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MEASUREMENT AND EVALUATION OF THE ACOUSTIC NOISE OF A 3 TESLA MR SCANNER

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ABSTRACT

We measured the sound level and frequencies of the acoustic noise generated by a 3 Tesla (T) MR scanner, and investigated the subjective sound level for 30 healthy volunteers with either earplugs, headphones or both. The sound level of 3T was found to be higher than that of 1.5T in all sequences. The peak sound pressure level of 3T ranged from 125.7 dB for MR angiography to 130.7 dB for single shot EPI on the linear scale. The equivalent noise level was from 110.0 dB for FLAIR to 115.8 dB for T1-IR on the A-weighted scale, which exceeded 99 dB, the level regulated by the International Electrotechnical Commission (IEC). The study of the subjective sound level showed that the effect of noise reduction was not significantly different between earplugs and headphones. However, the use of both devices could reduce the subjective sound level significantly better than either one alone ($P<0.01$). Thus we propose wearing both devices for ear-protection during 3T examinations.

Key Words: Magnetic resonance (MR), Acoustic noise, 3 Tesla MR

INTRODUCTION

As acoustic noise during MR exams not only makes communication with patients difficult and causes them discomfort, but can also induce transient or permanent hearing disturbance, it is important to take protective measures.[1,2] In particular, patients who have taken some drugs such as aminoglycoside or cisplatin may suffer an increased risk of inner ear damage.[3,4] In addition, the noise poses a hazard for pediatric patients who need sedation and for activation study patients subjected to functional MRI. The current mainstream status of clinical MRI is shifting from 1.5T to higher field scanners. Thus, since continuous attempts to improve the diagnostic quality of MRI require a higher static field and high-speed gradient switching, the attendant acoustic noise has become a matter, deserving of serious consideration.

Given such circumstances, trials should be undertaken to measure the objective acoustic noise level and categorize the subjective noise level in order to accumulate the quantitative data needed for comparison. Moreover, it should prove useful to optimize ear protection methods and suggest the best strategy to implement them.

In this study, we tried to clarify the relationship between the measured noise level and the subjective noise level by showing the results of noise measurements and of the frequency analysis of several representative pulse sequences. We also sought to determine the optimum ear

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protection method during 3T.

MATERIALS AND METHODS

A 3T MR scanner, Medspec S-300 (Bruker Inc., Germany) and a 1.5T MR scanner, Visart Ex (Toshiba Inc., Tokyo, Japan) were used for the study. A transmit and receive quadrature head coil was used for each scanner. The gradient coil was an asymmetric head only insert coil for 3T and a whole body coil for 1.5T. A noise meter type NL-18 (RION Inc., Tokyo, Japan) and a digital oscilloscope type TDS3052 (Tektronix Inc., USA) were used for measurements which were performed according to the basic setup mode of the International Electrotechnical Commission (IEC) 60601-2-33.[5)]

Noise measurement experiment

A microphone was positioned at the anatomical ear site of a patient's head. Pulse sequences measured included Spin Echo T1-weighted (SE-T1), Fast Inversion Recovery T1-weighted (FIR), Fast Spine Echo T2-weighted (FSE-T2), Fast Fluid Attenuated Inversion Recovery (FLAIR), Single Shot Echo Planar Diffusion Weighted (SSEPI-DW), and 3-Dimensional Time-Of-Flight MR Angiography (MRA). The scan parameters employed were those of routine clinical examinations and are shown in Table 1. For both scanners, the equivalent noise level (on the A-weighted scale) and the peak sound pressure level (on the linear scale) were measured for 20 seconds for each pulse sequence. The alternative current output from the noise meter was transferred to the digital oscilloscope in order to analyze the frequency of digitized sound data.

Subjective noise evaluation

Thirty normal volunteers were sent into a gantry without ear protection to hear the baseline noise using a 2-Dimensional Field Echo (2D-FE). Then they stayed on to hear the noise of each pulse sequence first with earplugs, then with headphones and lastly with both devices. They were then asked to score one-by-one the points of subjective noise levels using the baseline noise as a standard of 100 points. They heard the gradient noise of each pulse sequence in the following order; SE-T1, FIR, FSE-T2, FLAIR, SSEPI-DW, MRA. Each noise was transmitted to the volunteers immediately after they heard the noise of 2D-FE as a reference, and they were asked to respond with a subjective score of each noise compared to the 2D-FE noise.

