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Quantitative assessment of acoustic noise levels during clinical spinal MRI

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Abstract Magnetic Resonance Imaging (MRI) is crucial for spinal diagnosis but generates significant acoustic noise from rapidly switching gradient fields, affecting patient comfort and hearing. This study quantitatively assessed the acoustic noise during a standard 1.5T spinal MRI protocol across eight sub-sequences. Sound pressure levels were measured simultaneously in both the examination and control rooms to evaluate isolation effectiveness. Results showed highly dynamic, sequence-dependent noise profiles. The examination room reached peak sound pressure levels exceeding 100 dB (e.g., during STIR sequences), with L_{Aeq} reaching up to 90.8 dB in T2 TSE sagittal sequences. Significant acoustic attenuation (27–34 dB reduction in L_{Aeq}) was confirmed between the two environments, proving existing shielding is effective, especially at higher frequencies. These findings emphasize that noise varies significantly based on specific pulse sequences. Continued adherence to robust noise mitigation protocols is essential to safeguard patient hearing and enhance overall comfort during high-noise imaging procedures.

Keywords: Magnetic Resonance Imaging (MRI), Acoustic Noise, Sound Pressure Level (SPL), Gradient Switching, Acoustic Attenuation, Noise Mitigation Strategies

1. Introduction

Magnetic resonance imaging (MRI) has become an essential modality for evaluating spinal pathology owing to its superior soft tissue contrast, multiplanar capability, and lack of ionizing radiation. As clinical demand for spinal MRI continues to grow, attention has increasingly turned toward the acoustic environment in which these examinations occur. MRI systems are known to generate high levels of acoustic noise, predominantly due to rapid switching of gradient magnetic fields, which induces Lorentz forces that vibrate gradient coil structures and surrounding hardware. These mechanical vibrations propagate through the scanner bore as sound waves, resulting in measured sound pressure levels that routinely reach or exceed 80–110 dB during routine imaging sequences [1-3]. In certain conditions, peak levels may surpass 120 dB, posing risks for patient comfort and, in some cases, auditory health.

The magnitude and spectral properties of MRI-generated noise vary substantially with pulse sequence design and operational parameters. Gradient intensive sequences, such as turbo spin echo, echo planar imaging, and diffusion weighted imaging, produce particularly elevated noise outputs because of their high slew rates and strong gradient amplitudes [3-5]. Recent studies have shown that even modest modifications to gradient waveforms or sequence timing can significantly alter the sound pressure profile, underscoring the complex relationship between imaging technique and acoustic exposure [5, 6]. Moreover, the presence of a patient or phantom within the bore can modulate acoustic fields by introducing additional reflective surfaces, increasing local sound pressure levels by 5–10 dB in certain regions [4, 7]. The clinical implications of MRI acoustic noise are wide-ranging. Elevated sound pressure levels contribute to patient discomfort, anxiety, and communication challenges during scanning [8, 9]. Although appropriately fitted hearing protection typically prevents permanent auditory injury, temporary threshold shifts have been documented in susceptible populations and high noise imaging scenarios [10-12]. The clinical environment is also affected; noise transmission into control rooms and adjacent spaces may influence staff fatigue and occupational exposure, necessitating appropriate architectural noise mitigation strategies [13, 14].

Within this context, evaluating sequence specific and room specific acoustic characteristics in routine spinal MRI examinations provides critical insight for both safety management and patient centred care. Spinal imaging relies heavily on sequences known to produce substantial gradient activity, yet relatively few studies have quantified noise behaviour across the multiple subcomponents of a standard clinical spinal protocol. Understanding the acoustic profile at both the examination table and control room positions is

essential for optimising protection strategies, improving clinical workflows, and informing future scanner and sequence design.

In this paper, we present a quantitative acoustic characterization of clinical spinal imaging sequences performed on a 1.5T Siemens MAGNETOM Sempra MRI system. The study systematically evaluates the sound pressure levels across several standard clinical subparts within a routine spinal MRI protocol. Performing comparative measurements between the examination and control room, we aim to identify the specific sequences that contribute most significantly to peak acoustic loads and assess the noise within the MRI setups. Through this analysis, we provide critical data on high-energy acoustic peaks that are essential for evaluating hearing protection protocols and improving patient comfort during routine spine examinations.

