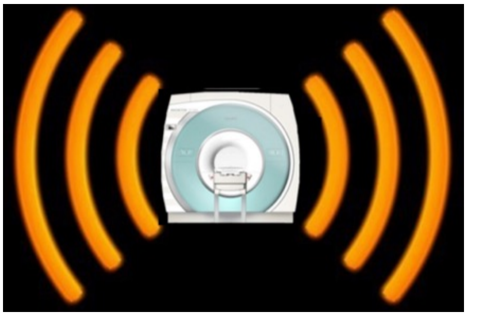
Acoustic Noise in the MR Environment

David Price, MR Physics, GSTT NHS Foundation Trust (david.price@gstt.nhs.uk)



Together with the confined space of the scanner, the loud nature of MR scanning is the most noticeable feature for those undergoing an MR scan. This article seeks to discuss the causes and characteristics of MR acoustic noise, the potential hazards and ways to protect patients and staff.

Causes and Characteristics

As the MR scanner operates vibrations in the gradient coils are generated by Lorentz forces, induced by the currents flowing through the gradient coils within the static magnetic field.

Lorentz forces are proportional to main magnetic field strength and the current flowing through the coils which is in turn proportional to the gradient amplitude.

That's why scans on high field magnets and scans with high spatial resolution, low repetition times or short echo spacing (all things that need high gradient amplitudes and high slew rates) have increased acoustic noise levels **[1]**.

The highest noise levels are normally associated with fast gradient echo and echo planar imaging (EPI) pulse sequences.

The range of absolute sound pressure (P) that the ear can detect is rather large. Therefore we use Sound Pressure Level (SPL)-a logarithmic scale in decibels (dBs).

$$SPL = 20 \log_{10}(P/P_0) \quad P_0 = 20\ \mu Pa$$

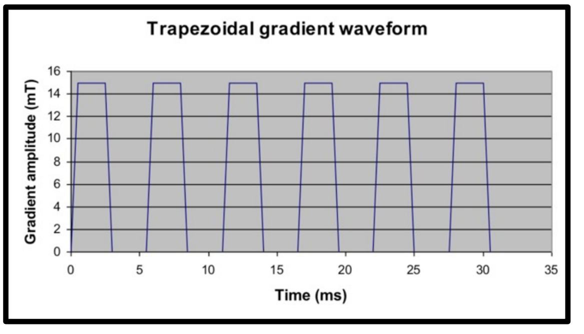
Its important to know that a 3dB increase in SPL represents a doubling of the sound intensity.

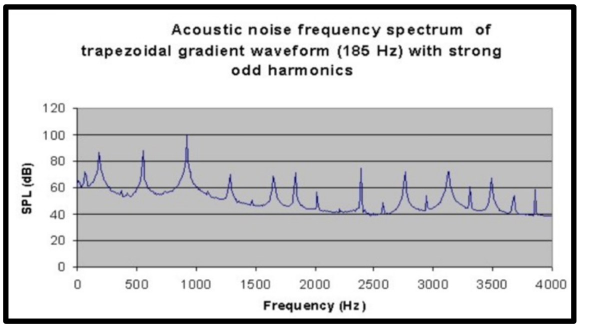
We also use the A-weighted scale which matches the frequency response of the human ear.

In one survey of worst-case clinical pulse sequences on a range of MR systems, noise levels varied from 77 dB(A) on a 0.2 T scanner to 118 dB(A) on a 3 T system [2].

Typical noise levels on and 1.5T and 3 T clinical MRI systems vary from about 80 dB(A) to 110 dB(A).

The figures below show a typical trapezoidal gradient waveform switching at 185 Hz and the resultant acoustic noise spectrum **[3]**





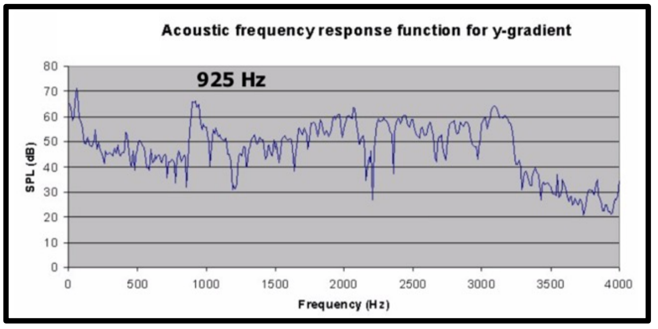
The acoustic frequency spectrum of a MR pulse sequence appears as a peak at the gradient switching frequency (fundamental frequency) and series of higher frequency peaks called harmonics spaced out at multiples of the fundamental frequency.

