The Influence of MR Gradient Acoustic Noise on fMRI

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MR acoustic sound or noise due to gradient pulsings 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 brain fMRI. Especially in brain fMRI, sound noise is one of the serious noise sources which obscures the small signals obtainable from the subtle changes occurring in oxygenation status in the cortex and blood capillaries. Therefore, we have studied the effects of acoustic or sound noise arising in fMR imaging of the auditory, motor and visual cortices. The results show that the acoustical noise effects on motor and visual responses are opposite. That is, for the motor activity, it shows an increased total motor activation while for the visual stimulation, corresponding (visual) cortical activity has diminished substantially when the subject is exposed to a loud acoustic sound. Although the current observations are preliminary and require more experimental confirmation, it appears that the observed acoustic-noise effects on brain functions, such as in the motor and visual cortices, are new observations and could have significant consequences in data observation and interpretation in future fMRI studies.

Index words : fMRI, acoustic sound or noise effects on ; fMRI ;
fMRI on motor, visual, and auditory stimulation

Introduction

The susceptibility or blood oxygenation level dependent (BOLD) effect can be exploited to provide activation maps of the human brain by MRI when performing various tasks (1—11). In fMRI, however, acoustic or sound noise due to gradient pulsings has been a problem, unlike in the case of conventional MR Imaging (12—14). The sound level of the conventional gradient echo (CGE) sequence, which is most widely used for fMRI, is often as large as 100dB or more and shows peaks at about 500Hz (see Fig. 1(a)) (15). Similarly, the sound level of the echo-planar-imaging (EPI) sequence is also found to be over 100dB in the C mode and shows many discrete frequency peaks spread over the entire spectrum (see Fig. 1(b)) (15). It appears that above 1KHz, the simple passive ear protection is efficient. Below 1KHz, however, simple passive ear protection may be insufficient to bring sound noise levels down to a safe limit (16). Therefore, simple passive ear protection is no longer sufficient for obtaining an accurate fMRI response (16). Possible effects of the loud sound noise for research subjects are many and may in-

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clude the exhaustion of brain cognitive function which may reduce the sensitivity of the response during brain activation. Some of the signal fluctuation in the fMRI are believed to be originated from the unwanted stimulation of auditory pathways in the brain. Therefore, it was felt that the systematic study of acoustic noise effects on fMRI would be of interest for future endeavours in the areas of fMRI. We report the results of preliminary tests on the effects of acoustic noise in fMRI for various cortical responses due to auditory, motor and visual stimuli, either separately or in combination with other stimuli.

Methods

Experiments were carried out using the conventional gradient echo (CGE) sequence with the KAIS 2.0T whole-body MRI system. Healthy human volunteers (five volunteers, ages = 22 – 30 years) were studied for motor and visual stimulation. The volunteer was positioned and secured in the standard head coil to avoid misregistration artifacts. Initially for each fMRI experiment, an inversion-recovery T1-weighted image was obtained for the anatomical reference. For the experimental study, a repetition time of 60msec., an echo time of 27msec., a flip angle