2. Methods

The acoustic measurements were conducted in a clinical environment utilizing a 1.5 Tesla Siemens MAGNETOM Sempra MRI system shown in Figure 1. The sound levels were recorded simultaneously in two locations: the Examination Room (where the patient is positioned) and the Control Room (where the operator resides). The data was recorded using omnidirectional free field condenser type ½ inch microphone (model: SVANTEK 7052E) with frequency range of 20-20000 Hz and dynamic range of 10-135 dB, placed inside the examination room and control room. The microphone inside the examination room was positioned at 2 m distance from scanner and 1 m height from the floor, while the microphone in control room is positioned at the operator position at height of 1 m from the floor. The microphones were connected to the sound level meter (model: SVAN971, make: SVANTEK) using shielded cable. The setup was compliant with the IEC 61672 Class 1 standard for high precision measurements [15, 16].

Figure 1. 1.5T Siemens MAGNETOM Sempra MRI system.

Acoustic sound pressure signals were recorded during the operation of a clinical MRI scanner executing a standardized spine imaging protocol. The acoustic evaluation focused on the structural and diffusion-weighted sequences of the clinical exam. Anatomical and fluid-sensitive imaging was performed using T2-weighted Turbo Spin Echo (TSE) sequences in both the sagittal (acquired with a 3 mm slice thickness) and transverse planes, alongside a TSE Short Tau Inversion Recovery (STIR) sequence. Additionally, a T1-weighted Spin Echo (T1 SE) sequence was acquired in the sagittal plane. High-resolution diffusion-weighted imaging was performed using the RESOLVE technique in the sagittal plane with b-values of 0 and 800 s/mm^2, generating both Trace Weighted (TRACEW) and Apparent Diffusion Coefficient (ADC) maps. Sound pressure data were continuously captured throughout the execution of these diagnostic sequences to characterize the acoustic noise profiles generated by the scanner's gradient coils under each specific imaging parameter. The sequence of sub scan procedure is presented in Table 1.

Table 1. Imaging sub sequences during spine imaging protocol.

Number	Scan sequence
(1)	T2-Turbo spin echo (TSE) sagittal
(2)	Turbo spin echo (TSE) stir
(3)	T2-Turbo spin echo (TSE) transverse
(4)	T2-Turbo spin echo (TSE) sagittal-1
(5)	Resolve diffusion sagittal TRACEW
(6)	Resolve diffusion sagittal TRACEW-1
(7)	Resolve diffusion sagittal ADC
(8)	T1-Spin echo (SE) sagittal

The recorded acoustic signals were analysed in SVANPC++ software. Sound pressure levels were quantified using three standardized metrics: L_{Aeq} (A-weighted equivalent continuous), L_{Apeak} (A-weighted peak), and L_{Cpeak} (C-weighted peak). Measurements were recorded simultaneously in the examination room and control room for each imaging sequence. Background noise levels were measured prior to scanning to establish baseline conditions.

3. Results

The time-domain acoustic waveform for the complete clinical spine protocol is shown in Figure 2. The figure tracks the sound pressure levels through eight sequential phases, ranging from various weighted sequences (Segments 1–8). The acoustic analysis reveals a highly dynamic noise profile that fluctuates significantly depending on the specific MRI sequence being executed. The waveform highlights the sequence-dependent nature of MRI-induced noise, characterized by intermittent high-amplitude acoustic transients during heavy gradient-duty-cycle sequences, such as STIR and T2 TSE, interspersed with periods of lower acoustic activity.

