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Original Article

Quantitative and Qualitative Evaluation of Noise in Magnetic Resonance Imaging. Measured Values, ISO-9612 Standards and Biological Effects

Evaluación Cuantitativa y Cualitativa del Ruido en Resonancia Magnética. Valores medidos, Normas ISO-9612 y Efectos Biológicos

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ABSTRACT

This study focuses on the evaluation of magnetic noise based on sound pressure levels and its impact on the health of exposed personnel and patients in a Magnetic Resonance Imaging (MRI) service in the city of Asunción. **Objectives:** To evaluate noise exposure by applying the analytical formulas of the ISO 9612 standard to sound pressure levels measured with a sound level meter. Scientific databases were also consulted to identify potential biological effects. **Materials:** General Electric Signa Prime 1.5T AIR Recon DL MRI scanner, Quest Technologies 1900 e sound level meter, PCE-322A sound level meter, ISO-9612 analytical model. **Methods:** On-site noise level measurements were taken. The Task-Based Measurement Strategy of ISO 9612 was applied to calculate the 8-hour time-weighted average daily noise exposure of clinical staff. Finally, a comprehensive literature review was conducted to identify the potential biological effects of noise exposure on staff and patients. **Results:** Noise levels within the equipment room reached peaks of up to 93 dBA, while measurements in the control room remained within acceptable limits. The calculated noise exposure level indicated that the occupational risk of chronic hearing loss is classified as low. Finally, the observed biological effects are consistent with the measured noise levels. Effects caused by the intensity of acoustic stress and other reported potential effects cannot be ruled out if protective measures fail.

Key words: Magnetic Resonance Imaging, Noise, Noise Control, Auditory Threshold, Occupational Exposure, Physiological Phenomena, ISO 9612.

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RESUMEN

El presente trabajo se centra en la Evaluación del Ruido Magnético basado en los niveles de presión sonora y el impacto en la salud del personal expuesto y de los pacientes en un Servicio de Resonancia Magnética de la Ciudad de Asunción. **Objetivos:** aplicación de fórmulas a los valores de presión sonora medidos con un sonómetro, conforme al modelo analítico de la norma ISO-9612. Además, se consultaron bases de datos científicas con el fin de identificar los posibles efectos biológicos. **Materiales**: Equipo de Resonancia Magnética General Electric, Signa Prime 1.5T AIR Recon DL, Sonómetro Quest Technologies 1900 e, Sonómetro PCE-322A, Modelo Analítico ISO-9612. **Métodos:** Se realizaron mediciones in situ de los niveles de ruido, se aplicó la Estrategia de Medición Basada en Tareas de la norma ISO 9612 para calcular la exposición acústica diaria ponderada de 8 horas del personal clínico y finalmente, se llevó a cabo una exhaustiva revisión bibliográfica para identificar los posibles efectos biológicos de la exposición al ruido en el personal y los pacientes. **Resultados:** Los niveles de ruido dentro de la sala del equipo alcanzan picos de hasta 93 dBA y las mediciones en la sala de comandos se mantuvieron dentro de límites aceptables. El nivel de exposición sonora calculada indicó que el riesgo ocupacional de pérdida auditiva crónica es clasificado como bajo. Finalmente, los efectos biológicos observados son consistentes con los niveles de ruido medidos. Existen efectos causados por la intensidad del estrés acústico y otros posibles efectos reportados que no pueden ser descartados si las medidas de protección fallan.

Palabras claves: Imagen por Resonancia Magnética, Ruido, Control del Ruido, Umbral Auditivo, Exposición Profecional, Fenómenos Fisiológicos, ISO 9612.

Introduction

The most important physical components of a magnetic resonance imaging system are presented according to [1,2]. The main magnet is the component from which the characteristics of the magnetic resonator are derived, composed of a superconducting coil that generates the high-intensity static magnetic field (B0) (between 0.5 and 3 T in the clinical setting). The gradient coils operate at room temperature and create local magnetic fields when switched on and off. The radiofrequency (RF) coils emit pulses that excite protons and act as receiving antennas to detect the signal emitted by tissues during relaxation.