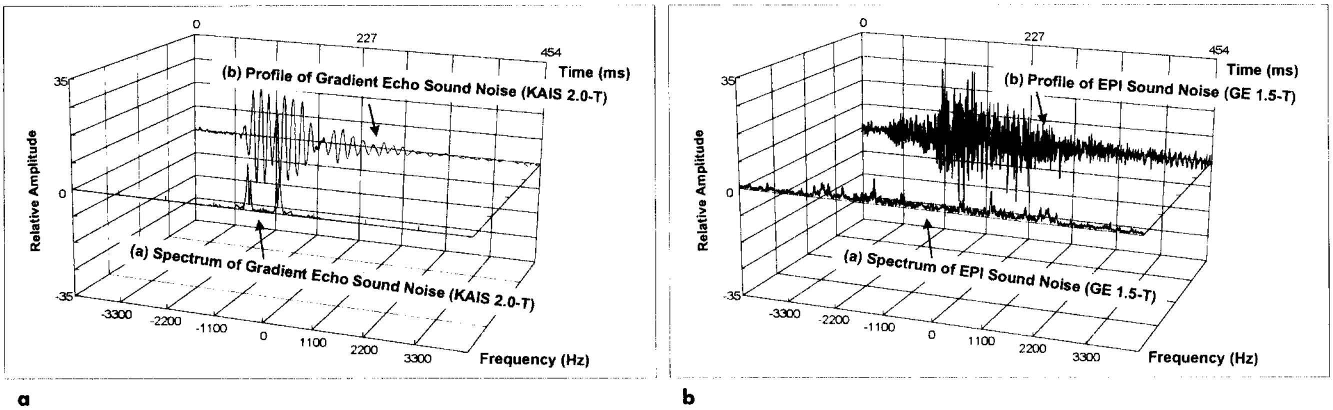


Fig. 1. a. Gradient-Echo sequence sound-noise profile and its spectrum obtained from a prototype research scanner (KAIS 2.0T). **b**. EPI sequence sound-noise profile and its spectrum obtained from a GE 1.5T scanner.

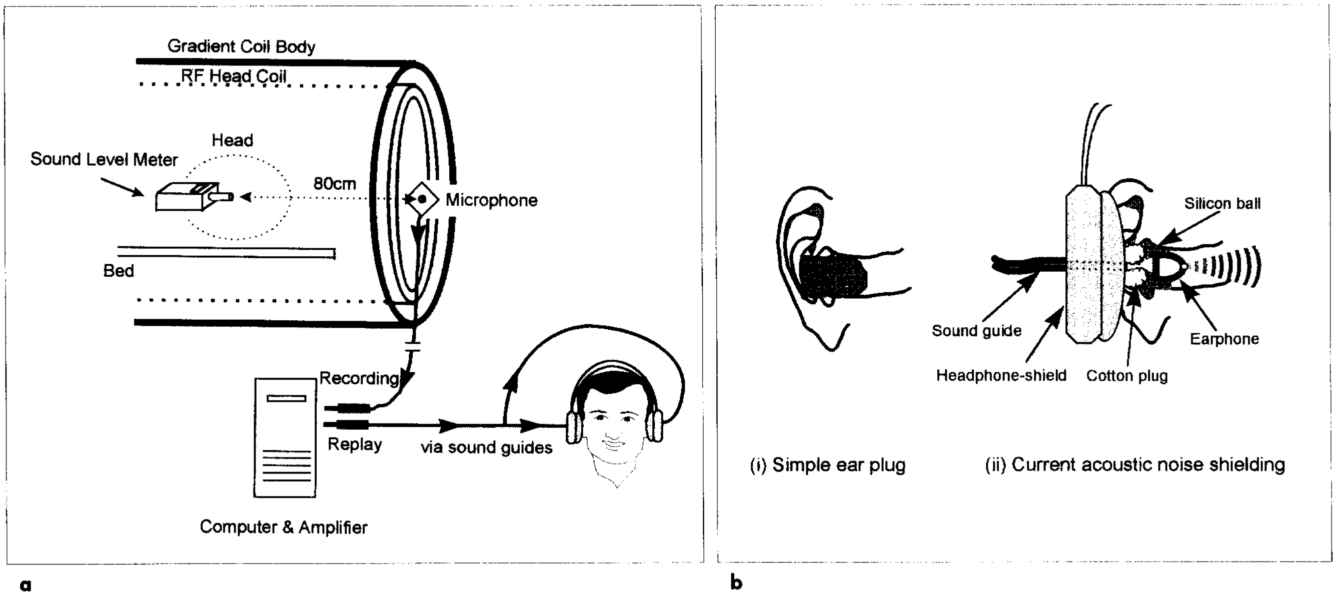


Fig. 2. Detailed setting of the experiments. To record the acoustic or sound noise in an MRI scanner setting, we have installed a piezo-electric microphone (Sunmicrophone, Sun Microsystems Computer Corporation, USA.) near the rf coil which is placed at the middle of the gradient coil set and the output of the microphone is then recorded and sound levels are monitored by a sound meter. Sound is then reproduced on headphones and compared with actual sound levels experienced by the volunteer while he or she was in the scanner.

of 40°, a FOV of 220mm, a slice thickness of 10mm, and a total acquisition time per image of 10 seconds were used. To verify the sound noise effect, two sets of experiments were performed for each cortical stimulation. To ensure an acoustic noise free situation, an elaborate acoustic shield was made by silicon balls in the ears and additional headphone sound shield as shown in Fig. 2(b). This elaborate acoustic shield was found to be effectively attenuating the acoustic sound (due to gradient pulsings) as much as 20dB at near 500Hz. This condition is designated as a case without (W/O) acoustic noise. The second case with (W) acoustic noise was made under the same acoustic shielding as the first, but

