자기 공명 영상법에서의 소음 분석에 관한 연구

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Study on Analysis of Acoustic Noise in MRI

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ABSTRACT

Acoustic or sound noise due to gradient pulsing has been one of the problems in MRI, both in patient scanning as well as in many areas of psychiatric and neuroscience research, such as functional MRI (fMRI). Our recent observations in fMRI for the visual and motor cortex show very different results with sound noise in comparison with the results obtained without sound noise. Although a number of ideas has been suggested in the literature about the possible elimination or reduction of sound noise, progress has been slow due to the basic role of gradient pulsing in MR imaging. Therefore, we report on some typical behavior of sound noise observed from MRI scanners and the analyses of their characteristics. Data are obtained both from a commercial MRI scanner (GE Signa 1.5-T EPI system).

INTRODUCTION

The basic gradient pulsing in conjunction with the magnetic field in MRI produces what is called acoustic or sound noise. Ever since the appearance of clinical MRI scanners, it has been one of the most disturbing obstacles for MRI patient scanning, especially for psychiatric patients and small children (1, 2, 3). There have been some attempts to reduce sound noise by using the anti-phase noise-cancellation technique (3, 4) and the Lorentz-force-cancellation technique (5, 6). Most of these techniques have not been very successful and significant sound noise still remains. A simpler and perhaps more widely used technique is the use of ear plugs but this method seems to protect only against sounds transmitted by the auditory canal to the ear and does not protect against sound or acoustic transmission to the brain either directly or indirectly through the body structures i.e., bones in the skull. In fact, we still experience loud sound noise even after wearing ear plugs since ear plugs suppress only the high-frequency sound noise within the audible frequency band (4).

With the increasing role of MRI in the fields of research such as the neural and cognitive sciences, it has become apparent that sound noise is one of the serious noise sources in the measurement of subtle changes in the oxygenation status in the cortex and blood capillaries (7, 8). Although some studies have been reported, it is felt that a more quantitative physical analysis of sound noise produced by recently available MRI systems would be an important asset for future research on this important problem, especially in connection with the newly developing fMRI and other cognitive science research. In this paper, we report on a few typical sound-noise profiles and spectra collected from a typical commercial whole-body MRI scanner (GE 1.5-T EPI).

METHOD OF MEASUREMENTS AND EXPERIMENTAL RESULTS

1. Method of Measurements

To measure the acoustic or sound noise in an MRI scanner setting, we have installed a non-magnetic microphone(Sun microphone, Sun Microsystems Computer Corporation, USA.) near the rf head coil (see Fig. 1). The output of the microphone signal was coupled to an IBM PC via a 16-bit ADC plug-in card(Creative Labs, Inc., Singapore) with 44.1-kHz sampling for digitization and recording. To calibrate the sound noise levels more quantitatively, a sound-level meter was also used since the recorded sound noise retained no information on sound levels but only sound noise profiles. We found acoustic or sound noise levels that were observed with a sound meter for various pulse sequences are similar to those of several previously reported measurements. A variety of pulse sequences were then tested and compared, both the signal profiles or shapes and their corresponding spectra. The pulse sequences tested were: *Prescan, Spin-Echo, Gradient-Echo, and EPI (Echo-Planar Imaging)*. For reference, we recorded the sound noise *at rest*, which includes the pumping noise of liquid-helium recycling in the case of the commercial scanner. The parameters used for each sequence are shown in Table 1. Each sound noise

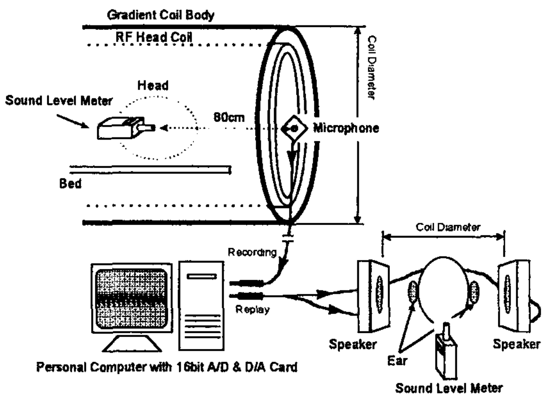

Fig. 1: Experimental setup for the acoustic noise measurement with which both sound levels and profiles are measured and recorded.