Noise in a magnetic resonance imaging system is produced due to Lorentz forces: when electrical currents pass through the gradient coils within the main magnetic field (B0), the coils experience mechanical forces that cause them to vibrate. These vibrations are transmitted to the air and to the structure of the equipment, generating the characteristic noise defined as impulsive [3]. Passive shielding proposes adding a cylindrical structure made of conductive material (such as copper or aluminum) surrounding the gradient coil. It works in such a way that when the coil attempts to vibrate, this passive shield generates eddy currents that create their own magnetic fields opposing the motion, thereby reducing the generation of acoustic noise [4].

Regarding the physics of the phenomenon, sound is a mechanical disturbance that propagates through an elastic medium in the form of pressure waves. Acoustics is understood as the study of the generation, transmission, and reception of these waves. In terms of human perception, the ear responds to sound intensity logarithmically. For this reason, the decibel (dB) is used as a dimensionless and comparative unit [5,6].

The instrument designed to measure sound pressure level in a manner similar to human hearing perception is the sound level meter. The sound level meter consists of a microphone, which is a transducer that converts sound pressure variations into a proportional electrical signal. The preamplifier then amplifies the electrical signal before processing. Filters (weighting networks) are subsequently applied to adjust the signal according to different response curves (A, C, or Z). The detector calculates the effective value of the acoustic signal and, finally, the integrator averages the sound energy over a given period to obtain levels such as L_{eq} [7].

The biological impact derived from exposure to high sound pressure levels in a Magnetic Resonance Imaging (MRI) environment is multidimensional, affecting not only the auditory system but also neurological and systemic functions. The most immediate and documented consequence is Temporary Threshold Shift (TTS). This phenomenon represents fatigue of the hair cells of the inner ear which, although it usually reverses within 24 hours, constitutes an early warning sign [8]. If this exposure is recurrent and preventive action levels such as the 82 dB limit established in the PREXOR protocol are not respected, the damage may progress to Permanent Threshold Shift (PTS), where apoptosis or death of hair cells in the organ of Corti makes hearing loss irreversible [9].

Associated with this damage, tinnitus frequently occurs. This is defined as the perception of a buzzing sound in the ears or head without the presence of an external sound source. Biophysically, tinnitus is a response of the brain attempting to compensate for the lack of auditory signals after acoustic trauma. This condition is often accompanied by ear pain and headaches [10].

At the neurological level, intensities reaching 110 dB not only stress the auditory apparatus but also alter functional connectivity between brain networks. One possible effect is the modification of Regional Cerebral Blood Volume (rCBV). Variations in rCBV indicate changes in metabolic demand and blood flow in specific areas of the cortex. The consequences of this alteration include acute cognitive fatigue, reduced concentration capacity, and altered responses to external stimuli [11].

The literature [12,13] also emphasizes that these biological effects are enhanced in 3.0 Tesla equipment, where noise and radiofrequency energy (SAR) are higher. In addition to auditory effects, the release of stress hormones such as cortisol and catecholamines increases blood pressure and heart rate, constituting a long-term cardiovascular risk for exposed personnel. Therefore, the implementation of "Silent Imaging" technologies, which can reduce noise by up to 40 dB, is presented not only as an improvement in comfort but as a biological necessity to preserve the neurological and auditory integrity of patients and professionals [14].

The documentation of working conditions, such as sound exposure levels, and adherence to international standards for obtaining sound pressure level results allow evaluation of occupational health of clinical personnel in the MRI environment [15].

In order to formally assess occupational risk, ISO 9612 is applied. This standard focuses on critical parameters of potential damage. First, the Equivalent Continuous Sound Pressure Level (Lp,A,eqT) represents the constant total energy dose that would contain the same energy as the actual fluctuating noise.

$$L_{p,A,eqT} = 10 \cdot \log_{10} \left[\frac{\frac{1}{T}\int_{t_1}^{t_2} p_A{}^2(t)dt}{p_0{}^2} \right] dB \quad (1)$$

For this calculation, A-weighting is applied, which simulates the ear's sensitivity to chronic damage. Second, the Peak Sound Pressure Level (Lp,C,peak) measures the maximum instantaneous pressure to evaluate impulsive noise.

$$L_{p,C,pico}=10\cdot log_{10}\left[\frac{p_{C,pico}{}^{2}}{p_0{}^{2}}\right]\ dB \quad (2)$$

In this case, C-weighting is used, capable of capturing the frequency spectrum of impacts to prevent acute mechanical damage.