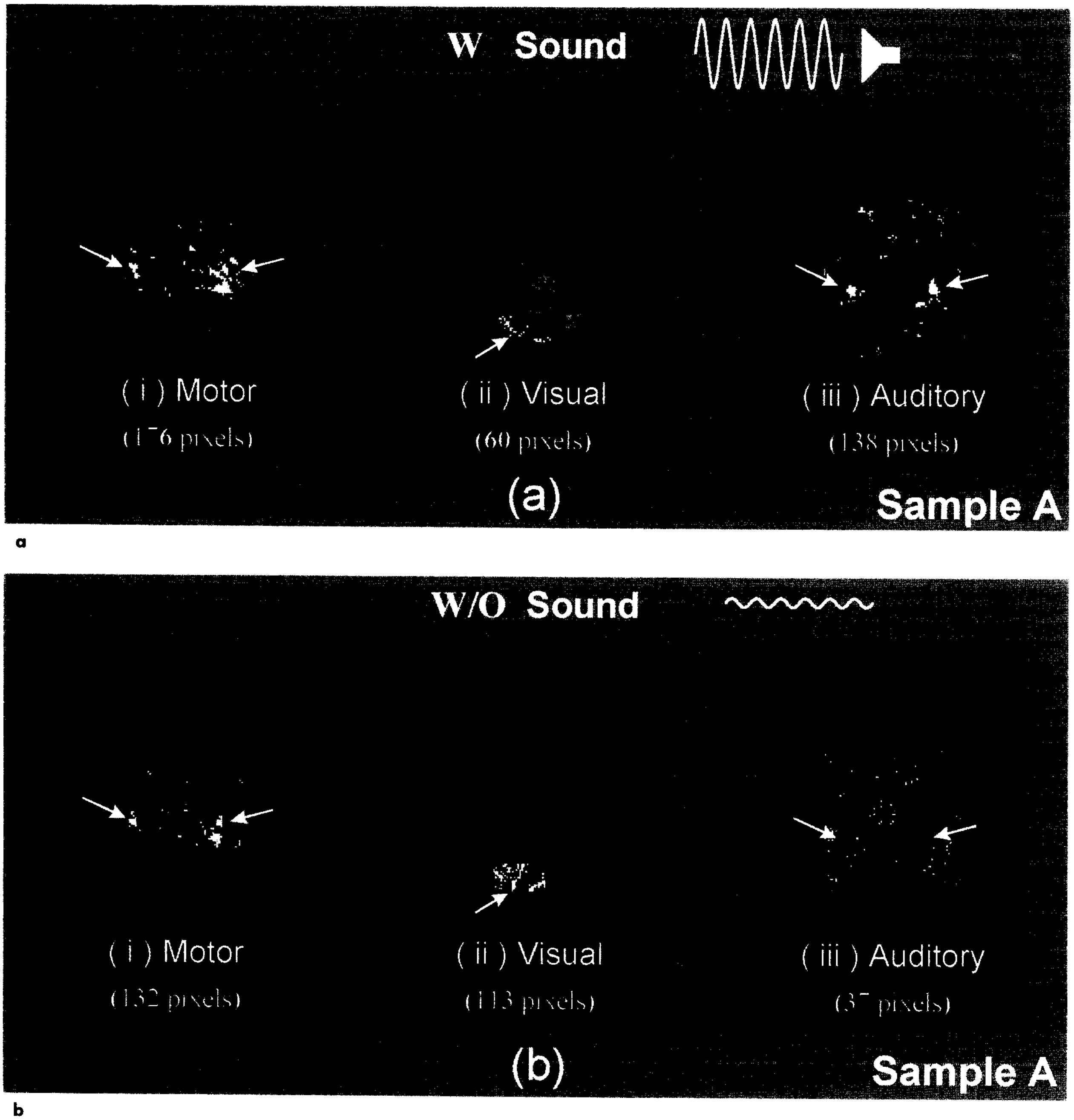
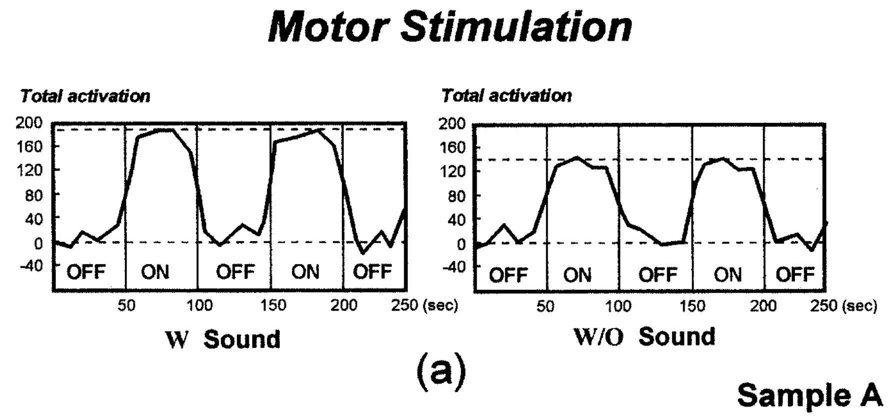


