hearing protection, with the discomfort caused by the noise in the U.C. university stadium.

Symptom		Discomfort with noise		
		No	Yes	P. Value
Headaches	No	37 – 41,6%	52 – 58,4%	0,071
	Yes	1- 11,1%	8 – 8,89%	
Tiredness	No	35 – 47,9%	38- 52,1%	0,001
	Yes	3 - 12,0%	22 - 88,0%	
Difficulty concentrating	No	37 - 64,9%	20 - 35,1%	<0,001
	Yes	1 - 2,4%	40 - 97,6%	
Irritation	No	36 - 52,2%	33 - 47,8%	<0,001
	Yes	2 - 6,9%	27 - 93,1%	
Ringing in the ears	No	37- 41,1%	53- 58,9%	0,110
	Yes	1 - 12,5%	7 - 87,5%	
Pressure in the ears	No	38 - 40,9%	55 - 59,1%	0,080
	Yes	0- 0,0%	5- 100,0%	
Vibrations in the body	No	37- 38,5%	59- 61,5%	0,628
	Yes	1 - 50,0%	1- 50,0%	
No symptoms	No	5- 8,2%	56 - 91,8%	<0,001
	Yes	33 - 89,2%	4 - 10,8%	
Busiest days in the complex	No	32 - 57,1%	24 - 42,9%	<0,001
	Yes	6 - 14,3%	36 - 85,7%	
Periods of heavy traffic near the location	No	35 - 66,0%	18 - 34,0%	<0,001
	Yes	3 - 6,7%	42 - 93,3%	
Interference in the performance of activities	No	31 - 53,4%	27 - 46,6%	<0,001
	Yes	6 - 15,4%	33 - 84,6%	
Use of hearing protectors	No	36 - 39,1%	56 - 60,9%	0,365
	Yes	1 - 20,0%	4 - 80,0%	
Usefulness of PPE use in the complex	No	33 - 42,9%	44 - 57,1%	0,050
	Yes	4 - 20,0%	16 - 80,0%	

Table 6 presents the data resulting from the application of chi-square tests and their integration. We analyzed noise exposure as a cause of discomfort and, possibly, symptoms and factors that potentiate this discomfort, as well as interference with activity during stays at the U.C. sports complex.

The symptoms most strongly associated with noise discomfort are:

Difficulty concentrating ($p < 0.001$), Irritation ($p < 0.001$), Fatigue ($p = 0.001$)

The external factors that most contribute to discomfort:

Busiest days in the complex ($p < 0.001$), Periods of intense traffic nearby ($p < 0.001$), Interference in the performance of activities ($p < 0.001$)

Symptoms such as ringing in the ears, headaches, and pressure in the ears show trends toward association, but are not statistically significant.

Absence of symptoms is strongly related to the absence of noise discomfort.

The use of hearing protectors does not show a significant association with discomfort, but the data suggest that those who use them tend to feel more discomfort (a possible effect that only those who are most uncomfortable use them).

4. DISCUSSION

In table 1, we observe that the evaluation of occupational noise is extremely important for the protection of workers' hearing health, corroborating what was found in other studies of similar scope. Noise is responsible for the degradation of the hearing function of many workers exposed to it.

Given this scenario of noncompliance with the legal framework, senior management must take measures to mitigate this situation. It is the employer's duty, in activities likely to present noise exposure risks, to assess the levels to which workers are exposed. If these exceed the lower action value, the employer must also ensure that audiometric tests are performed every two years to protect workers' hearing health and comply with the legal precepts set forth in Decree-Law 182/2006. The occupational noise exposure of workers at the University Stadium is below the limits established by Portuguese legislation.

Based on the results obtained, we can state that exposure to infrasounds differs at different frequencies, as shown in Table 2. Even so, at all frequencies analyzed, the average infrasound levels were below the reference limit values stipulated in the Russian Federation standard.

This reinforces the hypothesis that the evaluated environments do not pose a risk of exposure to infrasound, at least within the parameters established by the Russian standard (Russian Federation, 2004).

