

Sound-Level Measurements and Calculations of Safe Noise Dosage During EPI At 3 T

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This paper describes systematic methods for measuring and controlling sound levels within a magnetic resonance scanner. The methods are illustrated by application to the acoustic noise generated by a 3 T scanner during echoplanar imaging (EPI). Across five measurement sessions, sound pressure levels at the center of the head gradient coil ranged from 122 to 131 dB SPL [123 to 132 dB(A)]. For protection against damaging noise exposure, UK and US industrial guidelines stipulate that the maximum permitted daily noise dosage is equivalent to 90 dB(A) for 8 hours, where noise dosage is a function of the level of an acoustic signal and the length of exposure to it. Without hearing protection, this equivalent level would be exceeded by less than 5 seconds of exposure to the measured levels of scanner acoustic noise. These findings highlight the importance of noise reduction and hearing protection for those exposed to the acoustic noise generated during EPI. J. Magn. Reson. Imaging 2000;12:157–163. © 2000 Wiley-Liss, Inc.

Index terms: scanner acoustic noise; EPI; hearing; safety

THIS PAPER DESCRIBES appropriate methods for measuring sound levels and illustrates their application with measurements of acoustic noise generated by a scanner ("scanner acoustic noise") during functional MRI using echoplanar imaging (EPI) at 3 T. Industry guidelines are used as a starting point to define an acceptable noise dose for scanner acoustic noise in research. Practical methods of assessing and limiting noise exposure are also discussed.

The intense acoustic noise generated during MRI arises from interactions between the gradient coils and the magnet. Currents flowing through the gradient coils produce the small magnetic field gradients that are central to the formation of images. During the imaging sequence, the currents are rapidly switched in a complex pattern and, since this happens within a large magnetic field, Lorentz forces deform the gradient coils.

These abrupt movements translate into intense acoustic noise.

Intense sounds can damage hearing, and the effects of high sound levels are cumulative over time. In industry, hearing conservation programs and legislation now limit noise exposure to a safe level (1,2). Brummett et al (3) demonstrated that, without hearing protection, scanner acoustic noise generated during MRI was capable of inducing mild temporary hearing loss.

Scanner acoustic noise has been reported to be as intense as 115 dB(A) using EPI at 1.5 T (4). Counter et al (5) also made sound-level measurements from five MR scanners and reported levels up to 117 dB SPL, using linear frequency weighting and a peak measure. McJury et al (6,7) have also reported that levels generated by 1 and 1.5 T scanners can exceed safety guidelines unless ear protection is used. Maximum levels occur at the center of the scanner bore (4,8). However, Hedeén and Edelstein (8) have also observed that, with a subject in place, the sound level can be 3 dB above that measured in an empty bore. Very high-field scanners (3 and 4 T) are becoming more commonly used for functional MRI, and there is evidence that the sound level is greater than at 1.5 T. For example, Ravicz and Melcher (9) reported a peak level of 134 dB SPL at a 1.4-kHz gradient-switching frequency during EPI at 3 T. In addition, pulse sequences in development, such as echovolumar imaging (10), have the potential to generate even higher levels of scanner acoustic noise than current EPI techniques.

Noise reduction is required to attenuate the scanner acoustic noise to comfortable and safe levels. Ravicz and Melcher (9,11) have determined the efficacy of several noise reduction methods for attenuating noise transmission routes through the ear canal, head, and body to the inner ear. Passive methods predominantly include ear defenders and earplugs, which reduce air-conducted noise transmission through the ear canal. The acoustic attenuation of both ear defenders and earplugs combined, however, is less than the theoretical attenuation computed by the sum of each method alone, because the head and body are also effective transmission paths. To attenuate transmission through these bone-conducted pathways may require the use of foam helmets or even "whole-body pods" that could affect the safety and comfort of subjects and are

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therefore not necessarily practical solutions. We explored the less intrusive strategy of lining the bore of the scanner with acoustic foam, as a method of passive noise reduction. The efficacy of the foam relies on an acoustic impedance transition between the layers. This transition results in internal reflection, thereby effectively doubling the width of foam available for absorption of the acoustic energy. In principle, the foam reduces the contribution of sound reflected back to the center of the coil from the radial walls of the bore.

