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Efficacy of Motion Correction in fMRI

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INTRODUCTION

Global head motion is a major source of artifacts in functional magnetic resonance imaging (fMRI). Although motion-correction techniques mainly with image realignment method(1) have been generally used, their efficacy to reduce artifacts is still unclear. It has been questioned whether 2D-motion correction is sufficient or whether 3D-motion correction is necessary despite time-consuming processing of a few hours by the case. To answer these questions and reveal the limitation of motion correction, we performed whole brain echo planar imaging (EPI) with a matrix size 64×64 in rest condition and analyzed time series of images to obtain power spectral intensity images. The power spectral intensities of each pixel were tested by the threshold based on the thermal noise intensity, then the number of tested pixels was counted as artifacts before and after 2D and 3D-motion correction. The efficacy of motion correction was also evaluated for each spatial resolution of image (64×64, 128×128, 256×256).

METHODS

All experiments were performed on a 1.5 Tesla standard clinical scanner (GE SIGNA Horizon LX) using a head coil. To observe influence of physiological fluctuation in fMRI, 3 volunteers aged 22 ± 2 were imaged in rest condition (no task). Subject's head was fixed tightly by bandages in a head coil. We performed whole brain gradient echo-EPI with gap less 32 axial slices to obtain 70 time series of images (32 × 70 images). A single shot-EPI pulse sequence was used with the condition of repetition time (TR); 6 s, echo time; 26.0 ms, flip angle; 90°, slice thickness; 3 mm, field of view; 200 mm and matrix size; 64 × 64. The EPI with these parameters is typical for whole brain fMRI studies.

The first six scans were discarded to remove transients produced as the system settled to dynamic equilibrium. For the 64 time series of images (32×64 images), we carried out 3D and 2D-motion correction using SPM96. These data sets of 64 time series with/without motion corrections were analyzed to obtain power spectra which were calculated for the time course of fluctuations in each pixel and averaged for pixels in brain area. Then the spectra were normalized by the spectral intensity of background noise(2). This normalization leads a quantitative comparison of spectral intensities based on the thermal noise intensity. Additionally, the power spectral intensities of each pixel were also tested by the threshold so highly as to depict one pixel stochastically for the thermal noise, which follows Rayleigh distribution. Then the number of tested pixels was counted as artifacts in each power spectral intensity image.

Furthermore, to evaluate the efficacy of motion correction for each spatial resolution (matrix size; 256 × 256, 128 × 128, 64 × 64), a volunteer in rest condition was imaged with a single slice EPI (TR=1s). The data set of 128 time series out of 138 ones, free from transient changes, was analyzed to yield the normalized power spectra of a time course of fluctuations in brain area with/without motion correction.

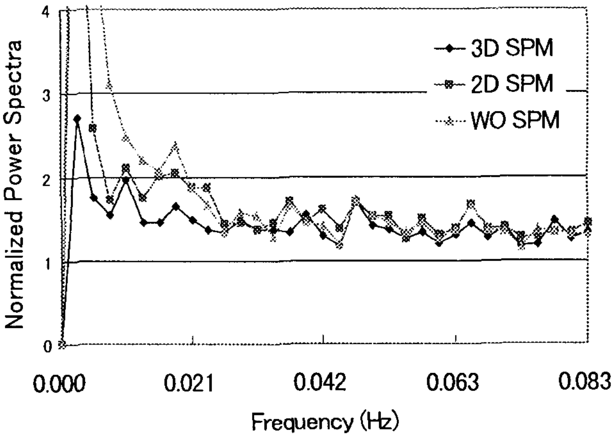


Figure 1. Typical normalized power spectra of signal fluctuation averaged for pixels in brain area of a slice in whole brain EPI with/without 2D and 3D-motion correction (SPM). The Nyquist frequency (0.083 Hz) is calculated by 1/(2TR)

RESULTS

Typical example of normalized power spectra clearly shows reduction of low frequency artifacts (global head motion of drift type) by 2D and especially 3D-motion correction (Fig. 1). The number of artifacts even for no motion correction decreased with the increase in the frequency of task paradigm (Fig. 2). Two dimensional-motion correction significantly reduced the number of artifact pixels only for 0.017Hz in Fig. 2 (192±39 (SD) vs. 107±48, P <0.001). While 3D-motion correction reduced artifacts to around 40 pixels for task-paradigm frequencies over 0.021Hz (Fig. 2).

High spatial resolution had advantage for motion correction (Fig. 3). Although the spectrum after motion correction in low spatial resolution of 64×64 shows poor reduction of artifacts (Fig. 3C),