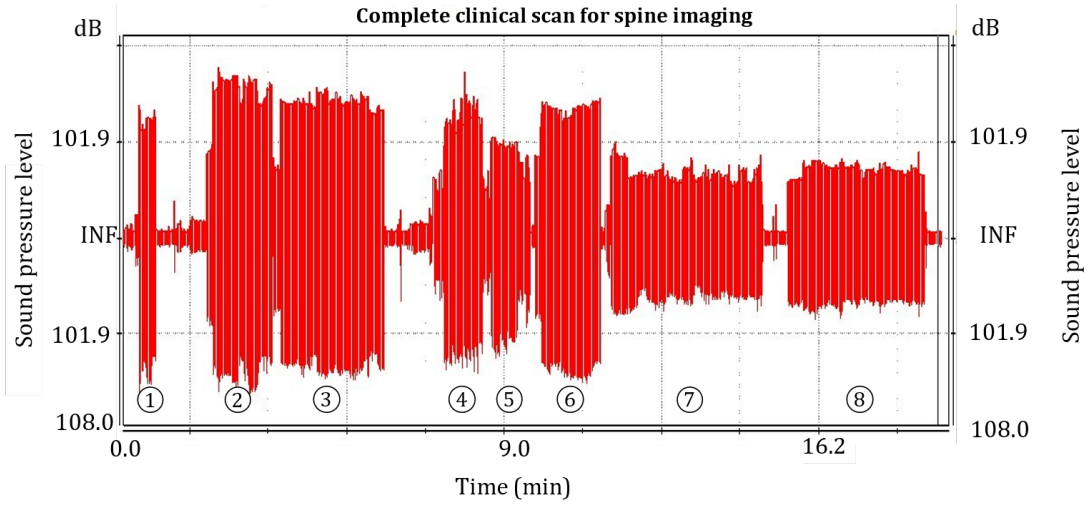

Figure 2. Time-domain waveform of SPL variation inside the scanning room (the sub-scan sequences are presented as circled number referred from Table 1.)

The quantitative profiles for the examination room and the control room are presented in Figures 3 and 4, respectively. Their comparison demonstrate a substantial disparity in noise characteristics. The comprehensive numerical results from the analysis are presented in Table 2. In the examination room, the L_{Aeq} levels reach as high as 90.8 dB during T2 TSE sagittal sequences, with peak sound pressure levels (L_{Cpeak}) exceeding 100 dB during STIR sequences. The control room maintains significantly lower noise levels. The background noise in the control room is recorded at a much lower 40.8 dB L_{Aeq} compared to 52.8 dB in the examination room. During the scanning process, the control room noise shows corresponding elevation in the sound pressure profiles. The noise control room shows rise in L_{Aeq} sound pressure level by 22.3 dB above the background level, where the examination room showed raise of 38.0 dB in L_{Aeq}.

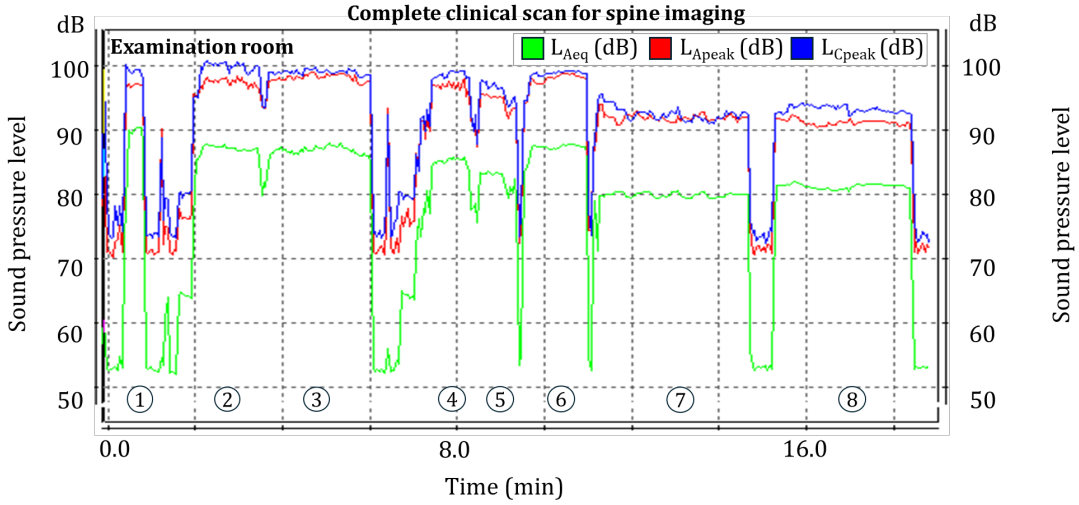

Figure 3. Acoustic profile of clinical spinal scan presenting L_{Aeq}, L_{Apeak}, and L_{Cpeak} over scan duration in examination room.