In this regard, the standard establishes three differentiated measurement strategies:

Task-based measurement: Divides the workday into specific activities, being the most accurate for MRI services due to the intermittent nature of the noise.

$$L_{EX,8h}=10\cdot log_{10}\left[\frac{1}{T_0}\sum_{m=1}^{M} T_m\cdot 10^{0,1\cdot L_{p,A,eqTm}}\right]\ dB \quad (3)$$

Work-based measurement: Evaluates a complete activity cycle when tasks are difficult to separate.

Full-day measurement: Uses personal dosimeters for workers with high mobility and variable exposure.

Finally, ISO 9612 requires the calculation of the Combined Standard Uncertainty. This value is obtained from the quadratic sum of equipment uncertainty (σM), sampling uncertainty (σS), and repeatability uncertainty (σR).

$$\sigma_{L_{EX,8h}}=\sqrt{\sigma_M{}^2+\sigma_S{}^2+\sigma_R{}^2} \quad (4)$$

Therefore, the inclusion of this parameter ensures that the estimation of occupational risk is scientifically defensible and allows for the determination of precise confidence intervals for the worker's actual exposure (16).

SPECIFIC OBJECTIVES

1. To perform real measurements of sound pressure level in the magnetic resonance area using a sound level meter.
2. To analyze the analytical model "ISO-9612" of acoustic noise in magnetic resonance imaging for the calculation of the normalized daily sound exposure level.
3. To identify the possible biological effects of occupational and patient exposure to noise in magnetic resonance environments.

Materials and Methods

Study Approach

The object of study is the noise generated in the magnetic resonance imaging service of the Sanatorio Adventista de Asunción and its possible impact on the occupational health of clinical personnel and patients.

The research used a mixed approach with predominance of the quantitative component. The quantitative approach was applied for the measurement and numerical analysis of noise levels (Objective 1) and the application of the ISO-9612 analytical model for calculating the sound exposure level (Objective 2).

The qualitative approach was used to explore in depth the possible biological effects for both clinical personnel and patients in the MRI area (Objective 3).

Study Design

The study follows a non-experimental design. Variables are not manipulated but observed in their natural setting. Noise measurements are collected in hospital environments without altering existing conditions.

Furthermore, the study adopts a cross-sectional (transeccional) approach, with data collected at a single point in time, providing a snapshot of the current situation.

Methodology for Sound Pressure Level Measurements

Measurements were carried out using a Magnetic Resonance Imaging (MRI) system manufactured by General Electric (GE), model Signa Prime 1.5T AIR Recon DL, with a magnetic field strength of 1.5 Tesla (T). The equipment was installed at the hospital in December 2024.

Noise Measurement Details:

Two sound level meters were used to assess acoustic intensity:

1. Quest Technologies 1900 e (Class 1): A high-precision instrument used for reference measurements, applying C-weighting.

Figure 1: Class 1 sound level meter, used for measurements. Source: own elaboration.

2. PCE-322A (Class 2): A complementary sound level meter used for measurements in areas with more limited access, applying A-weighting.

Figure 2: Class 2 sound level meter, used for measurements. Source: Viaindustrial, n.d.

Note on the calibration date of the sound level meters:

The sound pressure levels presented in this study were primarily used for practical demonstration and for validating the applied analytical model. In this context, the measurements had an exploratory nature; therefore, the calibration date of the measurement equipment was not included.

Consequently, the results should be interpreted as relative indicators intended to illustrate the mathematical application of the ISO 9612 model, rather than as a formal assessment of compliance with this standard.

Data Collection Period:

Sound pressure level measurements in the magnetic resonance imaging (MRI) service were conducted on October 8, 2025. The selection of sequences was non-probabilistic and depended on the MRI studies performed and the calibration sequences applied.

Measurement Protocol:

Three key measurements were conducted, representative of routine operational and testing conditions:

- Shoulder MRI and Knee MRI: Measurements during standard clinical sequences to assess noise under typical operating conditions.