Table 1 MR Imaging parameters used in evaluation of acoustic noise during MR imaging

	SE-T1	FIR	FSE-T2	FLAIR	SSEPI-DW	MRA
TR (msec)	460	4000	4000	9774.5	6502.242	35
TE (msec)	14	45.2	80	120	119.1	8
FOV (cm)	23*23	18*18	20*20	20*20	25*50	15*15
Matrix	256*192	384*256	512*384	384*224	128*256	384*256

TR=repetition time, TE=echo time, FOV=field of view

RESULTS

For all pulse sequences, the noise level of 3T exceeded that of 1.5T (Table 2). The peak sound pressure level of 1.5T ranged from 101.8 dB for SE-T1 to 111.7 dB for SSEPI-DW. The peak sound pressure level of 3T ranged from 125.7 dB for MRA to 130.7 dB for SSEPI-DW. And the equivalent noise level of 1.5T ranged from 89.1 dB for FIR to 99.6 dB for SSEPI-DW.

Table 2 Sound levels generated by 3T and 1.5T MR scanners

	3T	3T	1.5T	1.5T
	Lpeak	Leq	Lpeak	Leq
SE-T1	126.0	112.8	101.8	90.0
FIR	128.1	115.8	103.4	89.1
FSE-T2	126.8	114.4	104.2	92.2
FLAIR	128.0	110.0	104.4	89.9
SSEPI-DW	130.7	112.9	111.7	99.6
MRA	125.7	112.5	107.3	92.3

Lpeak=peak sound pressure level (dB),
Leq=equivalent noise level (dB)

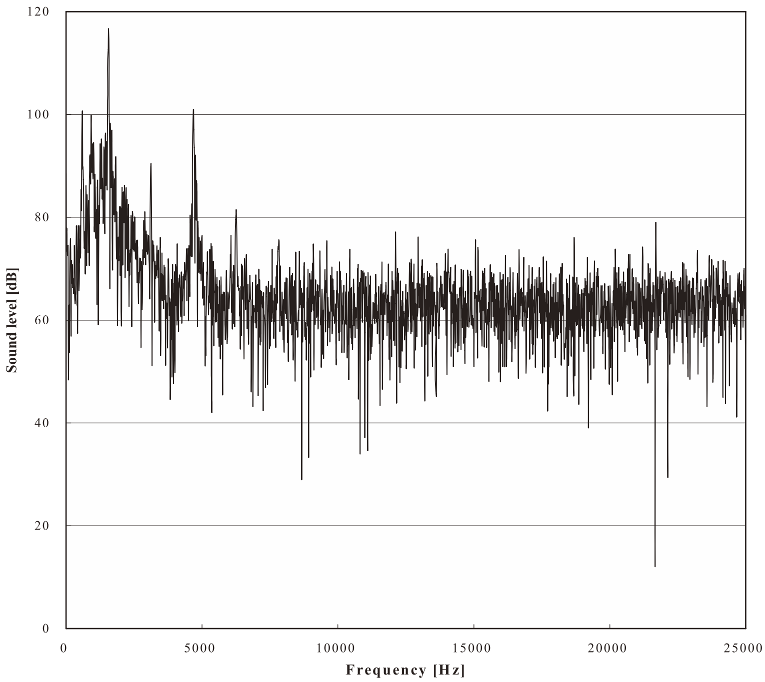

Fig. 1 Spectral content analysis for single shot EPI sequence. Specific noise peaks were found at 600, 900, 1550, 3200, and 4700 Hz. The wave shape was composed of the basic frequency of 1550 Hz and the second and third harmonics frequencies.

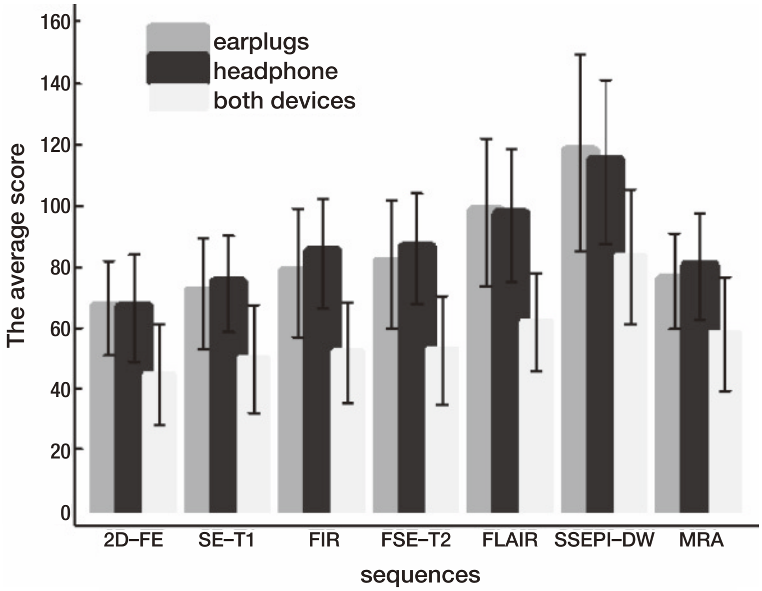

Fig. 2 Graphic display of Subjective sound level

Moreover, the equivalent noise level of 3T ranged from 110.0 dB for FLAIR to 115.8 dB for FIR. Fourier analysis of the spectral content showed a band of acoustic energy with spectral peaks from about 0 to 9 kHz during SSEPI-DW that was wider than those of the other sequences with peaks from about 0 to 4 kHz. For SSEPI-DW specific noise peaks were found at 600, 900, 1550, 3200, and 4700 Hz. The wave shape was composed of the basic frequency of 1550 Hz and the second and third harmonic frequencies (Fig. 1).