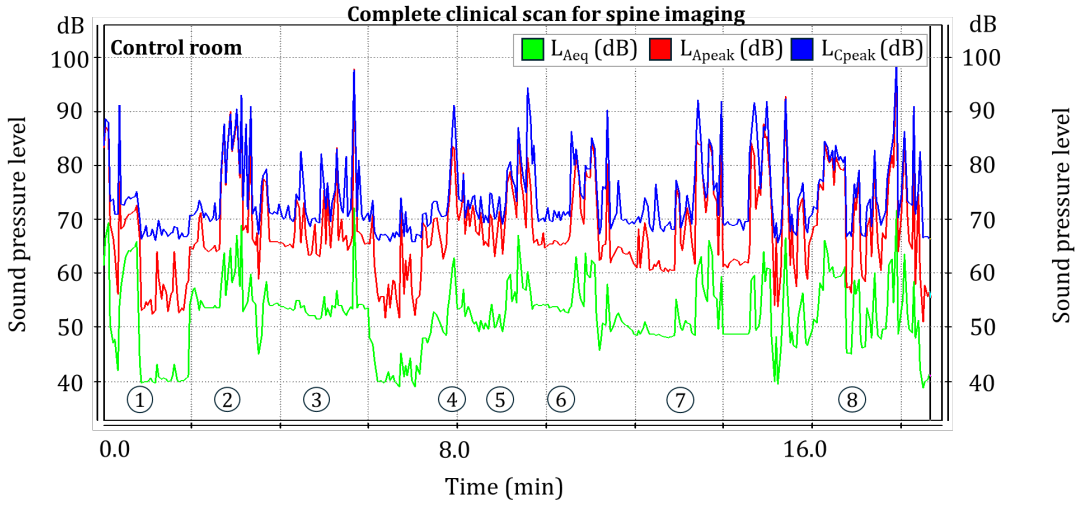

Figure 4. Acoustic profile of clinical spinal scan presenting L_{Aeq}, L_{Apeak}, and L_{Cpeak} in control room.

Table 2. Quantitative results from the acoustic analysis of the sub-sequences for spine imaging.

MRI sequence	Sound pressure level (dB)					
	Examination room			Control room		
	L_{Aeq}	L_{Apeak}	L_{Cpeak}	L_{Aeq}	L_{Apeak}	L_{Cpeak}
Background	52.8	70.9	73.8	40.8	64.0	69.9
T2-Turbo spin echo (TSE) sagittal	90.8	97.3	99.5	63.1	72.6	75.0
Turbo spin echo (TSE) STIR	88.2	98.4	100.9	59.8	92.3	93.1
T2-Turbo spin echo (TSE) transverse	88.6	99.0	99.8	53.8	76.8	82.7
T2-Turbo spin echo (TSE) sagittal-1	86.3	98.1	99.3	54.9	83.4	91.1
Resolve diffusion sagittal TRACEW	83.9	95.7	97.9	56.0	86.8	86.9
Resolve diffusion sagittal TRACEW-1	88.0	98.8	99.3	56.9	81.9	94.3
Resolve diffusion sagittal ADC	80.7	94.4	95.6	54.6	84.7	92.2
T1-Spin echo (SE) sagittal	81.9	92.4	94.3	57.5	84.1	84.1

Significant attenuation of acoustic energy was observed between the examination room and control room. The average difference in L_{Aeq} values across all active sequences was approximately 27-34 dB, indicating effective acoustic isolation. The largest difference was in the T2 TSE transverse sequence with

34.8 dB L_{Aeq} difference, while the smallest was in the DWI ADC sequence at 26.1 dB, demonstrating that the facility's acoustic shielding is more effective at higher frequencies.

The variation of acoustic signatures within the scanning sequency necessitates frequency domain analysis of the individual sub-sequences, as the overall spectrum over the complete scanning time would average out the dynamic frequency content. The 1/3rd octave frequency spectra of individual subparts within the spinal scan are presented in the Figure 5. The frequency spectra shows comparison between the noise characteristics in examination room and control room.