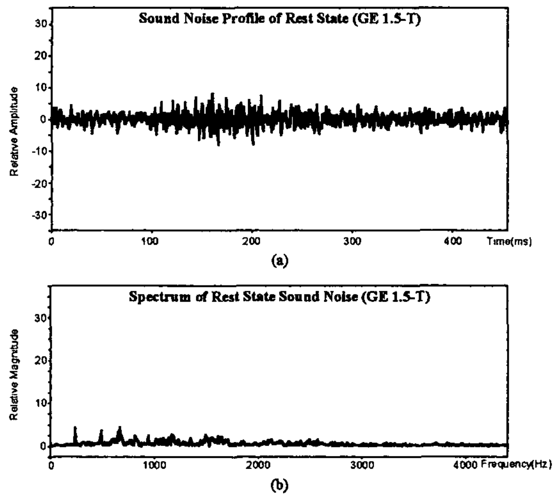

Fig. 2: Rest-state sound-noise profile and its spectrum obtained from a GE 1.5T scanner (a) Sound-noise profile (b) Sound-noise spectrum.

signal or profile was then Fourier transformed to visualize its corresponding frequency spectrum. The profiles shown in Figs. 2 through 6 are used for the FFT to produce corresponding frequency spectra. The relationship of the spectral magnitudes obtained from the FFT of the noise data to the pain threshold curves of hearing can be used to estimate the expected disturbance to the patients.

2. Experimental Results

The acoustic or sound noise of various pulse sequences were measured and analyzed. The first measurement was made on the GE 1.5-T scanner at rest. The sound noise was already loud, even without any imaging pulse sequence. The sound-noise level measured at rest by the sound-level meter was about 80 dB (C mode or linear mode). This noise was mostly from the helium recycling pump. In Fig. 2, a noise profile or signal shape of the sound noise of the GE scanner at rest and its corresponding spectrum are shown. The sound-noise spectrum appears concentrated in the frequency range of about 550 Hz, but there was scattered noise around 1100 Hz and up to 2750 Hz.

a. *Prescan Sequence*

The next measurement was the *prescan* sound-noise spectrum and its profile obtained from the GE 1.5T scanner as shown in Figs. 3(a) and (b). The *prescan* sound-noise spectrum shows a frequency distribution widely scattered over the entire spectral range up to about 4000 Hz. The peak spectral amplitudes in the vicinity of 2400 Hz are especially large compared with other imaging sequences and many smaller peaks are also found in the spectral range around 550 Hz. Prescan noise was found to be the noisiest(loudest) among the pulse sequences so far tested.

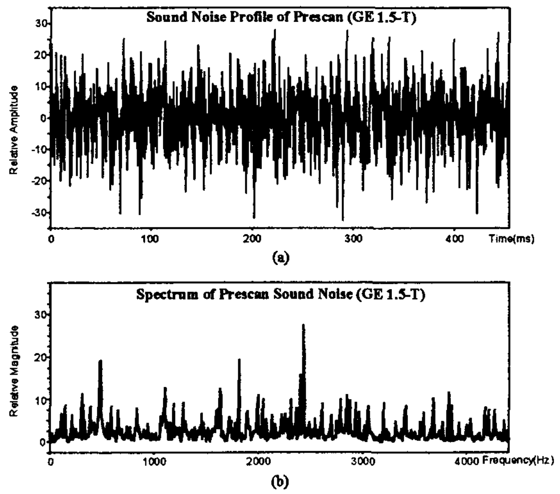

Fig. 3: Prescan sound-noise profile and its spectrum obtained from a GE 1.5T scanner (a) Sound-noise profile (b) Sound-noise spectrum.

b. *Spin-Echo Sequences*

The sound-noise profile and its spectrum of the *spin-echo sequence,* the most commonly used sequence, was obtained from the GE 1.5-T scanner and are shown in Fig. 4. Sound noise of the *spin-echo sequence* is not only substantially smaller in its peak amplitude compared with the *prescan sequence* sound noise, but its spectrum also shows quite different characteristics.

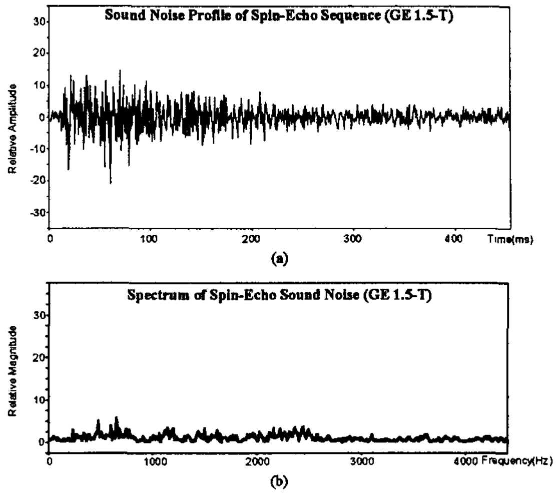

Fig. 4: Spin-Echo sequence sound-noise profile and its spectrum obtained from a GE 1.5T scanner (a) Sound-noise profile (b) Sound-noise spectrum.

c. *Gradient-Echo Sequences*

Shown in Fig. 5 is the sound-noise profile and its spectrum of the *fast gradient-echo sequence* obtained from the GE 1.5-T scanner. The spectrum of this *fast gradient-echo sequence* appears to be somewhat similar to that of the *spin-echo sequence,* but is much larger in amplitude.

d. *EPI (Echo-Planar Imaging) Sequence*

In Fig. 6, the sound noise profile and its spectrum of an *EPI sequence* obtained from the GE 1.5-T scanner are shown. As expected, a large sound noise of a short duration is observed. The frequency spectrum of this sound noise appears quite different from the others, showing many discrete frequency peaks spread all over the spectrum.

