Realistic Computer Generated fMRI Phantoms with Motion Correlated Susceptibility Artifacts

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Introduction

As an extension of work on computer-generated phantoms [1-2], more accurate, realistic phantoms are generated by integrating image distortions and signal loss caused by susceptibility variations. With the addition of real motions and activations determined from actual fMRI studies, these phantoms can be used by the fMRI community to assess pre-processing algorithms such as motion correction, distortion correction, and signal loss compensation methods with higher fidelity. We perform activation analysis on these phantoms based on a block paradigm design using SPM [3], and the results demonstrate that susceptibility artifacts affect activation detection and thus represent a critical component of phantom generation.

Methods

High-resolution anatomical volumes from a 3T Philips MR scanner are acquired and segmented into white matter, gray matter and CSF using a brain tissue segmentation tool [4]. With assigned spin density, T1, and T2* values, the segmented tissues serve as inputs to an MR simulator [5] to generate a T2*-weighted, distortion-free EP image. This image is replicated 99 times to generate a template for our phantoms. Simulated activations are added to these copies by choosing ten activation regions in the brain with different activation levels based on a block paradigm design and modifying the pre-distortion image intensities accordingly. Susceptibility artifacts are caused primarily by the susceptiblity difference across air and tissue interfaces. Hence, an air-tissue model is created by segmenting a high-resolution anatomical volume into air and tissues. A temporal rigid motion model estimated from real fMRI studies is then applied to this air-tissue model, and a susceptibility induced field inhomogeneity is then numerically calculated at each position [5]. Note that we need to calculate the field map for each volume in the time series because rotation of the head does not result in a simple rotation of the field map but instead causes a much more complex change [6]. The interaction between motion and susceptiblity artifacts is shown in Figure 1. The distorted image is analytically created from the distortion-free image and a field map based on the fact that image voxels in EP image are spatially warped in phase-encoding direction according to $y_1 = y + \gamma\Delta B\,\mathrm{FOV}/\mathrm{BW}$, where γ is the gyromagnetic ratio, y and y_1 are the real position and the distorted position respectively, ΔB is the field inhomogeneity, and BW and FOV are the bandwidth and field of view in the phase-encoding direction. An intensity modification model is used to account for both the Jacobian factor and intravoxel dephasing in order to get a realistic simulated EP image [7]. Finally, Rician noise is added independently to each voxel in the time series.

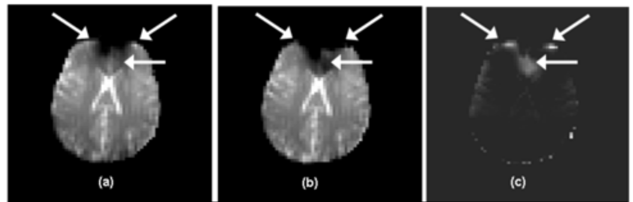

Figure 1. Interaction of motion and susceptibility. (a) and (b) are simulated images. (a) is the distorted image after head is rotated. (b) is the rotated distorted image. (c) is the difference between (a) and (b). The arrows highlight areas of big differences between (a) and (b).

Results

Phantoms with and without susceptibility artifacts are generated and used for activation analysis based on a block paradigm design study. After motion correction, the activation maps are detected using SPM as shown in Figure 2. The true activation map is shown in Figure 2 (a). From Figure 2 (b), we can see that all the true activations with different levels shown in (a) are detected using SPM, but some false activations indicate that the motion correction algortihm is imperfect. Figure 2 (c) shows spatially shifted activations, and intensity changes due to distortions and signal loss give rise to additional false activations that are not observed in (b). The additional errors in (c), not present in (b) demonstrate the importance of adding susceptibility artifacts in order to create realistic phantoms for fMRI study. Note that severe signal loss which mainly appears in air-filled spaces of the nasal cavity and auditory canal didn't affect the detecton of true activations we added in this study. However, increasing concerns about activations in these brain areas would be affected [8].

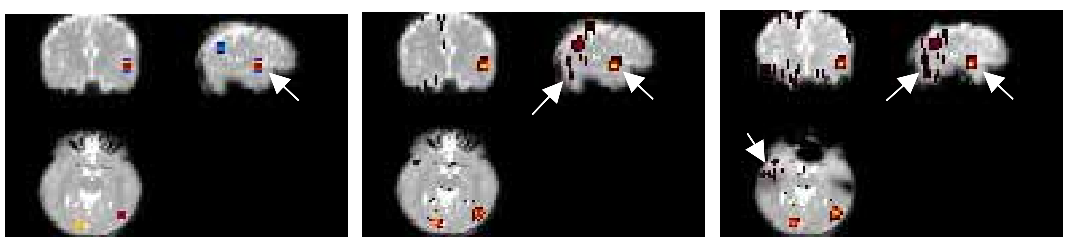

Figure 2. Comparision of activation maps with and without susceptibility artifacts from SPM2. (a) true activation map. (b) activation map detected from phantoms without susceptibility artifacts. (c) activation map detected from phantoms with susceptiblity artifacts. More false activations are obsevered in (c), and the detected activation regions are spatially shifted relative to the true map (arrows show examples).

Conclusions

Computer-generated phantoms with real motion and realistic susceptibility artifacts have been used to generate an EPI time series and that series has been tested using SPM. Image distortion and signal loss in the series contribute to false activations. The new phantoms will provide a better test bed for pre-processing algorithms that are designed to compensate for motion, susceptibility artifacts. Improvements are in progress to include the effect of spin-history [9].

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