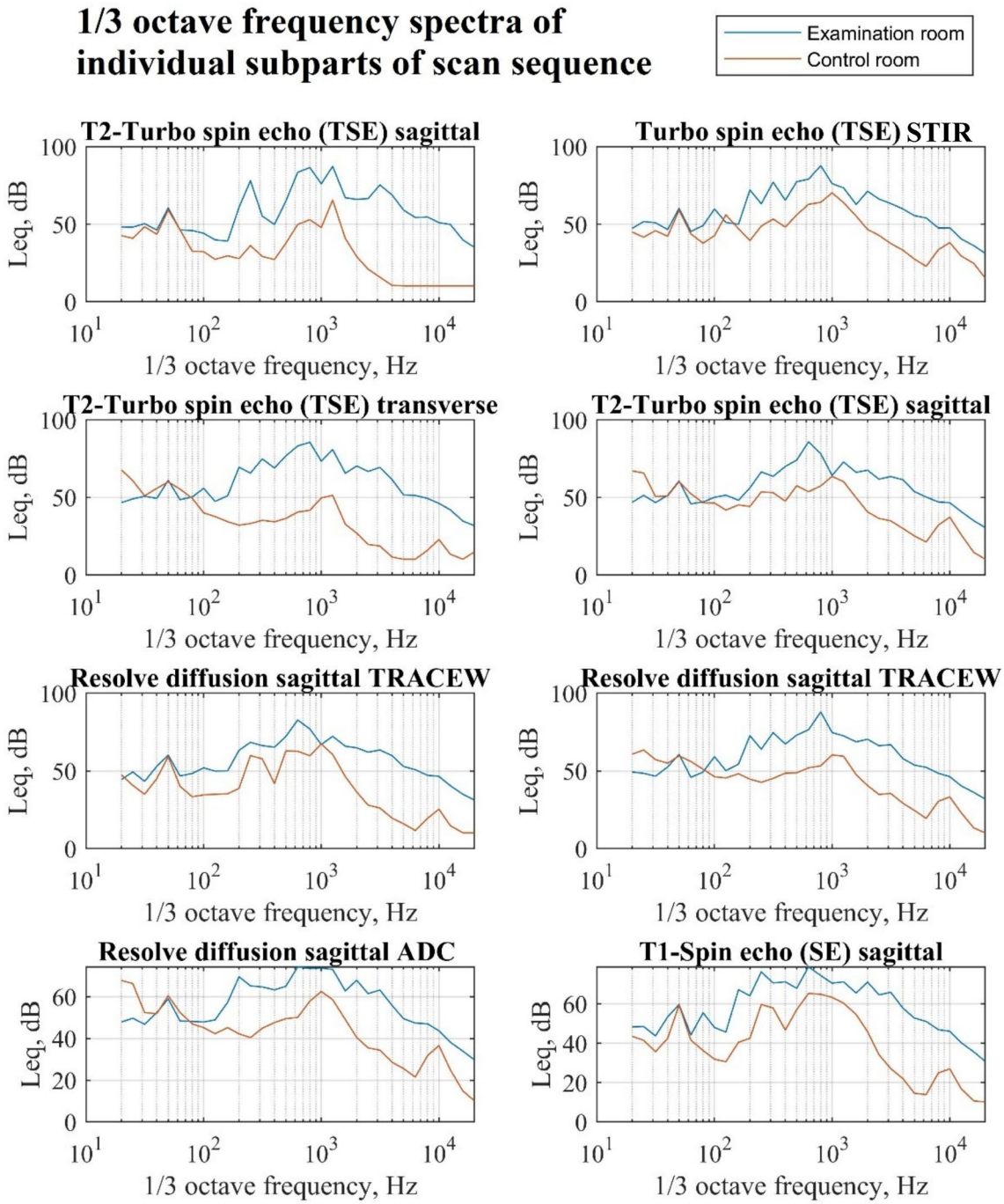

Figure 5. Comparison of 1/3rd octave spectra between the examination room (blue) and control room (orange) for all sub-parts of the scan sequence.

The 1/3 octave frequency spectra illustrate the spectral distribution of sound pressure levels (Leq) across various clinical spinal MRI sequences, comparing the acoustic environment of the examination room to the control room. A consistent spatial disparity is evident across all examined subparts, with noise levels

in the examination room significantly exceeding those in the control room. The spectral profiles reveal that the acoustic energy is not uniformly distributed but is instead characterized by distinct peaks within the low-to-mid frequency ranges (predominantly between 200 and 2000 Hz), reflecting the mechanical vibrations induced by gradient coil switching. Furthermore, the magnitude of these peaks is highly sequence-dependent; while sequences such as T2 TSE sagittal and STIR exhibit much higher spectral density and broader frequency peaks, other sequences like the Diffusion ADC and T1 SE Sagittal demonstrate relatively lower acoustic energy, indicating that the acoustic load on the patient is primarily driven by specific high-gradient pulse sequences