Fig. 3. Responses to motor, visual and auditory stimuli under the influence of acoustic noise in MRI. All the pixels that are above the threshold value of 0.4 are superimposed on the anatomical images. **a**. Responses of motor, visual and auditory cortices to the corresponding stimulation with (W) sound noise. **b**. Responses of motor, visual and auditory cortices to the corresponding stimulation without (W/O) sound noise. Note the differences in the activated areas (number of pixels above TH level) marked by the arrows.

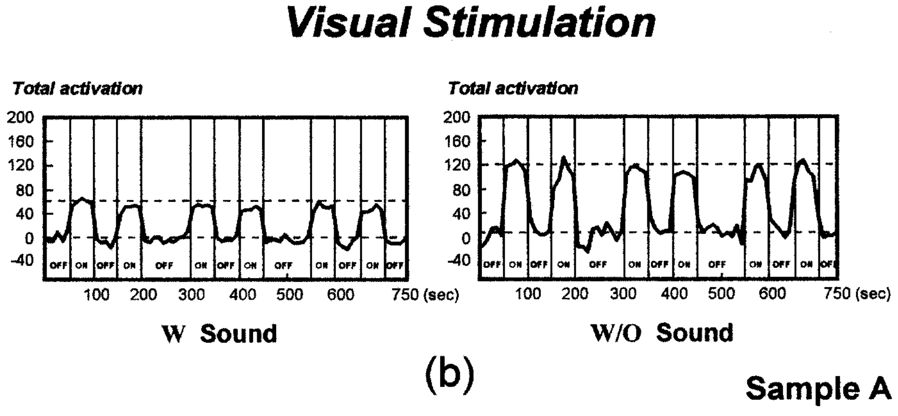
with the addition of artificially created acoustic noise (previously recorded acoustic noise from an MRI scanner during the scanning is played back to the subject's ears via a set of build in sound guides, see Fig. 2(b)-(ii)).

In each experiment, we have collected two sets of data. The first set we note as without (W/O) acoustic noise, while the second set is noted as with (W) acoustic noise, respectively. Motor and visual functional experiments were then performed under the two conditions. First to confirm how the MR scan acoustic noise affects the auditory cortex, a set of auditory stimulation experiments is performed for the case of without (W/O) and with (W) acoustic noise and results are shown in Fig. 3(a)—(iii) and (b)—(iii), respectively. For the case of an auditory experiment without (W/O) acoustic noise, a set of continuous image data were obtained without delivery of any acoustic noise for the images from number 1 to 25. As expected, for the case of without (W/O) acoustic noise, no activation in auditory cortex were seen. Imaging paradigm used for the case of auditory experiment with (W) acoustic noise, image number 1 to 5 were obtained at the resting state (W/O), while image number 6 to 10 were obtained with (W) sound (delivery of artificially generated acoustic noise to the ears via sound guides) and repeated same pattern up to image number 25.