PROCEDURAL CHALLENGES AND DOSAGES

Challenges in Making Sound-Level Measurements

The sound measuring equipment must meet two criteria before the level of scanner acoustic noise can be measured safely and accurately. First, the equipment must be magnetically transparent. Second, steps must be taken to ensure that measurements reflect air-borne sound pressure rather than artifactually induced signals.

Electrical equipment may contain ferromagnetic components that are attracted by the static magnetic field, thus becoming dangerous projectiles. Equipment may also be damaged by high field strengths. It is therefore necessary to check the safety of the equipment with the manufacturer prior to its use near the scanner. In Europe, the equipment of choice for sound-level measurement and calibration is manufactured by Brüel & Kjær (DK-2850, Nærum, Denmark and 92, Uxbridge Road, Harrow, UK). The manufacturer, and also an independent UK national measurement laboratory (National Physical Laboratory, Teddington), were consulted about the safety of the measuring equipment.

The large and fluctuating magnetic and radiofrequency (RF) fields generated by MR scanners can present a second obstacle to measuring sound levels. Potentially, measurements could reflect not only air-borne sound, but also electrical signals induced by the time-varying magnetic fields of the scanner and by movements of the leads within static magnetic fields. To circumvent this problem, some researchers have adopted additional electromagnetic shielding of the microphone and amplification of its signal to measure levels with adequate sensitivity and accuracy (4,12,13). The method we describe has the advantage of not requiring additional electromagnetic shielding or amplification, as it uses a relatively sensitive microphone (47 mV/Pa) to give an acceptable signal-to-noise ratio in the measuring equipment and cables.

Safe Noise Dosages

Sound dosage and noise-exposure criteria are based on the principle that a higher sound pressure level is tolerable for a shorter period of time and that dosage "adds up" over the total exposure time. Guidelines and legislation in different countries (and as developed by different researchers) disagree on the precise nature of the tradeoff between the level of the acoustic signal and the duration of exposure to it. We summarize below the current industry guidelines for both the United Kingdom and the United States.

Table 1
Acoustic Noise During EPI at 3 T^a

Date	Notes	Sound level (dB SPL Fast)
April 1, 1998		127
November 16, 1998	New room	131
February 5, 1999		127
March 15, 1999	New coil	122
June 25, 1999		122
June 25, 1999	Foam lining	112

^aMeasurements were made at the center of the scanner head coil.

In industry in the United Kingdom, the maximum permitted sound dosage for daily exposure is effectively equivalent to continual stimulation at 90 dB(A), with an additional "peak action level" of 140 dB. The Noise at Work Regulations 1989 (1) express the measure in dB(A) for a daily 8-hour noise exposure. However, the Regulations recommend that hearing protection should be considered for levels above 85 dB(A). Calculations of maximum dosage use the equal-energy criterion, where an increase of 3 dB in level is regarded as equivalent to doubling the duration of exposure and hence doubling the sound dosage. For example, exposure to 90 dB(A) for 8 hours is regarded as equivalent to 93 dB(A) for 4 hours. An increase of 10 dB is equivalent to a 10-fold increase in sound dosage. For purposes of research with human volunteers, the MRC Institute of Hearing Research recommends a 10-dB more conservative criterion for daily exposure, expressed as 80 dB(A) 8-hour equivalent level, with the additional condition that no sound must exceed 120 dB(A) (14).

In industry in the United States, the maximum permitted sound dosage for daily exposure is also the equivalent of 90 dB(A) for 8 hours [Occupational Safety and Health Act (OSHA); 2], but calculations use the criterion that an increase of 5 dB in level may be regarded as equivalent to doubling the duration of exposure [eg, 90 dB(A) for 8 hours is regarded as equivalent to 95 dB(A) for 4 hours, etc.]. For leisure and nonoccupational noise, the more conservative criterion of 90 dB(A) for 1 hour is suggested (2), or 95 dB(A) for 30 minutes, etc. The US Food and Drug Administration has applied the OSHA guidelines to exposure to scanner acoustic noise and has stipulated a maximum permissible average level of 105 dB(A) (for 1 hour) and an overall maximum limit of 140 dB without ear protection (15). However, the International Electrotechnical Commission has specified a maximum permissible average noise level of only 99 dB(A) (16).

