

Theoretical Modeling of MRI signal changes induced by neuronal magnetic fields

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Introduction: Currently used fMRI techniques rely on measuring regional cerebral hemodynamics to infer neural activation, rather than detecting neuronal activity directly. This indirect measurement of neuronal activity bears several limitations. Directly mapping neuronal activity using MRI by detecting neuronal magnetic field offers clear advantages. However, whether MRI can be used for direct detection of neuronal activity is a matter of debate [1-3]. In this abstract, we theoretically explore the feasibility of direct MRI detections of neuronal magnetic field.

Theory and Methods: A neuron in the brain typically consists of a single axon and multiple dendrites. We model each dendrite or axon with a modified current dipole model. The interaction of dipoles is considered by taking into account the effect of the spatial relationship between current dipoles and magnetic field distributions. The overall neuronal magnetic field is a vector summation of the magnetic field generated by each single dipole. The component of neuronal magnetic field parallel to the B_0 causes the spins at point in the transverse plane to acquire additional phases and decreases the MRI signal.

Results: For convenience, we define that the y-axis is along the B_0 field and the z-axis is along the dendritic current. The distributions of magnitudes of neuronal magnetic field on the x-y plane are computed and shown in Figures 1a (Parallel configuration, all dipoles are in the same direction) & 1b (Anti-parallel configuration, any two adjacent dipoles are in the opposite direction). MRI magnitude signal changes of the activated voxel corresponding to different parameters of neural firing are summarized in Table 1. For parallel configuration, the msMRI signal changes could be up to 2% and are strong enough to be detected, assuming the 1 million dendrites fired. The relationship between MRI signal changes and the number of dendrites firing is plotted in Figure 2. For anti-parallel configuration, the signal change is very small and cannot be detected.

Discussion and Conclusion: 1). Unlike MEG which measures the strength of the neuronal magnetic field, msMRI focuses on the accumulated effects of neuronal magnetic field during the echo-time, TE. All neural firings during the TE will contribute to the dephasing of the proton spins and cause MRI signal change, no matter whether these neurons fire simultaneously or not. 2). Neuronal activity may be detected as phase or magnitude changes of MRI signals. For phase imaging, the overall phase shift of all spins in the voxel tends to be destructively added and is approximately zero. However, for magnitude imaging, neural activity will increase the fluctuations of magnetic fields and increase phase dispersion of nuclear spins. This phase dispersion will result in a decrease of MRI magnitude signal during brain activation. Hence, the magnitude measurements should be more sensitive than phase measurements. 3) The msMRI signal change mainly depends on the number and configurations of dendrites. The real number and configurations of dendrites in the brain are complicated to measure. Based on MEG literatures [4, 5], the evoked magnetic fields on the scalp are in the order of $\Delta B=10^{-13}$ T. It is believed that there are over one million dendrites firing coherently to generate such a field. Over one million dendrites firing coherently should generate strong enough msMRI signals to be detectable using current MRI techniques.

In summary, our model demonstrates that MRI signal changes induced by neuronal magnetic field are in the detectable range of current MRI techniques. Magnitude measurements are far more sensitive for detecting *in-vivo* neuronal activity than phase measurements.

References: [1] Kamei, H, et al. IEEE Trans. Magn. 35: 4109-4111, 1999. [2] Xiong J, et al. Human Brain Mapp. 20: 41-49, 2003. [3] Chu R, et al. NeuroImage. 23: 1059-1067, 2004. [4] Cohen D. Science. 161: 784-786, 1968. [5] Hamalainen M et al. Rev. Mod. Phys. 65: 413-497, 1993.

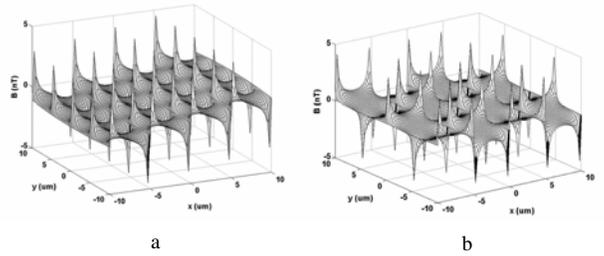


Fig. 1

Table 1 MRI magnitude signal changes of the activated voxel corresponding to different parameters of neural firing

Neuronal Current ^a	Configuration ^a	5 ms ^a	10 ms ^a
1nA ^a	Parallel ^a	-0.02% ^a	-0.08% ^a
	Anti-Parallel ^a	-1.3x10 ⁻⁸ % ^a	-5x10 ⁻⁷ % ^a
5nA ^a	Parallel ^a	-0.49% ^a	-2.0% ^a
	Anti-Parallel ^a	-3.2x10 ⁻⁷ % ^a	-1.3x10 ⁻⁶ % ^a

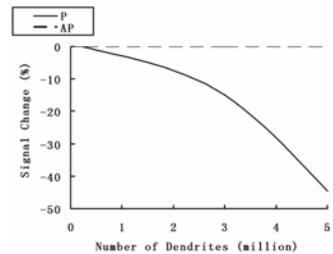


Fig 2