Next, for the visual stimulation experiments, a standard 8-Hz checker board was used, while for the motor cortex studies, two-handed finger tapping was performed by right-handed volunteers. Finger tapping is self-paced (around 3Hz) and consists of sequential thumb-to-digit oppositions. For "ON-OFF" stimulation, 25 images for motor stimulation and 75 images for visual stimulation are collected with a time interval of 10sec per image data (see Fig. 4). For both motor and visual stimulation, images of number 1 to 5 are obtained at the resting state (OFF), while images of number 6 to 10 are obtained with



a



b

Fig. 4. a. Total activation-time course data of motor stimulation which corresponds to Figs. 3(a)—(i) and (b)—(i).

b. Total activation time course data of visual stimulation which corresponds to Figs. 3(a)—(ii) and (b)—(ii). These two sets of "ON-OFF" stimulation data clearly demonstrate the influence of acoustic noise on two different types of stimulation.

stimulation (ON). This stimulation paradigm is then repeated up to image data 25 for motor and 75 for visual, respectively. A set of experimentally obtained images with (W) and without (W/O) acoustic noise cases for motor and visual stimulation will be shown (see Fig. 3). Time course data of motor and visual stimulation will also be shown (see Fig. 4). Another set of complementary experiments is performed by varying the levels of acoustic-sound, ranging from soft music to loud music as well as the loud sound from MRI pre-scan (see Fig. 5). Time-course signal processing was carried out using the correlation coefficient (cc) method for each pixel (17). The box-car waveform is used as the reference waveform (17). The value of "cc" is varied between -1 and $+1$. A threshold value "TH" is set between 0 and $+1$ and each pixel is then selected and assumed activated if cc is larger than "TH", i. e., cc $\leq$ TH. These activated pixels are then superimposed on the anatomical images and time course data is obtained by calculating the total activation, A_T, which is defined as A_T = number of activated