MATERIALS AND METHODS

The Scanner

The 3-T scanner used in the study was equipped with purpose-built gradient coils and a birdcage RF head coil. The scanner hardware and gradient coil designs are described by Bowtell and Mansfield and colleagues (17–19). Between measurement sessions, changes were made to the gradient coils and to the room in which the scanner was housed, as described in Table 1. However, essentially the same EPI signal for functional imaging

was used in all measurements of sound pressure levels. The EPI pulse sequence was a modulus blipped echoplanar single-pulse technique (MBEST). This sequence involves rapid sinusoidal-switching of a strong magnetic gradient to form a series of gradient echoes, each with a different degree of phase encoding, which can be reconstructed to form a single image. A set of such images was acquired using a clustered-volume acquisition (CVA) sequence (20). Using this method, 16 images were acquired in 1.07 seconds, with a quiet period before the next image acquisition, the length of which was determined by the chosen repetition time.

Sound-Level Measurements

Sound-level measurements were made with Brüel & Kjær equipment on five occasions over a period of 15 months. At the start of each measuring session, the measuring system was calibrated using a calibrator (type 4230), whose output is traceable to national standards of sound pressure level.

The sound-level meter (type 2235), which had the standard frequency weightings and time constants (21; type 1), was positioned about 5 m away to the side of the scanner, a point at which the static magnetic field was approximately 10 mT (100 Gauss). Only the microphone (type 4165, 12.7 mm, freefield response) and screened connecting cables (type AO 0128) were positioned within the scanner bore. The microphone was held in place by, and protruded 50 mm from, a foam block in the approximate center of the otherwise empty bore of the scanner head coil. For the measurements reported, the long axis of the microphone was aligned with the axis of the coil and was pointed toward the point that would be occupied by the top of the subject's head. Measurements were made to the nearest 0.1 dB but are reported to the nearest 1 dB, since readings within a measurement session generally replicated within ± 1 dB, but occasionally varied by up to ± 3 dB, including variation with cable placing. To minimize such variations, the microphone position was marked and the cable taped to a wooden ruler suspended along the bore. The microphone and cable positions were matched as far as possible from one measurement session to the next.

Sound pressure levels were measured in both dB SPL and dB(A) for the following reasons. The dB SPL scale incorporates a linear frequency weighting and is appropriate for reporting levels of signals that have a specific tonal content, as is the case with noise generated during EPI. The alternative dB(A) scale, however, is usually used for noise measurements and particularly for calculating sound exposure. The standard "A" weighting approximates the way in which the sensitivity of the human ear varies with frequency (21). Sound levels were measured on both scales with the standard "Fast" root-mean-square (RMS) time constant (125 msec) (21), which is appropriate in relation to safety guidelines. Levels were also measured using a "Peak" characteristic (a manufacturer-specified rise time, $< 100 \mu\text{sec}$ for this sound-level meter), which tends to give a higher measured level related to the short-term peaks in the signal. The "maximum hold" digital display on the sound-level

meter allowed the level for each CVA noise burst to be measured reliably despite its short duration. Background noise levels were also measured using the "Fast" RMS time constant.

Sound levels were measured without the RF signal, in order to minimize electromagnetic interference (4), although a few measurements made with the RF signal present showed no systematic differences in measured levels. To verify formally that measurements were of sound pressure level and not of electrical interference, measurements were taken with and without an acoustic cap placed over the microphone, a procedure that has also been used by Hedeon and Edelstein (8). The cap was constructed using a calibrator insert (type DB 0311) and a plastic dehumidifier cap. Provided that capping produces attenuation of 10 dB or more, any electrically induced signal must contribute less than 0.5 dB to the measured signal level (combining "signal" and induced "noise" levels using Eq. [2] below). In fact, the acoustic cap attenuated the level of the scanner sound by 24 dB or more and the background noise by 17 dB or more. Thus, interference artifacts made a negligible contribution to the measures reported below.

To study the temporal and spectral characteristics of the imaging signals, recordings of the acoustic waveforms were made from the sound-level meter onto digital audio tape (DAT) using a SONY DTC-690 recorder positioned in the scanner control room. For comparison, the electrical signals driving the three gradient coils were picked off at current-monitoring points, mixed, and recorded on the other channel of the DAT tape. The true relative levels (voltages) of the broadening, sinusoidally-switching, and slice-select electrical signals were not preserved on the recording since they were subsequently amplified by 20, 80, and 60 A/V, respectively, to drive the gradient coils.

