Neurogenic Inhomogeneity Localization for Detection of Activity (NILDA)

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Introduction: For several years, we have been investigating an MRI technique for direct detection of neuronal firing, as have others working independently [1-3]. The method relies on imbalance caused in echo acquisition sequences by the magnetic effect of neural activity present during only part of the sequence. We refer to it by the name and acronym in the title above. The magnetic effect of transient neural currents not uniform throughout the acquisition sequence will result in additional spin dephasing and appear as localized signal loss in the reconstructed magnitude image. Several aspects of the phenomenon can be analyzed more quantitatively in vitro than in biological preparations. This investigation was undertaken to probe the sensitivity of the magnitude signal change in a wire phantom experiment.

Methods: The phantom was constructed from a glass sphere (135 mm diameter) filled with silicone oil in which a carbon fibre wire was immersed as shown in Fig. 1. This was scanned in a single plane with a GE 3T Signa MR scanner and standard birdcage head coil using a gradient-echo EPI sequence (TR=1sec, TE=36ms, α=90°, 128x128 matrix with partial k-space and homodyne reconstruction, voxel size 1.56×1.56×6.0mm). Current pulse synchronisation and generation was carried out with in-house software and hardware. The following experiments were carried out to probe the sensitivity of the measurement. (i) The sensitivity to within-voxel conductor position was examined by moving the imaging plane over 4 mm in 0.5 mm steps using receiver frequency offsets in a direction perpendicular to B0 and the current flow. In this manner, 2 pixels were traversed. Other parameters: current pulse with amplitude (I_A)=99.1µA, duration (T_A)=20ms, position immediately after 90° pulse; 20 interleaved acquisitions (ON/OFF) after steady state. Results were compared with those obtained by a simulation of the Biot-Savart relationship. (ii) The sensitivity of the response to the placement of the current pulse within the pulse sequence as examined in an experiment in which a current pulse of constant duration was "walked-through" both GE and SE EPI (TE=36ms) sequences (I_A=7.8mA, T_A=5ms; 1ms steps; 260 interleaved acquisitions with current ON/OFF. (iii) The current sensitivity of the method was investigated by decreasing the amplitude of the current pulse (I_A=100-1.7µA, T_A=20ms; 100 interleaved acquisitions ON/OFF). For all experiments, magnitude images were analysed using a 2-sample t-test (p=0.001 uncorrected).

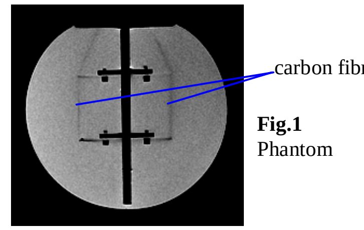

Fig.1
Phantom

Results: (i) Figure 2 indicates the sensitivity to the wire location with respect to the imaging voxel. The sinusoidal pattern reflects the symmetry of the circular field distribution around the wire and the subsequent cancellation of the phase distribution for a suitably positioned current source. (ii) Figure 3 shows the results of the walk-though experiment for the spin echo EPI sequence. The phase of the response inverts at the time of the 180° pulse. The response displays an increase in sensitivity around center of k-space acquisition. The response starts to change when then the leading edge of the stimulus pulse overlaps with a point that is close to the center of k-space. (iii) As expected, the significance of the effect decreases with a reduction in current. Figure 4 shows magnitude images with statistical overlay for the t+ve and t-ve results for a current pulse of 100µA amplitude and duration 20ms. At the 1.7µA current level, the effect of the current on the signal is on the margin of statistical significance. This is therefore the sensitivity limit for magnitude images for the 20ms pulse for our choice of imaging parameters.

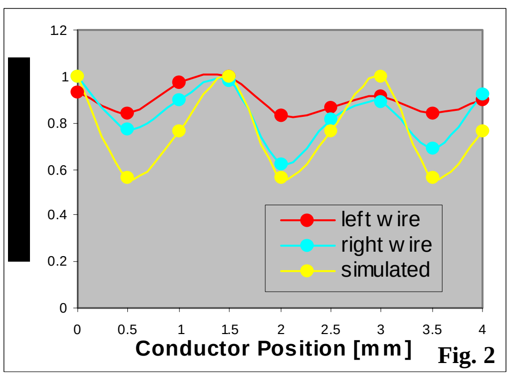

Fig. 2 Maximal experimental signal change in the left (red), right (blue) wires and simulation (yellow) as the wire position is shifted through the 2 voxels.

Discussion & Conclusions: The magnetic field component induced by the wire in the direction of B0 changes the precessional frequency of the spins in that location and the increase in phase dispersal across a voxel can be detected as an alteration in the magnitude signal intensity. Previous studies have used phase imaging (1,2). We have demonstrated that magnitude imaging may be even more sensitive. The size of the effect was shown by simulation and experiment to be sensitive to the conductor position within the voxel and the placement of the stimulus within the pulse sequence. With optimization of these and other parameters, magnetic field changes as small as 1.7µA and lasting for 20 ms can be detected. This corresponds to a magnetic field of 0.34nT at a distance of 1mm from the conductor. These limits for detection of current and field are close to those expected as a result of neuronal firing. The reliable detection of spontaneous or evoked brain activity is therefore a very realizable expectation.

References: (1) Bodurka J. Magn. Reson. 137:265 (1999) ; (2) Bodurka & Bandettini, Magn Reson Med 47:1052 (2002) ; (3) Xiong et. al. Hum Brain Mapp 20:41 (2003)

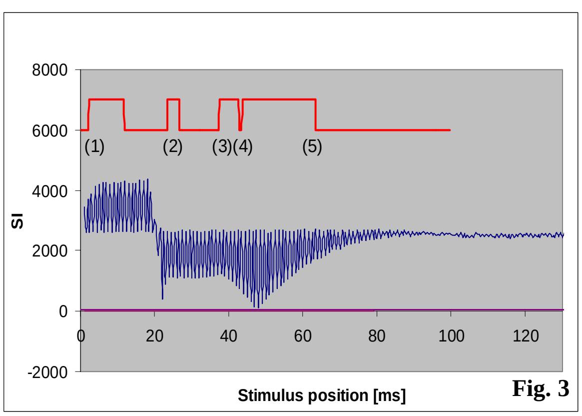

Fig. 3 Result of walk-through experiment in which the pulse position was stepped through the SE EPI sequence. The ON/OFF interleaving causes the jitter in the signal respone (lower blue line). The following significant points in the pulse sequence are depicted (upper line): (1) start of 90° pulse, (2) start of 180° pulse, (3) start of readout, (4) k-space centre and (5) end of readout. The signal changes begin to occur when the leading edge of the pulse enters the appropriate part of the pulse sequence.

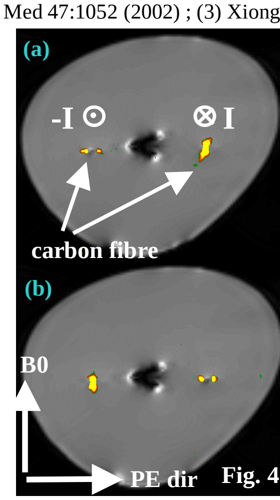

Fig. 4 Magnitude images with statistical overlay of the (a) t+ve and (b) t-ve results for a current pulse of 100µA amplitude and duration 20ms. The wire orientation and the phase encoding (PE) direction are indicated on the figure. The corresponding splitting of the significant area around one of the wires in each image is a result of the interaction of the PE gradient direction and its disturbance by the induced magnetic field around the wire. Opposite side of the wire (in the vertical direction) result in shifts in signal that are in opposite directions in the horizontal direction.