FAT Navigators for Functional MRI: Is There Sufficient Amount of Fat Signal in The Human Head for Accurate Motion Detection with Fat Navigator Echoes?

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INTRODUCTION

Subject head movement is a major problem in functional MRI that often involves acquiring repeated scans over a long period of time. Spherical navigator echoes (SNAVs) have been proposed to track head position during the fMRI scan by detecting head motion every few seconds [1]. From all initial reports, SNAV technique has the potential to be an ideal prospective motion correction technique for fMRI. However, SNAVs and fMRI imaging sequence both excite water; and therefore have the potential to interact with each other. We propose FAT navigators for fMRI, which tracks motion of the sub-cutaneous fat in human head without affecting the steady state of water signal. Selectively exciting fat eliminates the interaction of the fMRI and the SNAV by having these two sequences excite different tissues. The biggest argument against FAT navigators is the relatively small amount of fat contained in the human head, where the question can be stated as "Is there sufficient amount of fat in human head for accurate motion detection with FAT navigators?" In this abstract, we demonstrate that FAT navigators obtained from the head have sufficient signal-to-noise ratio (SNR), even though fat signal corresponds to only 3-5% of total MR signal from the human head.

THEORY

Our initial interest in FAT-SNAV was to eliminate interaction between the fMRI sequence and SNAV sequence to improve motion detection accuracy. Another potential benefit may be that FAT-SNAV having a higher SNR compared to water SNAV, called NS-SNAV here. There is only about 3-5% fat in the human head, which is estimated from a digital brain phantom [2] and from in vivo MR experiments. Therefore, the idea of FAT-SNAV having a higher SNR than NS-SNAV may seem counter-intuitive. However, there are several factors that must be taken into account when comparing SNR of different navigators, i.e. total available signal, flip angle, incomplete spin relaxations (T1 and T2), and proton density. Specifically, CS-SNAV has 3 main advantages over NS-SNAV in SNR calculations: 1) *Flip angle*. NS-SNAV must use small flip angles to minimize its effect on fMRI images, but CS-SNAV can use 90° flip angle since CS-SNAV and fMRI sequences excite different tissues. 2) *Amplitude Modulation*. Functional MRI sequence excites water for image acquisition and there is insufficient amount of time for the water spins to return back to equilibrium before NS-SNAV acquisition. This will result in amplitude modulation. This is not an issue for CS-SNAV since it excites only fat. 3) *K-space frequency content*. CS-SNAV has higher SNR at high spatial frequencies than NS-SNAV.

Weighting Factors	NS-SNAV	CS-SNAV
sin(Flip Angle)	0.17	1.00
Amplitude Modulation	0.64	1.00
T2 Relaxation	0.81	0.91
T1 Relaxation	0.87	1.00
Proton Density	0.71	1.00
Total Weighting	0.06	0.91
Available Signal	100.00	3.24
Measured Signal	5.55	2.95
CS-SNAV / NS-SNAV	**-**	**0.53**

Table 1: SNR calculation summary for simulated NS-SNAV and CS-SNAV data when k-space radius equals to 0, or center of k-space.

METHODS

We developed a sophisticated model to create SNAVs that are interleaved within a simulated fMRI experiment. This simulation model allows fine control over different parameters of the fMRI imaging sequence and their effect on the SNR of the selected SNAV. The weighting factors for SNR of the simulated SNAVs are summarized in Table 1. Since NS-SNAV excites the entire head, the weighting factors are a weighted average over all tissue types contained in the brain. Here, we assumed a 10° flip angle for NS-SNAV to minimize the effect of NS-SNAV on fMRI experiment. NS-SNAV uses low flip angles to minimize the amount of spin saturation before the fMRI sequence. A 10° flip angle excites only 17% of all the spins available in the human head. CS-SNAV selectively excites 100% of the fat with a 90° flip angle because the CS-SNAV and the fMRI experiment excite different tissues. After these weighting factors are taken into account the measured SNR of the CS-SNAV is only 47% less than the NS-SNAV. However, this calculation does not account for the differences in k-space frequency content. The majority of fat signal of CS-SNAV is from a thin layer of fat at the periphery of the head, thus fat can be thought as a spherical shell with higher frequency content. On the other hand, water signal of NS-SNAV is mostly from the brain and can be thought as a spherical ball with lower frequency content. Therefore, CS-SNAV has higher spatial frequency content than NS-SNAV. Figure 1 compares the SNR of water and fat k-spaces of human brain.

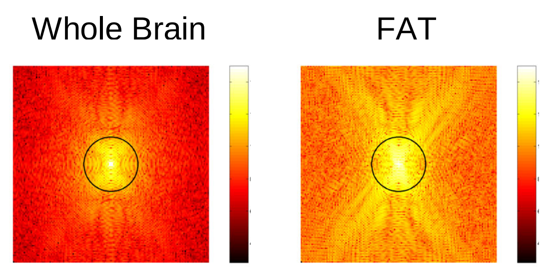

Figure 1: Simulated natural log images of 3-D k-space cross-section of water signal of NS-SNAV and fat signal of CS-SNAV displayed on the same scale. The circle represents the operating radius of both SNAV types

RESULTS and DISCUSSIONS

SNAVs sample a spherical shell of k-space to detect motion. Figure 1 shows an image of the natural log of the cross section of k-space of a NS-SNAV and a CS-SNAV displayed on the same scale. The CS-SNAV has higher frequency content than NS-SNAV because the fat signal is from a thin layer of fat at the periphery of the head. If the frequency content of the CS-SNAV and NS-SNAV are taken into account, the SNR of CS-SNAV is greater than NS-SNAV above a certain k-space radius. Figure 2.A plots SNR ratio of CS-SNAV to NS-SNAV as a function of radius. We hypothesize that the SNR of CS-SNAV will be same as, if not more than, the SNR of NS-SNAV in the radius range that motion detection is performed. Figure 2.B shows a high correlation between in vivo rotation detection results of CS-SNAV and NS-SNAV, which verifies that CS-SNAVs have sufficient signal to perform accurate motion correction.

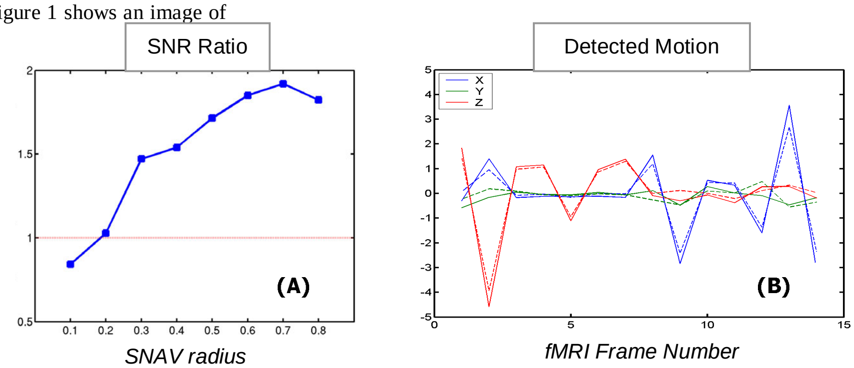

Figure 2.A: SNR ratio of CS-SNAV to NS-SNAV as a function of radius from the head of a volunteer. Figure 2.B: Comparison of detected rotations (X, Y, Z) with CS-SNAV (dashed line) and NS-SNAV (solid line) for an in vivo MRI experiment.

REFERENCES

[1] Welch, et al., MRM, 47: 32-41, 2002.
[2] Collins, et al. IEEE TMI, 17:463-468, 1998.