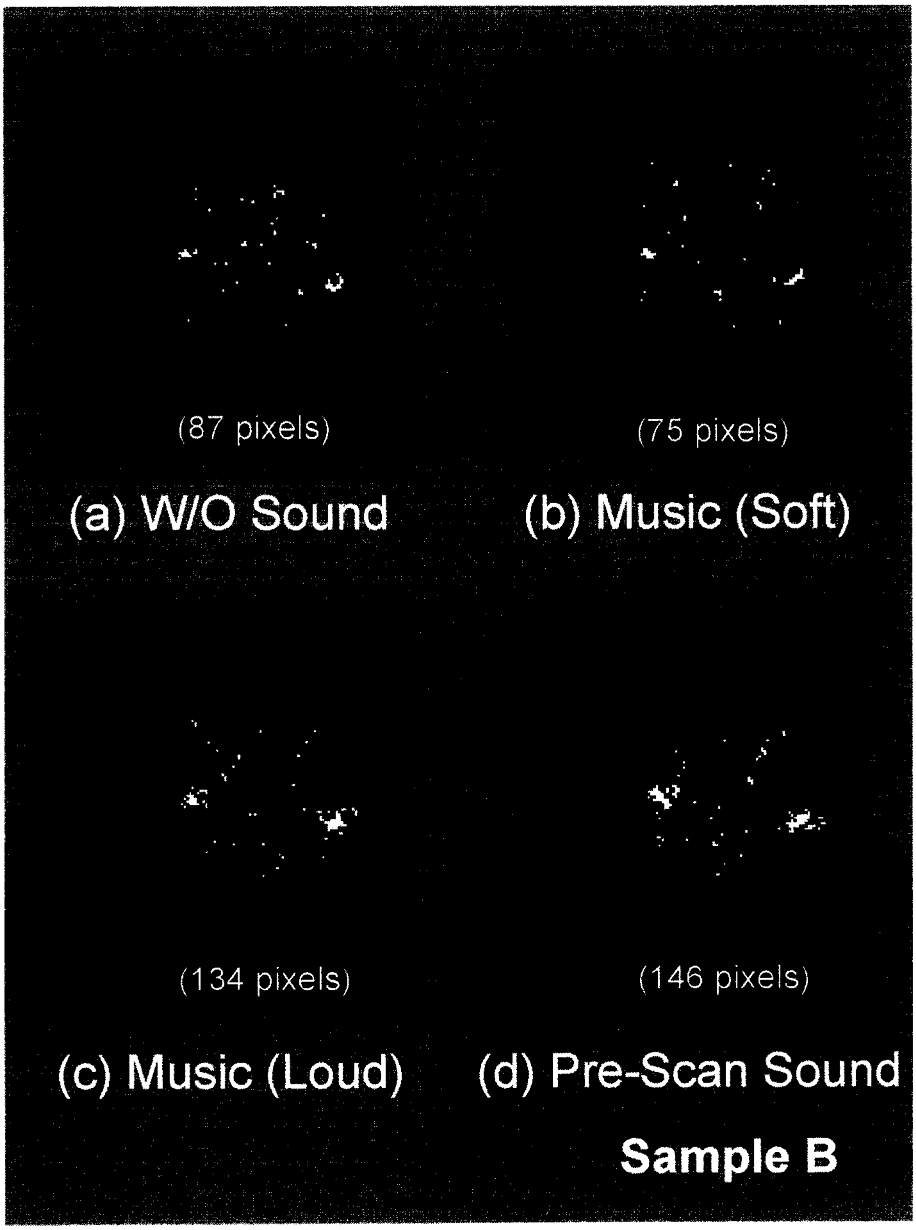


Fig. 5. A qualitative observation of various acoustic or sound noise effects on the motor cortex. All the pixels that are above the threshold value of 0.5 are superimposed on the anatomical images. **a**. Motor activation without (W/O) sound. **b**. Motor activation with (W) soft musical sound. **c**. Motor activation with (W) loud musical sound. **d**. Motor activation with (W) pre-scan MRI sound. Sound levels of the soft and loud music measured by sound meter were about 95dB and 105dB, respectively in C mode while pre-scan sound was about 106dB in C mode.

pixels × average pixel intensity. "TH" values of most of the study were set to 0.4 or 0.5.

Results

The summary of the various activations for five volunteers is given in Table 1. The number of activated pixels given in Table 1 is the number of pixels which have threshold values over 0.4. From Table 1, it is found that the differences between with (W) and without (W/O) acoustical noise in total activation are statistically significant for both the motor stimulation group (p=0.0086) and the visual stimulation group (p=0.0243). Although the results show differences in the number of activated pixels and the amount of average pixel intensity for the individuals (5-volunteers), all the subjects consistently have shown the same trends in activation for both motor and visual stimuli when the subjects are exposed to acoustic noise. A typical set of experimental results obtained from one of the volunteers is shown in Fig. 3. Fig. 3(a)—(iii) and 3(b)—(iii) are the auditory cortex responses with (W) and without (W/O) acoustic or sound noise, respectively. As noticed, with (W) acoustic or sound noise, clear responses are seen (Fig. 3(a)—(iii)) in both left and right auditory cortices while it was not the case for without (W/O) acoustic noise (Fig. 3(b)—(iii)).

Table 1. Summary of the various "total activations" of five volunteers in the case of with (W) and without (W/O) acoustic or sound noise.

Motor Stimulation

Subects		no. of activated pixels (cc ≥ 0.4)	Average pixel intensity	Total activation (AT)
A	W Sound	176	1.08	190
	W/O Sound	132	1.07	141
B	W Sound	225	1.08	243
	W/O Sound	142	1.07	152
C	W Sound	110	1.10	121
	W/O Sound	74	1.09	81
D	W Sound	106	1.08	114
	W/O Sound	79	1.07	85
E*	W Sound	171	1.17	200
	W/O Sound	106	1.10	117
Mean ± SD	W Sound	158 ± 45	1.10 ± 0.035	174 ± 49.1
	W/O Sound	107 ± 27	1.08 ± 0.013	115 ± 28.9

Visual Stimulation

Subects		no. of activated pixels (cc ≥ 0.4)	Average pixel intensity	Total activation (AT)
A	W Sound	60	1.05	63
	W/O Sound	113	1.08	122
B	W Sound	54	1.06	57
	W/O Sound	159	1.08	172
C	W Sound	37	1.09	40
	W/O Sound	72	1.09	78
D	W Sound	65	1.06	69
	W/O Sound	92	1.08	99
E*	W Sound	153	1.0.6	162
	W/O Sound	182	1.08	197
Mean ± SD	W Sound	74 ± 40	1.06 ± 0.014	78 ± 43.0
	W/O Sound	124 ± 41	1.08 ± 0.004	115 ± 44.2

SD : Standard Deviation

Total activation (AT) = no. of activated pixels × Average pixel intensity

* Note that the subject E appears somewhat unusual and substantially differs from the others.