- MRI with "Phantom": Measurements focused on specific test sequences for calibration and evaluation of maximum noise levels.

Measurement Locations:

- Control Room (Quest 1900 e and PCE-322A): Measurements were taken one meter away from the wall to determine the noise level to which operating staff are exposed.
- Interconnection Between Rooms (PCE-322A): Measurements were conducted through an approximately 4 cm diameter opening located in the wall separating the MRI room from the control room, in order to quantify the acoustic attenuation of the structure.

MRI Room (PCE-322A): Measurements were performed on the inner wall of the MRI room to avoid interference with or damage to the equipment.

Justification of the Number of Measurements:

The number of measurements was adjusted according to the time availability at the clinic. Three complete measurement cycles were carried out to ensure the acquisition of different sound intensity levels. This procedure allowed the application of the normalized daily sound exposure level formula using multiple reference values. The repetition of measurements ensured the consistency of the data required for the final calculation.

Methodology for the Calculation of Daily Sound Exposure (ISO 9612)

To meet the objective of analyzing normalized sound exposure, the ISO 9612 analytical calculation model was applied. Noise measurements obtained in situ during shoulder, knee, and phantom procedures were used as input data for the calculation.

Calculation Procedure:

- Determination of LAeq,T: A task-based method (or job-based approach) was employed to obtain the A-weighted equivalent continuous sound level (LAeq,T) over the measurement period.
- Calculation of Daily Noise Exposure (L_{EX},8h): The normalized daily sound exposure level over an 8-hour workday was calculated using the average exposure times of personnel in the MRI area.

For the calculations, a spreadsheet and a scientific calculator (CASIO, model fx-570LA PLUS) were used.

This analysis was not intended to certify regulatory compliance, but rather to provide a theoretical estimation of occupational exposure risk in the context of the Adventist Sanatorium of Asunción, directly linking the measurements with an international standard.

Methodology for the Identification of Biological Effects

The objective of identifying potential biological effects was addressed through a systematic literature review on the effects of noise exposure in MRI environments and other industrial settings.

Sources of Information: Specialized scientific databases were consulted, focusing on articles, theses, and occupational safety guidelines.

Use of Information: The identified biological effects were used as a theoretical framework for the discussion of results, comparing the symptoms and perceptions reported by participants with the risks described in the literature, and correlating them with the noise levels calculated according to the ISO-9612 standard.

LIMITATIONS AND METHODOLOGICAL BIASES

In measurement and application of formulas:

- Data collection was conducted during a single day due to clinic availability.
- The sample size was limited to three specific measurement cycles.
- The calibration certificate of the equipment was not included, as it was externally loaned.
- A single technique (task-based measurement) was applied to calculate the sound exposure level.

In the research process:

- The literature review depends on the availability of prior studies on biological effects.
- The relationship between measured noise and biological damage represents a theoretical estimation.

Results and Discussion

Sound Pressure Level Measurements:

Table 1. Measurements with the PCE-322A device.

Sequence	Operator Room	Wall Opening	Equipment Room
Proton Density with FAT and SAT	60 dBA	93 dBA	_
T1 Turbo Spin Echo	60 dBA	92 dBA	_
Angiography	57 dBA	96 dBA	93 dBA
Diffusion	55 dBA	85 dBA	90 dBA
T2 Gradient Echo	57 dBA	93 dBA	

Table 2. Measurements with the Quest Technologies 1900 e equipment.

Study	Lcpk-1	Lasmx-1	Leq-1
Shoulder	91	74	64
Knee	89	-	67
Phantom	94	-	69

For the calculation phase and application of the analytical model, the maximum values recorded by the sound level meter in each measurement cycle were used. It is important to clarify that, although these data correspond to the highest point measurements observed, the methodological assumption was made to treat them as the Equivalent Continuous Sound Pressure Level (LAeq,T) within the ISO 9612 standard formulas.

This decision is based on two fundamental objectives: first, to enable the implementation of the mathematical rigor of the standard's model despite sample variability; and second, to simulate a critical sound exposure scenario. By using these maximum values in the calculation of noise dose, the study projects a high-risk situation which, although unlikely under standard operating conditions, is essential for the preventive identification of the most severe biological effects to which both staff and patients could be exposed. In this way, the results serve as a safety framework that highlights the importance of protective measures against potential peaks in sound intensity within the Magnetic Resonance service.