The subjective sound evaluation experiment revealed that SSEPI-DW was the noisiest pulse sequence, followed by FLAIR and FIR. The result of a multi-variant comparison showed no significant difference in the effect between earplugs and headphones. However, the simultaneous use of both devices delivered significantly better subjective protection for all pulse sequences compared to that of earplugs alone or headphones alone (P<0.01) (Fig. 2).

DISCUSSION

Although so far several reports have been published concerning hearing protection based on western guidelines and legislations, none dealing with subjective noise evaluation has emerged. This will be the first report that analyzes the relationship between measured sound levels or frequency spectra and the subjective noise level at 3T. In addition, we tried to devise a recommended ear protection strategy based on our measurements.

The first report on gradient noise done by Hurwitz *et al.*, showed that the peak sound pressure level at 0.35 to 1.5T ranged from 82 to 93 dB on the A-weighted scale and from 84 to 103 dB on the linear scale, all of which were within the regulatory limits of the Occupational Safety and Health Administration; OHSA.[6] Some of the following reports described that the peak sound pressure level reached as high as 103 to 115 dB on the A-weighted scale at 1.5T.[7-9] In a recent report, since the super high-field MR scanners and EPI have emerged and required a high power gradient system, the peak sound pressure level of EPI at 3T has reached 118.3 dB on the A-weighted scale.[10)]

In the current study, the measured sound levels were not higher than those of previous reports at 1.5T but higher at 3T. The sound level at 3T was also significantly higher than that at 1.5T in all pulse sequences. The maximum sound level was observed in single shot EPI in both field strengths, which was compatible with the fact that the Lorenz force is proportional to the gradient amplitude. Though the peak sound pressure level was less than 140 dB, the regulation limit set by IEC, the equivalent noise level was higher than the IEC limit of 99 dB in all pulse sequences. This result suggests that at 3T, ear protection is essential for all pulse sequences.

According to the frequency analysis, the frequency range of 0-4 kHz for the sequences other than single shot EPI was compatible with the results of 0.2 to 2 kHz or 0.2 to 5 kHz described in previous reports by Counter *et al.*[9,11)] On the other hand, the frequency of single shot EPI ranged in a broad spectrum from 0 to 9 kHz. There has been no quantitative sound data published concerning single shot EPI.

In most of the pulse sequences, the sound peaks were observed between 0 and 4 kHz, especially in the frequency range bellow 2 kHz. This indicates that [dB(linear)], which is calibrated by linear specification, is better than [dB(A)], which is calibrated by A specification that tends to underestimate the sound level at a lower frequency for gradient noise evaluation.

The subjective noise evaluation revealed that the subjective sound level is well correlated with the peak sound pressure level but shows no significant correlation with the equivalent noise level. This might have something to do with the above-described frequency spectrum characteristics of gradient noise. In addition, the average of the subjective noise level for FIR was significantly higher than that of FLAIR even though these two both showed comparable peak sound levels. This is possible because the subjective noise level is reflective of the total amount of a partial sound.

As the noise meter adds all of the energy of each frequency-calibrated sound element, the measured noise level cannot always match the level actually perceived. This means that acoustic safety is not necessarily guaranteed if the measured sound level was within the regulation limit. As the considerable gradient noise during a MR exam may cause patients anxiety or an adverse psychological reaction,[12)] the current study evaluated the subjective noise and the ear protection devices should be noteworthy. As the published data of the noise reduction of 3M-earplugs were 34.3 to 44.4 dB within the specific frequency range, the use of earplugs alone may theoretically satisfy the IEC regulation limit. However, our evaluation study of subjective noise revealed that earplugs or headphones alone did not provide a sufficient noise-reduction effect. Thus, we recommend the use of both devices simultaneously during 3T MR exams.

CONCLUSION

The gradient noise level from a 3T MR scanner exceeded the regulatory limit of the equivalent noise level of 99 dB in all pulse sequences. Therefore, the use of proper ear protection devices is essential. Our subjective noise evaluation revealed that the simultaneous use of both earplugs and headphones is recommended during 3T use.

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