One of the total-activation time-course data of "ON-OFF" motor stimuli among the five subjects (which corresponds to Figs. 3(a)—(i) and (b)—(i)) are plotted in Fig. 4(a). In Fig. 4(a), in the case of motor activity with (W) acoustic or sound noise, we found increased activity of more than 30 % compared with the case of without (W/O) acoustic noise in the total activation. Simple observation of the activated areas shown in Figs. 3(a)—(i) and (b)—(i) already suggests that the total activation (number of activated pixels × average pixel intensity) would be larger with (W) acoustic noise than without (W/O). Another experimental study of acoustic noise effects on motor was performed. For instance, when subdued music is used, the activated motor area was found to be nearly the same (75 pixels) as the one without (W/O) acoustic noise (87 pixels). With an increased volume of music, however, the effect appears the same as the one with loud pre-scan MRI sound noise (134 and 146 pixels). Therefore, one can conclude that when the music is loud, as it should, the subject feels the same way as a loud MRI acoustic noise as shown in Fig. 5.

Similar to the case of "ON-OFF" motor stimulation, the total activation time course data of visual stimulation corresponding to Figs. 3(a)—(ii) and —(ii) are shown in Fig. 4(b). Clear and distinct differences between the cases of with (W) and without (W/O) acoustic noise are seen. It is found that the responses to visual stimulation decreased with (W) acoustic noise. In fact, "the total activation" is found to be diminished by a factor of 2 compared with the ones without (W/O) acoustic noise (see Table 1). The maximum signal change observed in the case of without (W/O) acoustic noise was about 160, while in the case of with (W) acoustic noise, the maximum cortical signal change was only about 70 (see Fig. 4 (b)). These time-course data as well as the visual observations shown in Figs. 3(a)—(i and ii) and (b)—(i and ii) clearly suggest that there exist differences between visual and motor stimulation when the acoustic noise is involved and, moreover, motor and visual responses have opposite cortical responses if subjects are exposed to a loud acoustic or sound noise.

Discussions and Conclusions

A possible explanation of the above-described two-characteristic differences may be that the motor response is self-motivated action while visual stimulation is an externally driven activity. The latter, probably due to the fact that the externally driven activity may require more concentration under noisy conditions, therefore, could have caused more rapid exhaustion of brain function. Although the current observation is preliminary and requires more careful experimental study, it appears that the acoustic noise effects on brain functions (such as the motor and visual cortical responses) produce significantly different results. The two opposite effects observed in the motor and visual cortical responses are due to acoustic noise, and hence, may require further attention and investigation if quantitative fMRI is of prime importance. Note that we have used a relatively large flip angle (40°) and a short echo time (27msec) to obtain larger S/N ratio, therefore, a large part of the observed signal is probably due to vascular effects.

In conclusion, we have observed a new result of acoustic noise effect on brain functional MRI, especially the motor and visual responses when subjects are exposed to an acoustically strong noisy environment. Most striking new findings are that the acoustical noise effects on motor and visual responses are opposite. The summary of the various "total activations" ("total activation" is defined in the Methods section) given in Table 1 further strengthens the notion that motor and visual stimulation differ when subjects are exposed to an acoustically noisy environment.

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MR 경사 자계 소음이 뇌기능 영상에 미치는 영향

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경사 자계 펄스에 의한 MR 소음은 환자의 촬영뿐만 아니라 뇌기능 영상과 같은 신경 과학 영상에도 문제점 중의 하나이다. 특히 뇌기능 영상에서 소음은 피질과 혈관의 산소량의 변화로부터 생기는 작은 신호의 변화에 영향을 미치는 심각한 잡음 중의 하나이다. 본 연구에서는 청각, 운동, 및 시각 피질에서 소음이 뇌기능 영상에 미치는 영향을 알아 보고자 하였다. 그 결과 소음이 운동과 시각 피질에 미치는 영향은 서로 반대였다. 즉, 운동 피질에서는 소음이 총반응을 증가 시켰고, 반대로 시각 피질에서는 소음이 총반응을 감소 시켰다. 현재의 연구가 시작 단계에 있고, 앞으로 더 많은 실험적 검증이 필요한 실정이나, 소음이 운동과 시각 피질의 뇌기능 영상에 미치는 영향에 관한 첫번째 보고이며, 이 결과는 앞으로 뇌기능 연구의 데이타 해석에 기초 자료로 이용될 수 있을 것이다.

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