Sound Pressure Level for Patients:

Additionally, it is necessary to consider that sound exposure for patients can be significantly higher. This is due to the direct proximity of the body to the center of the magnet during the examination. For safety analysis, the 3 dB rule must be applied. Sources [16,17] establish that an increase of 3 dB halves the safe exposure time. According to [3], sound pressure levels in a 1.5 T MRI scanner can reach up to 103 dB. This value is 18 dB above the permitted threshold of 85 dB for an 8-hour workday. By applying the 3 dB rule, the safe exposure time is halved six consecutive times. This calculation results in a maximum exposure time of 7.5 minutes without protection. A standard MRI examination lasts approximately 30 to 40 minutes. For this reason, the use of hearing protection for patients is absolutely mandatory. Clinical staff must ensure this preventive measure to avoid immediate biological damage [11,18].

Application of the ISO 9612 Analytical Model:

Task-Based Measurement (Equation 3):

$$L_{p,A,eqTe} = 10 \cdot log_{10}\left[\frac{1}{T_e}\sum_{m=1}^{m} T_m \cdot 10^{0.1 \cdot L_{p,A,eqTm}}\right] dB \ (3)$$

$$I_1\ (60\ dBA) = 10^{0,1 \cdot 6} = 1.000.000$$

$$I_2\ (93\ dBA) = 10^{0,1 \cdot 9,3} = 1.995.262.315$$

$$I_3\ (55\ dBA) = 10^{0,1 \cdot 5,5} = 316.228$$

$$D_1 : 2,5\ \text{h} \cdot 1.000.000 = 2.500.000$$

$$D_2 : 0,5\ \text{h} \cdot 1.995.262.315 = 997.631.158$$

$$D_3 : 3\ \text{h} \cdot 316.228 = 948.684$$

$$(D_{total}) : 2.500.000 + 997.631.158 + 984.684 = 1.001.079.842$$

$$L_{p,A,eqTe} = 10 \cdot log_{10}\left[\frac{1.001.079.842}{6\ \text{h}}\right]$$

$$L_{p,A,eqTe} = 10 \cdot log_{10}[166.846.640]$$

$$\boldsymbol{L_{p,A,eqTe} = 82,2\ dB}$$

Normalized Daily Exposure Level:

$$L_{EX,8h} = L_{p,A,eqTe} + 10 \cdot log_{10}\left[\frac{T_e}{T_0}\right]\ dB \ (5)$$

$$L_{EX,8h} = 82,2 + 10 \cdot log_{10}\left[\frac{6h}{8h}\right]\ dB$$

$$\boldsymbol{L_{EX,8h} = 80,95\ dB}$$

The ISO 9612 analytical model was applied to estimate the Normalized Daily Exposure Level (LEX, 8h) of the clinical staff. It is important to emphasize that this calculation was based on the actual sound pressure level (SPL) values obtained from in situ measurements and, fundamentally, that intentionally longer exposure times than the real task durations were used:

- I_1 and D1: I_1 corresponded to the measured intensity value in the control room during an MRI study. For D_1, the intensity value was multiplied by the effective exposure time, defined as the sum of all MRI procedure durations within a work shift. According to the measurement table, I_1 was equivalent to 60 dBA and was multiplied by an exposure time of 2.5 hours, a value exceeding the average.
- I_2 and D_2: I_2 represented the intensity measured inside the examination room without hearing protection, corresponding to 93 dBA according to **Table 2**. For D_2, this intensity was multiplied by an exposure time of 0.5 hours (representing the time clinical staff remain inside the

examination room), which was also considered conservative.

- I_3 and D_3: I_3 corresponded to the intensity measured in the control room when the MRI system was idle (no scan in progress), with a value of 55 dBA. For D_3, this intensity was multiplied by an exposure duration of 3 hours (representing time spent in the control room without active scanning), which was generally longer.