After analyzing the results obtained and presented in table 3, we can state that exposure to infrasound varies according to the type of location (indoor/outdoor) and the type of pavilions, being more pronounced indoors, although still below the maximum values permitted by the aforementioned Russian standard. This characteristic also applies to outdoor spaces.

Table 3 shows that, both in indoor and outdoor environments, the average sound pressure levels for frequencies from 2 Hz to 16 Hz are below the limit values established by the Russian standard, with statistically significant differences ($p < 0.001$).

This finding is relevant because even moderate infrasound values, although below normative limits, can cause physiological discomfort, stress, and adverse health effects in prolonged exposure, as pointed out by Leventhall (2007) and Berglund *et al.* (1996). This reinforces the importance of critically interpreting legal limits, as they do not always reflect individuals' subjective experience of infrasound.

Furthermore, it is observed that the values inside the pavilions are consistently higher than the values outside, especially at 8 Hz and 16 Hz. This amplification may be related to the reverberation and resonance effects typical of closed environments with reflective surfaces and large volumes, as described by Fields (1993) and Persson & Rylander (2001).

The data presented confirm that, although the averages are in compliance with the standard, there is a need for special attention to environments with specific acoustic characteristics, such as pavilions and large industrial spaces, as they can amplify infrasounds and generate perceptual discomfort even below regulatory levels (Broner, 2011).

Infrasound exposure are not very high, that is, they are below the recommended global limit value of the Russian standard, for this installation 75 dB, although many authors who argue that prolonged exposure to Infrasounds is associated with the development of DVA, even when the limit value is lower than the global reference value, with prolonged exposure over time – more than 10 years.

Observing infrasound exposure in the halls of the UC sports complex, we found compliance with the standard used as a criterion, with noise levels below the global maximum limit of 75 dB. Hall 2 presents higher levels than the others, which we believe is caused by increased human activity and equipment use in this reverberant space. The data suggest acoustically safe and comfortable conditions in all three halls with regard to infrasound. Our analysis can serve as a basis for decision-making regarding continuous monitoring and future interventions in these locations. We emphasize that hypothesis, as infrasound exposure varies across the different halls of the UC sports complex.

From our research, advances in metamaterials and smart materials, such as local resonance-based acoustic metamaterials (such as plates with negative mass or coiled channels), offer effective solutions, enabling good performance at low frequencies. The integration of smart materials (e.g., piezoelectrics) allows for the creation of tunable composites that adapt their acoustic response based on damping circuits or external stimuli. Integrating natural fibers and recycled polymers into microperforated panels or porous structures can enable sustainable and economically viable environmental solutions while maintaining high acoustic performance. The application of these materials meets environmental and public health demands in a world increasingly exposed to infrasound noise.

Based on the responses to the questionnaire administered to workers and users of the UC sports complex, we analyzed the perception of exposure to noise levels among workers and users of this space, see table 5. The perception of noise is directly related to the time of exposure to the environment.

This could have important implications for noise management actions, and advice to new users or employees, especially during the initial adaptation period. The longer they have been at the facility, the lower their perception of noise discomfort. Those with more than 5 years have a greater perception of low sound levels. Those with less than 6 months have more polarized perceptions (Very Low and Very Loud). The data suggest that there is a process of auditory/behavioral adaptation with time of exposure to the complex's sound environment. The categories "Very Loud" and "Very Low" practically disappear among the most experienced employees (more than 2 years).

According to the data obtained in the responses, we found that the time factor influences the perception of noise, as per (Guski *et al.*, 2017) and (Miedema & Vos, 1998).

Analysis of Table 6 shows a statistically significant association ($p < 0.001$) between noise discomfort and symptoms such as fatigue (88%), difficulty concentrating (97.6%), and irritation

(93.1%). These results are in line with studies that demonstrate the adverse effects of infrasound and infrasound on mental and cognitive health, especially in closed environments and with prolonged use (Babisch, 2002; Stansfeld & Matheson, 2003).