Passive Noise Reduction

We also evaluated a method of passive noise reduction by installing a lining of FBF-1M acoustic foam (NetWell Noise Control, Minneapolis, MN, <http://www.asknetwell.com/>) around the gradient coils. This foam is a composite material that combines a 6.4-mm backing foam, a 2.5-mm dB-Bloc barrier PVC vinyl, and a 25.4-mm front-facing foam, but without an optional aluminized Mylar facing. The foam was positioned between the shim coils and the gradient coils with the front-facing foam placed toward the gradient coils (ie, toward the noise source).

RESULTS

EPI Sound Levels

Sound levels measured in the center of the bore using the "Fast" RMS time constant ranged from 122 to 131 dB SPL and from 123 to 132 dB(A) across the five different measurement sessions, as described in Table 1. Scanner acoustic noise levels changed from the range 127 to 131 dB SPL (in the first three sessions) to 122 dB SPL (in the last two sessions) following the installation of new gradient coils (18).

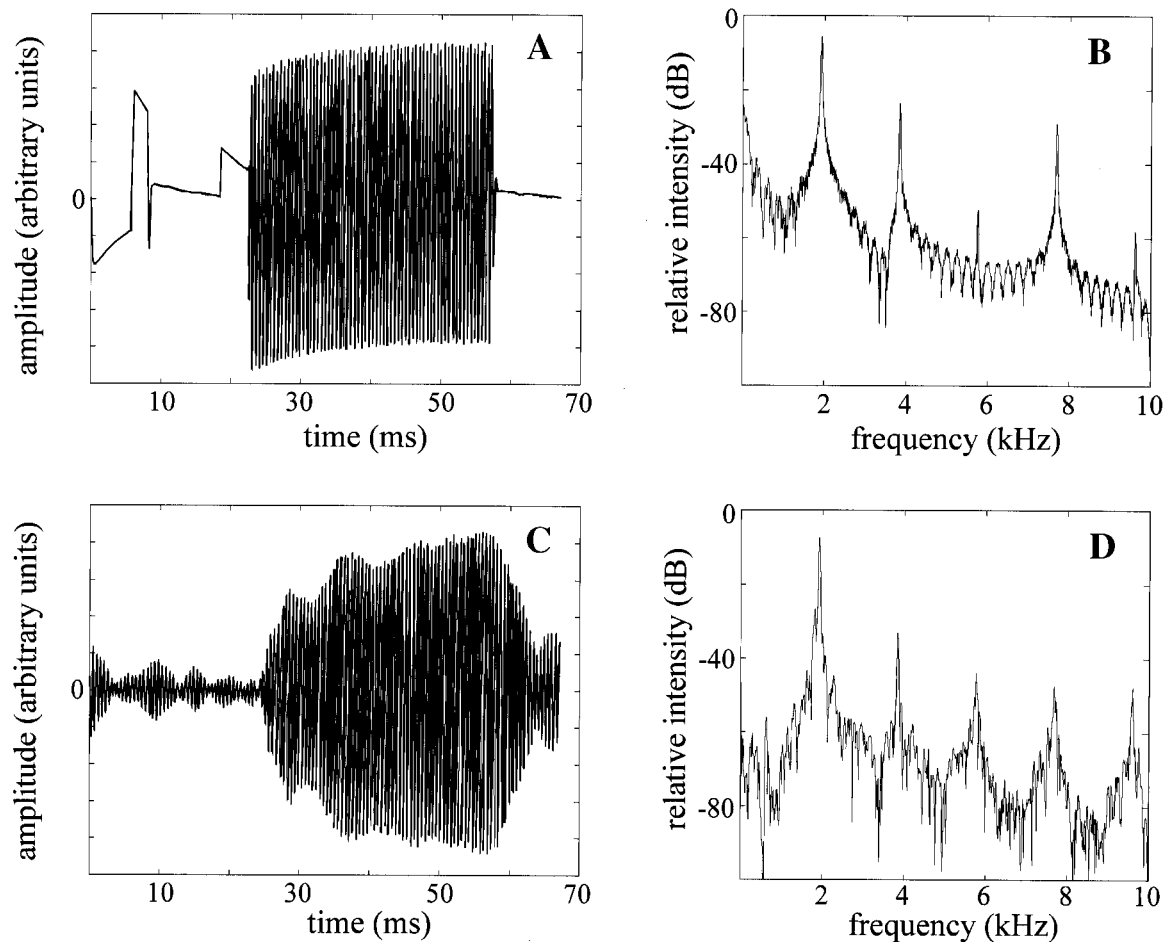


Figure 1. Temporal and spectral characteristics of the electrical driving signals to the gradient coils for a single image acquisition and of the concomitant scanner acoustic noise. **A:** Waveform of the electrical signal. **C:** Waveform of the acoustic signal. The electrical waveform shows the square-wave produced by the slice-select gradient followed by a complex sequence of driving signals generated by the sinusoidally-switching and broadening gradients. The acoustic waveform illustrates the system resonances that affect the envelope and duration of the waveform. **B:** Frequency spectrum of the electrical signal. **D:** Frequency spectrum of the acoustic signal. A peak in the frequency spectra occurs at about 1.9 kHz for both electrical and acoustic signals, with harmonics of significant intensity at about 3.8, 5.8, 7.7, and 9.6 kHz.

Levels measured in dB(A) were consistently 1 dB higher than those measured in dB SPL. This difference reflects the frequency response of the ear, where, at 1.9 kHz (the largest component of the EPI signal), the A-weighting is nominally +1.2 dB. "Peak" levels were consistently 8 dB higher (within ± 2 dB) than "Fast" RMS levels. This difference reflects the time-varying nature of the scanner acoustic noise where the peak predominantly reflects the sinusoidally-switching gradient amplitude. For comparison, a pure sinewave has a "Peak" level that is 3 dB higher than its "Fast" RMS level. A small set of measurements close to the ear position at the side of the head coil gave levels 3–10 dB lower than at the center position. Although these measurements were variable, this general finding is in agreement with previous reports that sound levels are greatest at the center of the bore (4,8,12).