All the sound noise intensities of these pulse sequences are also measured by the sound-level meter (TES-1350) and they are presented in Table 1.

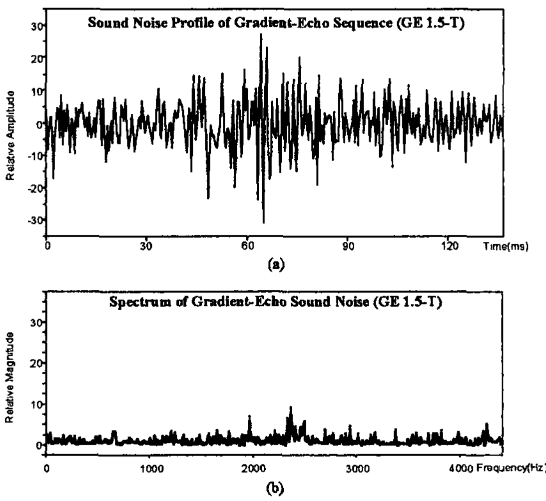

Fig. 5: Gradient-Echo sound-noise profile and its spectrum obtained from a GE 1.5T scanner (a) Sound-noise profile (b) Sound-noise spectrum.

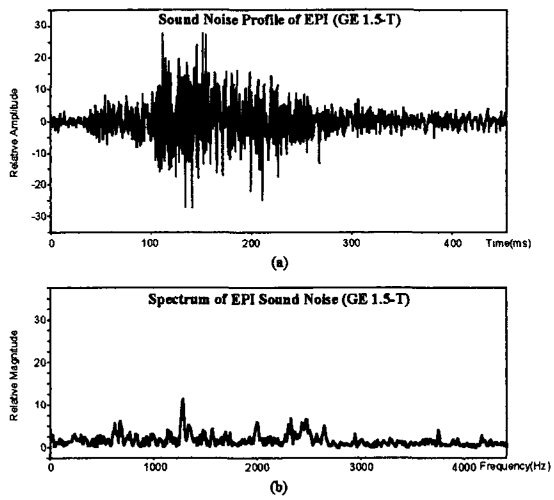

Fig. 6: EPI sound-noise profile and its spectrum obtained from a GE 1.5T scanner (a) Sound-noise profile (b) Sound-noise spectrum. Note relatively short and intense profiles.

DISCUSSIONS AND CONCLUSIONS

Through the analysis of acoustic noise, we find that the acoustic noise profiles and their frequency distributions are not only dependent on the pulse sequence employed but also are greatly dependent on the types of scanners, especially the coil structures and their supports. It appears that acoustic noise in MRI can be reduced by two approaches: one is the redesign of the gradient coil system currently employed in MRI scanners with an appropriately modified structure (or support) to tailor the sound noise profiles so that it becomes more amenable to the elimination of sound noise, for instance, by using the anti-phase noise cancellation (5), and the other is the development of new imaging sequences which are quieter than those currently employed.

The latter choice would involve the use of a new MR imaging sequence which has no gradient pulsings.(9, 10) Fortunately, since only two gradients among the three, namely, the phase-encoding (-y), and frequency-encoding (-x) gradient pulsings are the main noise sources (provided trans-axial imaging is used), it appears that the two major noise sources can effectively be eliminated if one eliminates the two gradient pulsings, namely x- and y-gradient pulsings. Test results show that the sound-noise level without these two gradient pulsings (namely, the x- and y-gradient pulsings) appears to be nearly identical to that of the rest state, indicating that the elimination of these two sound sources is the key solution to developing a "*Silent MRI*". It seems clear that future research on sound noise reduction should be directed at the elimination of these two gradient pulsings.

Table 1. Acoustic Noise Measurements of Pulse Sequences with Typical Parameters

Pulse Sequence	C mode (dB)
At Rest(He Recycling) (GE 1.5T)	79.5
Auto Pre-Scan (GE 1.5T)[i]	100.0
Spin Echo (GE 1.5T)	98

Gradient Echo (GE 1.5T)	103.5
EPI (GE 1.5T)	103.2
Spin-Echo (KAIS 2.0T)[ii]	77.1

i. There are four Pre-Scan sequences in the GE 1.5T scanner, namely, auto Pre-Scan, manual Pre-Scan, prefer Pre-Scan and Pre-Scan.

ii. Spin-Echo Sequence without x- and y-gradient pulsing

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