Magnetic field effect of neuronal currents on MRI: A snail ganglia study

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Introduction

Poor temporal resolution of fMRI imposes big limitations on dynamic studies of brain functions. Recently, new fMRI methods with faster response to neuronal activity than the blood-oxygenation-level-dependent (BOLD) method have been investigated in many ways. The neuronal magnetic field exerts Lorentz force on the firing neurons giving rise to motions of the neurons when they are in the main magnetic field of MRI. Even though the motion of firing neurons seems to be very small, it is thought that the motion may cause measurable change in MRI signal intensity, just like the diffusion effect in MRI [1]. Despite the increasing interests in measuring the fast responding components in fMRI, few experimental studies have been reported. That is partly due to the difficulty in making neural models in which the fast responding components can be separated efficiently from the slow responding components, i.e., the BOLD effect. In this study, we used dissected snail ganglia which have nonmagnetic hemocyanin as oxygen carrying protein [2]. Hemocyanin has copper ions to bind oxygens instead of ironic ions in the case of hemoglobin. Experimental results indicating the fast responding components in MRI signal to the neuronal activity are presented.

Methods

Achatina fulica, African agate snails, weighing 30-40g were anesthetized by injection of isotonic $MgCl_2$ (337mM, 50% of the body weight) and the whole ganglia were dissected out. The connective tissues surrounding the ganglia were carefully removed to prevent possible tissue contractions during the MRI studies. For the electrical stimulation, we applied 2 s long stimulation pulses with the frequency of 30 Hz. The stimulation voltage was set to 3V. The electrical stimulator has a sync output which is fed to the MRI spectrometer for the synchronization between the electrical stimulation and MRI scan.(Fig. 1) The ECR with the electrical stimulation has been performed outside the MRI magnet. During the MRI signal measurement with the electrical stimulation, we did not perform ECR due to excessive noises coming from the electrical stimulator. To investigate the fast responding components, we used a volume selection pulse sequence, rather than an imaging pulse sequence. Targeting the volume of interest to the visceral ganglia region, we observed the MRI signal intensity with and without applying the electrical stimulation. If we assume the neurons in the snail ganglia orient in random direction, the neuronal magnetic fields emanating from the firing neurons and consequent neuron motions exerted by the Lorenz force will attenuate the MRI signal as the T2 effect does. The volume selection MRI signal measurement was performed with a 3.0 Tesla whole body MRI scanner (Magnus 3.0, Medinus Inc., Korea) equipped with a gradient system capable of 35 mT/m. The dish containing the snail ganglia was positioned on a surface RF coil with the diameter of 5 cm. The surface RF coil was used for the MRI signal reception only and a birdcage RF coil with the diameter of 30 cm was used for the RF pulse transmission.

Results

The firing rate significantly increases when we apply the electrical stimulation. The average increase of the extracellular potential amplitudes with the electrical stimulation over the whole period is about 73.2 %.(Fig. 2a) We tried to compare the firing rates in the ECRs performed with and without electrical stimulation. However, it was difficult to quantify the firing rates, particularly in the case of electrical stimulation, because an extracellular potential peak often comprises many action potential peaks from multiple neurons near the micro-electrode. Classifying the action potential peaks manually, we observed that the firing rates were increased at least 7 times. Figure 2b shows average volume selection MRI signal intensities observed every 2 min for 20 min in the three snail experiments. The solid and dashed lines represent average MRI signal amplitudes without and with the electrical stimulation, respectively, in the three snail experiments. The MRI signal amplitudes were also normalized with the average value of the no stimulation case in each snail experiment. The average MRI signal decrease due to the electrical stimulation is about 2.97±1.10 % over the whole period.

Conclusions

With applying electrical stimulation to the dissected snail ganglia, we have observed the dependence of the MRI signal intensity on the neuronal activity. The increase of neuronal activity in the dissected ganglia resulted in the decrease of the MRI signal intensity. Since the snail blood has non-magnetic hemocyanin as oxygen carrying protein and the neuronal activity is increased steadily after the electrical stimulation, we expect that the snail ganglia model with the electrical stimulation can be used in quantitative studies of direct MRI measurement of neuronal activities with faster response time than the BOLD effect.

References

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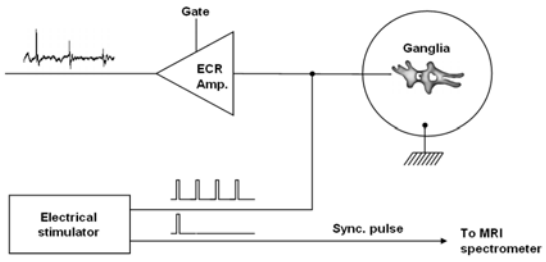

Fig. 1. A schematic diagram of the ECR with electrical stimulations

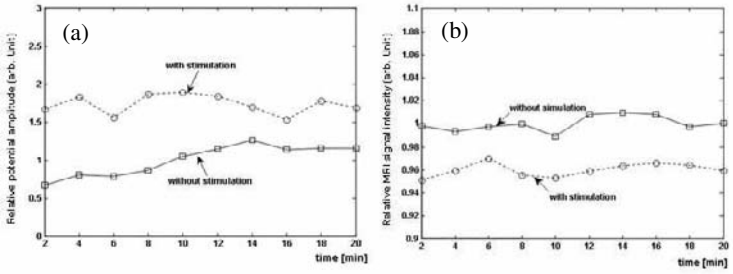

Fig. 2. (a) The extracelluar potential amplitudes and (b) the MRI signal intensity observed every 2 min for 20 min. The solid and dashed lines represent changes without and with the electrical stimulation, respectively.