The temporal and spectral characteristics of the EPI signal were evaluated by comparing the acoustic and electrical signals recorded on DAT tape. Waveforms and frequency spectra are shown in Fig. 1. The electrical

driving signals to the gradient coils (Fig. 1A) were precisely constrained in duration. In comparison, the acoustic waveform (Fig. 1C) contains echoes resulting from "ringing" and reverberation within the scanner and the room in which it is housed. The acoustic signal of the sinusoidally-switching gradient continued throughout the acquisition of each image and also for some time after the end of the 16-image volume, but with reducing amplitude. The prominent component of the acoustic signal was observed as a peak in the Fourier transform at 1.923 kHz (Fig. 1D). This frequency was generated by the sinusoidally-switching gradient and was also seen as a peak in the electrical signal (Fig. 1B). Currents through the slice-select gradient coil formed the initial square wave in the electrical waveform, and this component of the signal was audible as a low-frequency "knock." The broadening gradient generated a small triangular signal in the electrical waveform at each zero-crossing of the sinusoidally-switching gradient, reflecting the blipped phase encoding (not visible in the figure). When the sinusoidally-switching gradient

amplitude was reduced, the broadening-gradient amplitude was audible as a high-frequency component at 3.8 kHz (twice the switching frequency), and this peak can be seen in the acoustic frequency spectrum (Fig. 1D).

Background Noise Levels

During each session, sound-level measurements were taken in the center of the bore when the scanner was not in operation. Levels fluctuated slightly over the course of a session, and the convention of noting the lowest reasonably constant reading was adopted. Using the “Fast” RMS time constant, the ambient noise levels ranged from 63 to 68 dB SPL and from 45 to 48 dB(A) on different occasions after a new, smaller room with better fitting doors was installed around the scanner. The original scanner room included noise from the scanner power supplies and their air conditioning and gave higher levels in the region of 76 dB SPL and 63 dB(A). The background noise levels were comfortable and were low enough not to influence the scanner-sound measurements. Turning the lighting system transformers and fans off attenuated some components of the remaining background noise, but clearly the sources and levels of such background noise are specific to each imaging site. Knowledge of background noise levels is also important in calculating the effective signal-to-noise ratio at which acoustic stimuli are presented during auditory imaging experiments.