Difficulty concentrating and irritability, which presented the significant values ($p < 0.001$), are symptoms commonly associated with chronic exposure to environmental noise, including in educational and institutional settings (Hygge *et al.*, 2002). The literature shows that even noise levels considered acceptable can compromise cognitive performance, especially in tasks that require prolonged attention.

The fatigue reported by 88% of individuals who felt uncomfortable is also consistent with the physiology of prolonged noise exposure, which activates the hypothalamic-pituitary-adrenal (HPA) axis, increasing cortisol levels and leading to mental fatigue (Basner *et al.*, 2014).

Among the environmental factors, the following stand out: periods of intense traffic near the site ($p < 0.001$) and days of greater movement in the complex ($p < 0.001$), as strongly associated with discomfort, showing that the acoustic-dynamic context directly influences the perception of noise discomfort (Öhrström *et al.*, 2006).

Furthermore, interference in the performance of activities (84.6% among those uncomfortable) reveals the potential of noise to affect productivity and well-being in institutional environments, as shown by studies on occupational noise and mental health (Clark & Stansfeld, 2007).

Despite the perception of discomfort, only 20% of those who reported discomfort used hearing protectors, indicating low adherence to personal protective practices. This suggests that environmental noise is still seen as "part of the environment," even when associated symptoms are present—a phenomenon already described by Gjestland (2018), which points to the naturalization of noise nuisance in public spaces.

The usefulness of using hearing protectors in the complex was also significantly associated with discomfort ($p = 0.050$), indicating that individuals most affected by noise tend to recognize the importance of using hearing protection, which reinforces the need for educational and preventive actions, as proposed by Passchier-Vermeer & Passchier, 2000).

These values indicate the need for interventions in noise and infrasound control in this U.C. sports complex, in order to mitigate the effects of noise on days of greatest use of this space and intensity of road traffic on adjacent roads.

5. CONCLUSIONS

This study allowed us to conclude that workers at the University Stadium of U.C. are exposed to significant levels of occupational noise, in particular the worker in Pavilion 2, which is above the lower action level (80 dB(A)), with an $LEX_{8h} = 81.5$ dB(A). Although the results show acceptable values, as far as infrasounds are concerned, it is once again important to go against the existing literature on the risks of exposure to infrasounds, highlighting the urgent need to protect public health through Portuguese and European legislation, including specific regulations for exposure to infrasounds.

The results of this study on occupational noise and infrasound are of great importance for both public and occupational health. Data analysis revealed that noise levels inside and outside warehouses differ somewhat.

Noise mitigation measures must be implemented at the U.C. university stadium to reduce occupational noise and infrasound exposure. Furthermore, it is important to conduct regular occupational health assessments for exposed workers and develop information and training programs on the risks of infrasound exposure and audible noise.

For future research, it is recommended to expand the sample and include a greater number of measurement sites for better representativeness. The most effective mitigation strategies to reduce infrasound exposure should also be explored. Furthermore, longer, multidisciplinary studies will be essential to assess the long-term effects of infrasound exposure on workers and users of the U.C. University Stadium. It is extremely important to survey the symptoms of workers at the study site, regarding hearing health and possible vibroacoustic diseases (VAD).

We can also suggest actions regarding sound-attenuating materials in enclosures and buildings. Traditional materials (such as foam and honeycomb) have limited effectiveness for absorption below 500Hz, as they require large thicknesses or bulky structures. New approaches, such as microperforated panels (MPP), resonant units, and hybrid composites, have demonstrated the ability to achieve high absorption coefficients at low frequencies by building structures with reduced thickness.

It should also be noted that the application of vegetation and/or barriers near the sports complex fence, as well as equipping the buildings (Pavilions) with the aforementioned materials, would be a way of reducing/attenuating the noise emitted by reverberations of noise inside the pavilions, and also that emitted by traffic on adjacent roads, responding to the concerns of some respondents in the implemented questionnaire, as they mention that the lack of vegetation can be a factor facilitating the propagation of noise, vegetation that recent storms destroyed a substantial part of and has not yet been restored.

Conflicts of interest

The researchers declare that there is no conflict of interest.

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