4. Discussion

The present study characterized acoustic noise levels generated during routine spinal MRI examinations by quantifying A-weighted equivalent levels (L_{Aeq}), peak sound pressure levels (L_{Apeak}), and C-weighted peaks (L_{Cpeak}) in both the examination and control rooms. Across all sub-components of the clinical protocol, the findings demonstrate that MRI scanning remains a high-noise environment, with distinct variations in acoustic output between sequences and substantial attenuation between examination and control room spaces. These results align closely with established acoustic profiles reported for clinical MRI systems.

The measured L_{Aeq} values within the examination room ranged from approximately 80–91 dB, with peak levels regularly approaching or exceeding 95–100 dB. This pattern is consistent with known MRI acoustic mechanisms, where rapid gradient switching generates mechanical vibrations through Lorentz forces acting on the gradient coil assembly [17]. Sequences with higher gradient amplitudes and slew rates, such as turbo spin echo (TSE), short-tau inversion recovery (STIR), and diffusion-weighted acquisitions, produced the highest SPLs. This aligns with prior work demonstrating that gradient-intensive sequences routinely exceed 90 dB and can reach 110 dB depending on parameters and field strength [17]. The observed elevations in noise during these sub-sequences further correspond with reports showing that parameters such as thin slices, fast TR/TE, and high spatial resolution intensify acoustic output [18].

The results also reveal a substantial reduction in acoustic energy between the examination room and the control room, where L_{Aeq} values typically fell between 53–64 dB. This behaviour reflects the expected attenuation associated with distance from the bore and the shielding properties of room construction materials. Previous studies have shown that noise decays significantly outside the immediate bore vicinity, with control room levels remaining lower yet non-negligible during high-noise sequence operation [13, 14, 19]. The current findings are therefore consistent with known spatial gradients in MRI acoustic fields, including evidence that noise transmission is influenced by reflections, room geometry, and structural shielding [13, 19].

The examination room noise levels documented here surpass thresholds commonly associated with potential auditory risk in repeated exposure scenarios. Prior research indicates that MRI peak noise levels can induce temporary threshold shifts and contribute to discomfort, underscoring the need for protective measures [17, 18]. In this context, routine provision of ear protection remains essential. Furthermore, elevated noise is known to degrade patient experience and contribute to anxiety, with studies demonstrating that noise-reduction technologies such as quiet or Silent Scan protocols improve comfort without compromising diagnostic value [8, 20]. The present findings reinforce these considerations and highlight the value of incorporating noise-mitigation strategies into clinical workflow planning, especially for sequences shown to produce the highest SPLs.

5. Conclusion

This study systematically evaluated acoustic noise levels generated during a routine spinal MRI protocol, quantifying both equivalent continuous levels and peak sound pressure values across all sub sequences in the examination and control rooms. The findings demonstrate that spinal MRI remains a high noise procedure, with examination room L_{Aeq} values consistently ranging from approximately 80–91 dB and peak levels approaching 100 dB, particularly during gradient intensive sequences such as TSE, STIR, and diffusion acquisitions. These measured levels are fully consistent with established reports showing that clinical MRI scanners routinely generate 90–110 dB during typical imaging sequences. Substantial attenuation was observed between the examination room and the control room, where L_{Aeq} values fell to 53–64 dB, reflecting expected reductions in acoustic energy with increasing distance, shielding, and room architecture. Nonetheless, the control room values remained non trivial, particularly during high noise sequences, reinforcing that acoustic transmission extends beyond the bore environment. From a clinical standpoint, the documented noise levels exceed conservative auditory safety thresholds and highlight the importance of consistent use of hearing protection for patients and staff. Moreover, given evidence that

excessive acoustic noise can impact patient comfort and contribute to anxiety, the adoption of noise reduction strategies including quieter pulse sequences and technologies such as Silent Scan remains a valuable complement to routine workflow. Overall, the results of this study align closely with the established acoustic behaviour of MRI systems and underscore the need for ongoing safety monitoring, optimization of sequence settings, and implementation of patient centred noise mitigation practices. These findings provide a clear evidence base for informing clinical decision making, equipment evaluation, and policy development related to acoustic safety within MRI environments.

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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