Passive Noise Reduction

The temporary lining of acoustic foam between the shim coils and the gradient coils reduced the scanner sound level at the center of the bore by 10 dB (from 122 to 112 dB SPL). No additional attenuation was gained by placing a foam lining between the gradient coils and the RF coil, or at the head and foot of the scanner bore.

Calculation of Safe Noise Dosages

The calculations described below are based on the UK noise exposure formula for equal energy (1; Eq. [1]), where higher levels can be used for shorter periods. The purpose of the calculation is to convert the measured level (L_M) and duration (T_M) into their “8-hour equivalent level” (L_{Aeq8h} , here denoted L_R), which can then be compared with the levels permitted in industry. An example is shown of the conversion based on the sound level and duration reported in this paper [127 dB SPL at 1.9 kHz, equivalent to 128 dB(A) with exposure for 264 seconds]. These parameters arise in a typical fMRI experiment in which 240 acquisitions are made of a 16-image volume, where each volume acquisition generates scanner acoustic noise lasting approximately 1.1 seconds:

$$L_R = L_M - 10 \times \log_{10}(T_R/T_M) \quad (1)$$

L_M is 128 dB(A) and T_M is 264 seconds. Setting T_R to 28,800 (the number of seconds in 8 hours) yields L_R as the 8-hour equivalent level in dB(A). In this example, L_R is 108 dB LAeq8h. This is 18 dB above the 90 dB LAeq8h adopted for industry in the United Kingdom

and 28 dB above the 80 dB LAeq8h that we apply in research.

DISCUSSION

In five separate sessions, the 3-T MR scanner generated EPI acoustic noise that ranged from 122 to 131 dB SPL [123 to 132 dB(A)], measured at the position that would be occupied by a subject's head. The measurement method was able to demonstrate that a difference of 5–9 dB between two different gradient coils (Table 1) was a systematic reduction, which was larger than the differences of a few dB between different measurement sessions. The waveform of the acoustic noise derived primarily from the input gradient waveforms that defined the imaging sequence (8). The level and spectrum of the noise depended on the amplitudes of the gradient currents and on their switching frequency, which in turn related to image resolution and the time per echo.

For the EPI sequence used in the present study, the relatively short time per echo resulted in a sinusoidally-switching frequency of 1.923 kHz applied to the switching-gradient coil. This frequency was the most prominent component of the acoustic signal. Within our relatively small range of resolutions (3–4 mm) determined by the amplitude of the sinusoidally-switching gradient, a systematic effect of gradient amplitude on sound level was not apparent. Informal measurements using considerably coarser resolution in the plane of the sinusoidally-switching gradient (and hence a lower switching amplitude) produced a materially lower sound level. As the technology of MR scanners develops further and permits ever finer image resolution, larger switching amplitudes could result in higher sound levels than those reported here. These developments will further increase the need for accurate measurement of noise levels to ensure that safe exposure is not exceeded.

Other acoustic properties of scanner noise, such as bandwidth and peak frequency, are also likely to be influenced by the mechanical resonances of the coil assemblies and by acoustic resonances related to the shape and dimensions of the scanner coils (22). Acoustic resonances lasted for a short duration after the electrical driving signal but with rapidly reducing amplitude, making the duration of the scanner acoustic noise approximately the same as that of the pulse sequence (1.1 seconds).

Calculation of Safe Noise Dosages

The sound levels generated during functional imaging using EPI at 3 T without hearing protection, as calculated above, would be excessive and could damage hearing over sufficient time. Less than 5 seconds of exposure to scanner acoustic noise would exceed the maximum dosage accepted in UK industry. Appropriate hearing protection should reduce the sound dosage to acceptable levels. For example, ear defenders typically provide about 35 dB of attenuation around 1.9 kHz and would, therefore, reduce the sound dosage in this case to the acceptable level of 73 dB LAeq8h.