The harmonics make a significant contribution to the total noise. Generally the significant components of MR noise range up to a about 5 kHz.

The noise spectrum is modified according to the natural resonances of the gradient coil and other structures of the scanner. This behaviour is described by the frequency response function (FRF).

Resonances in the system mean that if a certain frequency is excited by the gradient waveform, it can lead to much higher noise levels than expected. Access to prominent resonance frequencies will normally be blocked by the manufacturers.

In the example below the FRF shows a very prominent resonance at 925 Hz that might be excited by a higher frequency harmonic resulting in high noise.



What are the effects?

Discomfort and stress

Unprotected exposure to excessive noise may cause immediate discomfort and stress. In normal individuals the discomfort threshold is around 120 dB **[4]**.

However sensitive individuals suffering from conditions such as recruitment or hyperacusis may be discomforted by significantly lower noise levels.

Noise has been identified as a factor amongst others, such as claustrophobia, in increasing anxiety amongst MR patients **[5]**.

Temporary and permanent threshold shifts in hearing

A short period of unprotected exposure to loud noise can also produce a temporary threshold shift (TTS) in the sensitivity of hearing. This is experienced as a dulling in hearing at the end of the exposure and can be accompanied in some cases by tinnitus.

Data from non-MR exposures indicate that a clinically significant threshold shift (>10 dB) may be avoided in most cases if noise is below 80 dB(A) and the exposure is limited to under an hour **[6]**.

Helpfully most MR noise is below 4 kHz where the ear is most sensitive to this effect.

Permanent threshold shifts and subjective effects

If the noise exposure is particularly severe or if it is continually repeated, there may be a permanent threshold shift (PTS).

The threshold of instantaneous and permanent acoustic trauma normally associated with exposure to impulsive noise is 140 dB.

Clinical MR systems compliant with the IEC MR Safety Standard cannot produce a peak sound pressure greater than 140 dB **[7]**.

The potential risk to MR patients is unlikely to involve the production of a PTS given the limited exposure time involved.

However, MR workers spending significant amounts of time in the scanner room during interventional procedures without adequate protection may be at risk of a PTS in common with others working in noisy environments.

There is some limited subjective evidence from leisure-related noise exposures and MR adverse incident reports that permanent effects may be induced in unprotected subjects from occasional exposures to loud noise (<140 dB) **[8]**.

Tinnitus and hypersensitivity have been reported in individuals exposed to loud noise at music concerts where noise levels may reach 120 dB(A). These effects may be permanent even after a single exposure.

Guidance from the MHRA states that all patients and volunteers should be fitted with hearing protection unless noise levels can be shown to be comfortably below 80 dB(A) [9].

Staff present in the scanner room during imaging on a regular basis may be at risk of permanent hearing damage if not protected adequately.

These exposures will fall under The Control of Noise at Work Regulations 2005. This stipulates that hearing protection must be worn if noise exceeds 85 dB(A) averaged over 8 hours [https://www.hse.gov.uk/noise/].

Fetal Exposures

A US review on the hazard of noise to the fetus and the newborn (non-MR related) concluded there was some evidence of shortened gestation and decreased birth weight from excessive noise exposure in pregnancy **[10]**.

Hepper and Shahidullah in an HSE report concluded that any effect on reproductive outcomes from noise is probably indirect due to its role as a stressor on the mother and that reducing this stress through the provision of suitable hearing protection may reduce the risks **[11]**.

Studies of hearing and cochlear function in children exposed to MRI in-utero show no evidence of impairment **[12, 13]**.

Protection

Noise reduction strategies

Manufacturers use mechanical damping to stop the vibrations from the gradient coils. Some scanners even have the gradient coils in a vacuum chamber to stop the sound waves travelling out from the coils.