The resulting sound exposure level was 82.2 dB over a 6-hour workday, which reflects the standard shift duration in the MRI service where the measurements were conducted. To compare this value with international recommendations, normalization to an 8-hour workday was required. This was achieved by applying a logarithmic adjustment, resulting in a normalized exposure level of 80.95 dB. This value falls within acceptable limits, remaining below the recommended threshold of 85 dB for an 8-hour exposure period.

This methodological approach was intentionally designed to estimate a "worst-case scenario" or upper exposure limit. Therefore, if the calculated L_{EX}, 8h under these maximum simulated exposure conditions remains below the World Health Organization (WHO) recommended threshold (85 dBA for 8 hours), it can be inferred that the risk of chronic occupational hearing loss under normal operating conditions is low. However, ISO 9612 requires the calculation of the Combined Standard Uncertainty to ensure legal and occupational validity of the results.

Nevertheless, an alternative scenario was also considered in addition to the conservative case. In this model, sound intensity levels in the control room were assumed to be constant for the staff. The main difference lay in the distribution of time and the location of the workers. It was assumed that clinical staff did not enter the examination room during image acquisition. The time spent in the control room during studies was 2 hours, while the remaining 4 hours corresponded to periods without MRI activity. The results showed a much lower normalized daily exposure level. This final value was equivalent to the sound level of a normal conversation [5].

Task-Based Measurement (Equation 3):

$$L_{p,A,eqTe}=10 \cdot log_{10}\left[\frac{1}{T_e}\sum_{m=1}^{m} T_m \cdot 10^{0.1 \cdot L_{p,A,eqTm}}\right] dB \ (3)$$

$$I_1\ (60\ dBA)=10^{0,1\cdot 6} = 1.000.000$$

$$I_2\ (55\ dBA)=10^{0,1\cdot 5,5} = 316.228$$

$$D_1 : 2\ h \cdot 1.000.000 = 2.000.000$$

$$D_2 : 4\ h \cdot 316.228 = 1.264.912$$

$$(D_{total}) : 2.000.000+1.264.912=3.264.912$$

$$L_{p,A,eqTe}=10 \cdot log_{10}\left[\frac{3.264.912}{6\ h}\right]$$

$$L_{p,A,eqTe}=10 \cdot log_{10}[544.152]$$

$$\boldsymbol{L_{p,A,eqTe}=57.35\ dB}$$

Normalized Daily Noise Exposure Level:

$$L_{EX,8h}=L_{p,A,eqTe}+10\cdot log_{10}\left[\frac{T_e}{T_0}\right]\ dB\ (5)$$

$$L_{EX,8h}=57.35+10\cdot log_{10}\left[\frac{6h}{8h}\right]\ dB$$

$$\boldsymbol{L_{EX,8h}=56.1\ dB}$$

Note on Combined Standard Uncertainty:

The calculation of the combined standard uncertainty was omitted in this study. ISO 9612 requires a minimum of three independent repetitions for each specific measurement task. These repetitions are necessary to statistically determine the repeatability component (σ R). In this investigation, measurements were carried out across different clinical sequences depending on the hospital's limited availability. Therefore, an adequate number of identical samples was not available to estimate uncertainty in accordance with the technical standard. The study focused exclusively on estimating the normalized daily noise exposure level as a proof of concept.

Identification of Biological Effects:

A review of various studies and protocols is presented below, translating sound pressure levels into biological, clinical, and subjective effects, thus providing a comprehensive perspective on the risks faced by both healthcare personnel and patients in the Magnetic Resonance Imaging (MRI) environment:

Study [18], conducted in Sweden, analyzed the impact of acoustic noise by comparing MRI personnel with a control group working in Computed Tomography. The results showed a higher prevalence of tinnitus, headaches, and unusual drowsiness among MRI professionals. These findings are based on subjective reports from workers regarding their health status. In the field of occupational health, this type of subjective information is a valuable tool for workplace assessment, as it helps identify symptoms of fatigue and sensory stress that may not be captured by external physical measurements, thereby providing a more comprehensive and human-centered understanding of risks in the MRI environment.