The calculation does not allow for the contribution to the noise dose of any acoustic stimuli (eg, tones, noise, speech, or music) presented during the experiment. As an example, consider a 40-minute experiment in which a 16-image volume lasting 1.1 seconds is obtained every 10 seconds (ie, 240 volumes, as in the above example). Ten stimuli, each half a second in duration, are presented at a level of 85 dB(A) between 5 out of every 6 volumes. Thus, during a 40-minute experiment, subjects are exposed to 1000 seconds of the stimuli. Equation [1] shows that the 8-hour equivalent level of these stimuli is 70 dB(A). Equation [2] can then be used to calculate combined the 8-hour equivalent level, L_C :

$$L_C = 10 \times \text{Log}_{10}(10^{(L_N/10)} + 10^{(L_S/10)}) \quad (2)$$

where L_N is the LAeq8h of the scanner acoustic noise and L_S is the LAeq8h of the experimental stimuli. In the example, the combination of 73 and 70 dB(A) yields a dose of 75 dB LAeq8h. Although the increase over the dose from the scanner acoustic noise alone is only 2 dB, the importance of taking the experimental stimuli into account can be seen by considering the consequences of running several experiments in one day with the same subject. If the acoustic stimuli are not taken into account, Eq. [1] indicates that a subject could undergo four experiments before our adopted limit of 80 dB LAeq8h is approached. If the acoustic stimuli are taken into account, the criterion is approached after only three experiments. Thus, both the acoustic stimuli and the scanner acoustic noise should be taken into account in deciding whether a planned experiment risks exposing subjects to an unacceptable noise dosage.

Methods for Noise Reduction

By reducing noise transmission through the ear canal, ear defenders can make a material contribution to the safety of subjects participating in fMRI studies, particularly at the high sound levels reported at 3 T. Ravicz and Melcher (9,11) have evaluated the combined benefits of ear defenders and earplugs. At 1.9 kHz, both acoustic and behavioral measurements showed that ear defenders and earplugs each separately provided about 35 dB of attenuation. However, in combination, ear defenders and earplugs provided only about 55 dB of attenuation measured acoustically and only about 45 dB measured behaviorally. Ear defenders and earplugs together reduce noise transmission through the ear canal so that almost all the residual noise heard by the subject is transmitted through the head and body directly into the middle and inner ear.

Additional energy may be transmitted to these sites from vibrations of the scanner bed, or if the subject's head or body are in contact with the scanner casing. Hence, although it is worth using both ear defenders and earplugs, the combined protection is less than the sum of their individual contributions because the bone-conduction pathway becomes dominant once the air-conduction pathway has been attenuated by 45 dB or so in the region of 1–2 kHz (23). However, when conducting auditory fMRI, the use of earplugs is likely to affect the quality of any acoustic stimuli and moreover

puts the subject at risk from the high levels at which such stimuli may need to be delivered in order to overcome the attenuation afforded by the earplugs. The frequency response of the earplugs affects stimulus quality since earplugs attenuate high frequencies more than low frequency signals [eg, 31 dB protection at 2 kHz and 18 dB at 125 Hz; manufacturer's data for E.A.R. plugs (Acero Limited, First Avenue, Poynton, Cheshire, UK)]. Experimenter control of the presentation level is also reduced, since the fitting of earplugs, and hence their efficacy, generally varies across subjects.

Because of these limitations, it would be advantageous to reduce scanner acoustic noise at the source. Commercial coil design has not yet been successful in addressing the problem of scanner acoustic noise, although this problem has been addressed, with some beneficial effect, in a research setting (24). The preliminary measurements reported in the present paper and by Ravicz et al (25) suggest that noise levels can be materially reduced by the installation of acoustic foam around the gradient coils. Further work is now required to maximize the attenuation that can be achieved.

RECOMMENDATIONS

1. Subjects and experimenters should be aware of the potential damage to hearing from the sound field generated within, and in the vicinity of, MRI scanners.
2. Subjects should always wear ear defenders. If the experiment permits, they should also wear earplugs.
3. Reduction of sound levels at source (in scanner design) and by passive attenuation should be explored further.
4. Scanner acoustic noise should be measured appropriately, and careful consideration should be given to ensuring that the noise exposure is within safe limits.
5. It should be verified that the sound-level measuring equipment works safely and reliably in the static and dynamic magnetic fields generated by the scanner. Specifically, measures should be taken with and without an acoustic cap over the microphone to verify that sound-level readings are sufficiently above any "noise" induced in the equipment or the connecting cables.
6. No subject or experimenter should subject themselves to more than the maximum noise dose recommended or permitted in the appropriate guidelines or legislation. We recommend a maximum noise dose of no more than 80 dB LAeq8h.

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