The Effect of Amplitude Modulation on Motion Detection Accuracy of Navigator Echoes in Functional MRI

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INTRODUCTION

Prospective motion correction methods commonly use navigator echoes (NAVs) to track head position throughout the fMRI experiment. The NAV sequence samples a small subset of k-space, as a snapshot in time, for each 3-D image in fMRI sequence and measures motion by comparing magnitude and phase of two consecutive navigator profiles [1]. An assumption with this approach is that changes in the magnitude and phase of the NAVs are solely due to the head motion. This assumption may be compromised when NAVs are acquired during an fMRI experiment. Since the navigator sequence and fMRI imaging sequence both excite water, they may not function independently. In this abstract, we investigate the interactions between a 2-D echo-planar imaging (EPI) sequence and a 3-D spherical NAV (SNAV) sequence. Computer simulations and fMRI experiments show that incomplete T1 relaxation can create up to 80% signal decrease in k-space when alternating between SNAV and the EPI sequences. We hypothesize that this amplitude modulation can significantly decrease the motion detection accuracy of the navigators.

THEORY

Most fMRI experiments acquire a set of 3-D brain images with a rapid multi-slice EPI acquisition. Prospective motion correction methods acquire NAVs in between imaging volumes to measure the head's position throughout the fMRI experiment. The interleaving of images with navigators results in each slice in the imaging volume having a different amount of time to return to equilibrium before the NAV is acquired. For example, slices acquired later in the EPI sequence will not have enough time to recover back to equilibrium prior to NAV acquisition. Timing diagram of this process is illustrated in Figure 1. Incomplete T1 recovery of the spins in the imaged slices will result in a slice-to-slice amplitude modulation across the object during the acquisition of the NAV. This amplitude modulation in k-space will reduce the accuracy of registration of navigator profiles for motion detection. One could eliminate the amplitude modulation by using small flip angle RF pulses for fMRI imaging sequence. However, it is not acceptable to reduce the flip angle of the imaging sequence for the sole purpose of motion correction. Another way of preventing this interaction is having a temporal delay between the imaging sequence and navigator sequence so that the spins will have sufficient time to return back to equilibrium. However, introducing a temporal delay will affect temporal resolution of the fMRI experiment and hence not feasible for most fMRI studies. We propose FAT navigators for motion detection in fMRI. Since the FAT navigators excite fat for motion detection and water for imaging, amplitude modulation is not an issue. FAT navigators for fMRI experiments will be introduced in a separate paper.

METHODS

We implemented the SNAV pulse sequence [2] and integrated this into our clinical EPI sequence on the GE TwinSpeed MR Scanner. Figure 1 illustrates the timing diagram of the interleaved EPI sequence and SNAV sequence used in our experiments. The first slice acquired in the imaging volume have the longest time to recover and, therefore, contribute the largest signal to the SNAV. While the last slice acquired in the imaging volume, which is the slice acquired immediately before the SNAV, have the shortest time to recover and, therefore, contribute the smallest signal to the SNAV. These timing differences result in slice-to-slice amplitude modulation function and banding artifacts also shown on the same figure. fMRI experiments were performed using a water phantom located on a motion platform with known displacement information. The motion platform allowed NAVs to be acquired from the water phantom at different positions.

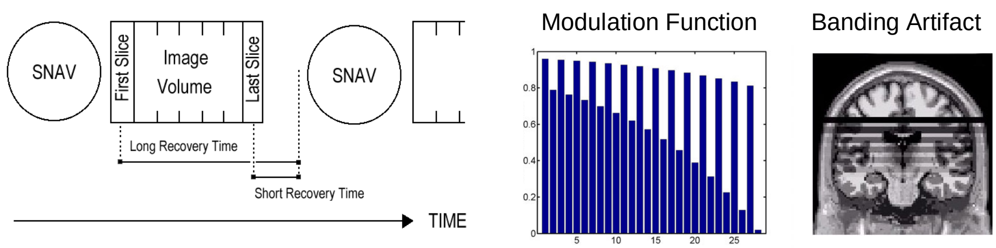

Figure 1: Left: Timing diagram of an interleaved fMRI imaging sequence and SNAV navigator sequence. Middle: Amplitude modulation function for interleaved slice ordering with 28 slices computed from a uniform phantom with a T1 of 600 ms and a TR of 2000 ms. Right: An example coronal image demonstrating slice to slice amplitude modulation as a banding artifact.

RESULTS and DISCUSSIONS

Figure 2.A shows SNAV magnitude plots with EPI RF pulse on/off, and difference of SNAV magnitude plots with and without the EPI RF pulse. In this example EPI imaging sequence introduced amplitude modulation of 38% for SNAV with a TR of 2000ms. Note that the difference signal for SNAV is highly positive therefore there is less signal: amplitude modulated as we proposed. Figure 2.B illustrates the impact of changing TR time of the EPI sequence on SNAV signal content. Amplitude modulation decreases from 38% to 3% by increasing TR from 2000ms to 7000ms. Figure 3 shows the motion detection results of SNAV technique obtained from an MR-compatibele motion platform for out-of-plane rotations and out-of-plane translations. We observed that amplitude modulation significantly affects out-of-plane motion detection accuracy of the SNAV technique. Further work is necessary to investigate this effect on in vivo studies and fMRI brain activation maps.

REFERENCES

[1] Ehman, et al. Radiology, 173: 255-263, 1989. [2] Welch, et al., MRM, 47: 32-41, 2002.

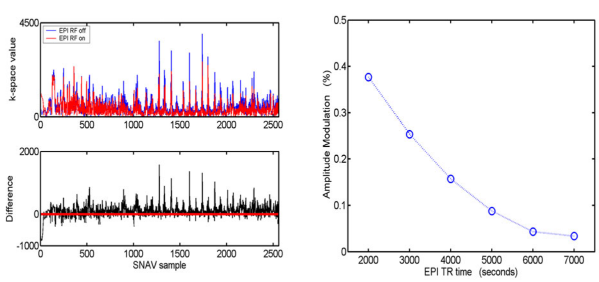

Figure 2: SNAV magnitude plots with EPI RF pulse turned on/off. Turning on EPI RF pulse introduces amplitude modulation for SNAV, and the amount of modulation changes as a function of TR.

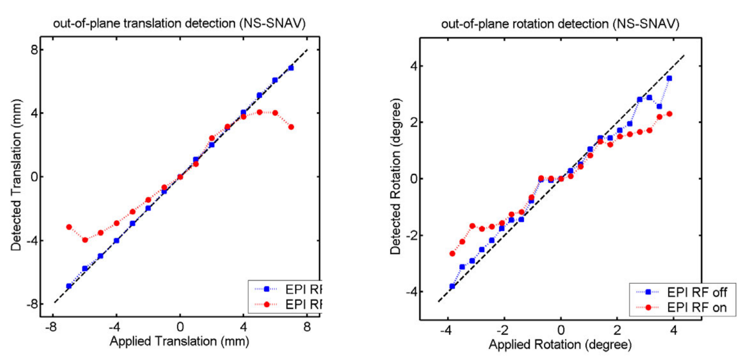

Figure 3: Out-of-plane motion detection accuracy of SNAVs interleaved within an fMRI sequence, with EPI RF pulse turned On / Off (Red / Blue).