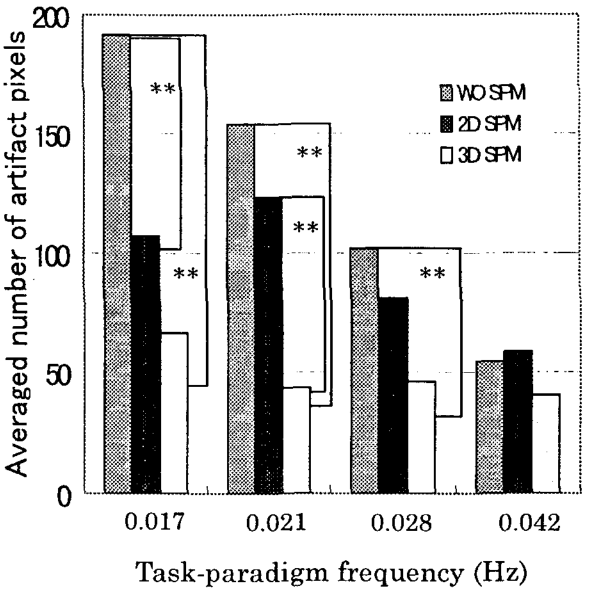
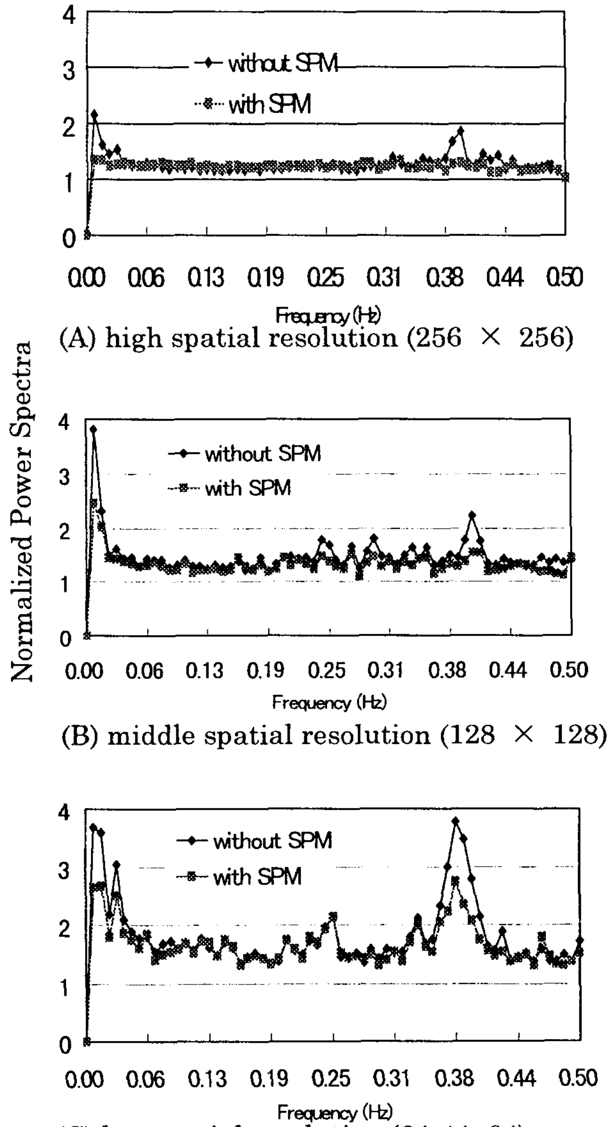


Figure 2. Averaged number of artifact pixels depicted with/without 2D and 3D-motion correction (SPM) in 3 typical slices of 3 volunteers at 4 typical task-paradigm frequencies. These frequencies corresponds to task-paradigm cycle of 60s (ex., on/off=30s/30s), 48s, 36s and 24s from the left side. ** P<0.001

the spectrum in high spatial resolution of 256 × 256 becomes flat (Fig. 3A). Two major spectral peaks without motion correction at the lowest frequency and around 0.4 Hz are attributed to global head motion and respiration, respectively. The spectral peak at around 0.25 Hz observed in Fig. 3B and 3C is understood as the aliased influence of pulsation. Because the conspicuous pixels having fluctuation due to pulsation, which were ascertained by another wide-range spectral experiment using TR=0.25s(3), appeared in the power spectral intensity image at around 0.25 Hz.



(A) high spatial resolution (256 × 256)

(B) middle spatial resolution (128 × 128)

(C) low spatial resolution (64 × 64)

Figure 3. Normalized power spectra of signal fluctuation averaged for pixels in brain area with and without 2D-motion correction. The Nyquist frequency (0.050 Hz), which is determined by TR=1s, is high enough to include fluctuation at around 0.4Hz caused by respiration.

DISCUSSION

Three dimensional-motion correction is more effective than 2D-motion correction in whole brain fMRI, which is clearly observed in Fig. 2. The number of artifact pixels was reduced to around 40 by 3D-motion correction for higher 3 task-paradigm frequencies (Fig. 2). This amount of pixels is totally about 4 cm^2. This limitation of 3D-motion correction may reflect insufficient correction due to low spatial resolution of 64×64 (Fig. 3C). On the other hand, high spatial resolution of 256×256 shows good efficacy of motion correction (Fig. 3A) (4). Even the spectral peak at about 0.4Hz caused by respiration disappeared. This indicates that respiration also causes global head motion at 1.5T, though influence of susceptibility modulation by chest movement due to respiration has been reported for the higher B_0 system(5). The dependency of spatial resolution on motion correction implies that coarser in-plane resolution than 1mm × 1mm (corresponding to the 256 × 256 image) causes discrepancy between actual brain structure and interpolated inter-pixel structure. Additionally, the limitation of 3D-motion correction may be caused by the influence of pulsation which is a kind of intracranial motion. The aliased spectral peak was observed to be at about 0.25Hz with bandwidth of around 0.06Hz in Fig. 3C. This type of spectral peak is aliased on to the spectrum with bandwidth of 0.083Hz for whole brain fMRI, covering most frequency ranges. As artifacts due to global head motion of drift type are larger for lower task-paradigm frequency, the number of artifact pixels at that frequency is larger than the limitation of about 40 pixels even with 3D-motion correction. The task-paradigm frequency over 0.021Hz is preferable.

CONCLUSION

We evaluated the efficacy of motion correction in SPM by using a quantitative analysis based on background noise intensity. It has been demonstrated that 3D-motion correction is more effective than 2D-one in whole brain fMRI studies, and its efficacy is limited to leave some artifacts totally around $4cm^2$ due to insufficient spatial resolution of 64×64 for motion correction.

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