Noise has been substantially reduced but not eliminated because electrical eddy currents are also induced in other metallic parts of the scanner causing vibration and noise independently of the sound waves transmitted from the gradient coils.

MRI manufacturers offer ‘quiet’ sequences that can be effective for scanning sensitive patients. These may use smoother gradient waveforms with longer rise times that have less powerful harmonic components, reduced gradient amplitudes or avoid acoustic resonances.

There is also interest in ultra-short or zero TE sequences that use radial k-space schemes.

A by-product of these sequences very slow changes in gradient amplitude is almost silent MRI **[1]**.

Unfortunately developing quiet versions of the noisiest sequences such as diffusion EPI has been more problematic.

Hearing protection


Ear plugs and ear defenders remain the main means to protect patients.

They will only be effective if properly fitted into the ear canal. Problems may occur in this regard if patients are left to fit the plugs themselves. Ear defenders are easier to fit.

However, they can be difficult to use in conjunction with some smaller head RF coils. Up to 35 dB of protection is offered by plugs and defenders at the frequencies of interest in MR.

Both can be worn together if noise is very intense generally providing up to 6 dB of attenuation above the most effective form of protection when worn alone.

Protection for neonates is clearly a concern. Dedicated neonatal ear-muffs and plugs are often used in combination with padding around the head.

MR manufacturers earphones designed for communication and playing music may not provide sufficient noise attenuation and earplugs should also be worn.

Risk assessments

MR Clinical Scientists can advise on acoustic noise levels and suitable hearing protection. They have equipment to measure noise levels sequences and perform risk assessments for sensitive patients and occupational exposures.

References

[1] McJury M (2022), Acoustic Noise and Magnetic Resonance Imaging: A Narrative/Descriptive Review J Magn Reson Imaging, 55:337–346.
[2] Price DL, De Wilde JP, Papadaki AM, Curran JS and Kitney RI (2001). Investigation of acoustic noise on 15 MRI scanners from 0.2 T to 3 T. J Magn Reson Imaging, 13, 288-293
[3] Price DL, De Wilde JP and McRobbie DW (2004). Proc ESMRMB 2004, Copenhagen, Denmark.
[4] Flindell IH. Fundamentals of human response to sound. Chapter 3 p 145 in Fundamentals of noise and vibration. Fahy FJ and Walker JG (Eds),. E and FN Spon London 1998.
[5] Quirk ME, Letendre AJ, Ciottone RA and Lingley JF. (1989). Anxiety in patients undergoing MR imaging. Radiology, 170(2), 463-6.
[6] Mills JH, Gilbert RM and Adkins WY (1979). Temporary threshold shifts in humans exposed to octave bands of noise for 16 to 24 hours. J Acoust Soc Am, 65(5),1238-48.
[7] IEC (2010). Medical electrical equipment. Part 2-33: Particular requirements for basic safety and essential performance of magnetic resonance equipment for medical diagnosis, IEC 60601-2-33:2010, Geneva, International Electrotechnical Commission.
[8] De Wilde JP, Grainger B, Price DL and Renaud C (2007). Magnetic resonance imaging safety issues including an analysis of recorded incidents within the UK. Progress in Nuclear Magnetic Resonance Spectroscopy, 51(1), 37-48.
[9] MHRA (2021). Safety guidelines for magnetic resonance imaging equipment in clinical use.
[10] Etzel RA, Balk SJ, Bearer CF, Miller MD, Shea KM and Simon PR (1997). Noise: A hazard for the fetus and newborn. Pediatrics, 100 (4), 724–727.
[11] Hepper P and Shahidullah B (1994). Noise and the foetus: A critical review of the literature. HSE Contract Research Report, 63.
[12] Reeves MJ, Brandreth M, Whitby EH, et al. Neonatal cochlear function: Measurement after exposure to acoustic noise during in utero MR imaging. Radiology 2010;257:802-809.
[13] Jaimes C, Delgado J, Cunnane MB, et al. Does 3-T fetal MRI induce adverse acoustic effects in the neonate? A preliminary study comparing postnatal auditory test performance of fetuses scanned at 1.5 and 3 T. Pediatr Radiol 2019;49:37-45.