Study [19] evaluated the effect of acoustic noise from a 1.5 Tesla MRI on patients' auditory function using high-precision audiometry. The results demonstrated a temporary threshold shift (TTS) immediately after the examination, significantly affecting frequencies of 4, 6, 8, 14, and 16 kHz. The most relevant aspect of this finding is that these alterations occurred despite the use of hearing protection, confirming that MRI-generated noise produces a measurable biological impact on the sensory system. However, the study concluded that this effect is transient, as auditory thresholds returned to baseline levels and were no longer observable after a 24-hour period. This evidence highlights the dynamic nature of biological risk.

The systematic review [20] provided a fundamental theoretical basis by detailing the molecular mechanisms of noise-induced damage. Unlike specific clinical studies, this work established that chronic exposure above 85 dB leads to progressive degradation of the outer hair cells of the organ of Corti, while noise peaks exceeding 140 dB may trigger acute acoustic trauma. A distinctive contribution of this study was its analysis of systemic extra-auditory effects. Noise was shown to act as a biological stressor, increasing the release of catecholamines (adrenaline and cortisol), which in turn caused a direct rise in blood pressure and heart rate. Furthermore, it identified that environmental noise levels above 45 dB disrupt circadian rhythms and restorative sleep. From a psychological perspective, it highlighted that noise-induced cognitive fatigue increases the risk of occupational errors by 15% to 20% in high-demand environments such as healthcare settings.

Generalizability of the results:

The external validity of this study presents certain limitations due to the measurement setting. Data were obtained using a specific 1.5 Tesla General Electric MRI system; therefore, sound pressure levels may vary across different models or manufacturers. Additionally, measurements depend on the pulse sequences selected during the data collection period. However, the methodology based on ISO 9612 is applicable to any radiology service worldwide. The analytical model allows replication of this assessment across different clinical configurations. Although the numerical values are specific to this center, the conclusions regarding hearing protection maintain general validity for patient safety.

Conclusions

The actual sound pressure level values obtained with the sound level meter confirmed that, for the most common diagnostic pulse sequences, noise levels inside the equipment room reach peaks of up to 93 dBA. These values exceed the action thresholds established in occupational safety regulations, especially in the high-frequency component, although background measurements in the control room remained within acceptable limits. On the other hand, the normalized daily noise exposure level (L_{EX},8h), calculated according to the analytical model of ISO 9612:2009 using the Task-Based Strategy (Strategy 1), made it possible to determine the equivalent sound pressure level (Lp,Aeq,T) for each specific task (e.g., pulse sequences and inactive periods) and to record its duration (T). The analysis of these data, which were integrated into a logarithmic formula that weights total exposure over a standard 8-hour period, indicated that the occupational risk of chronic hearing loss is classified as low under current operating conditions. Finally, the observed biological effects are consistent with the measured noise levels. The most immediate and frequent effect in patients is Temporary Threshold Shift (TTS), a reversible change that highlights the intensity of acoustic stress. In chronically exposed staff, the literature and reported symptoms suggest the potential development of tinnitus or transient neurosensory fatigue, and the risk of Permanent Threshold Shift (PTS) cannot be ruled out if protective measures fail. In conclusion, the impact on occupational and patient health in the Magnetic Resonance Service is twofold: the chronic occupational risk is low according to the L_{EX},8h calculation, but there is a significant short-term impact on patient comfort and well-being, manifested as anxiety and TTS, which makes the active management and mitigation of noise imperative in order to balance diagnostic excellence with safety.

Based on the findings obtained and with the aim of ensuring service integrity and regulatory compliance, the following recommendations are established for the Hospital: it is strongly recommended to perform calculations using task-based measurement (ISO 9612 Strategy 1). Although the daily time-weighted average exposure (L_{EX},8h) may be low, it is crucial to calculate the Combined Standard Uncertainty to ensure with scientific certainty that exposure values do not exceed current regulations and laws. In addition, as an extra measure to achieve maximum data reliability, it is advised that all measurements of noise levels from individual sequences and equipment idle times be repeated, using at least two Class 1 measuring devices simultaneously. Finally, it is essential that the technical frameworks for these measurements and calculations adhere to ISO 9612:2010, which ensures the scientific and legal validity of exposure assessment.

Author's contributions:

Nelson Andrés Valdez Velázquez: Supervisor.

Rafael Klassen Esau: Researcher.

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