Towards concurrent multi-locus TMS and functional MRI in rats

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Introduction

Concurrent TMS and functional MRI (fMRI) in animal models poses significant technical challenges:

- restricted space for TMS coil placement
- high mechanical stress caused by the interaction of MRI fields and TMS currents.

Aim: Develop an MRI-compatible, multi-locus TMS (mTMS) transducer optimized for rats that allows electronic control of the stimulus orientation inside the scanner.

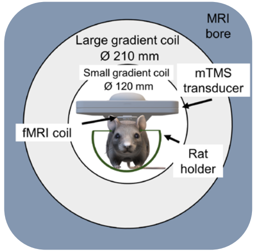
Methods

The mTMS coils were energy-optimized [Koponen et al., Brain Stimulation, 2018] for focal stimulation and rotation of stimulus orientation in a small-animal brain model with a 13.5-mm radius sphere.

We delivered TMS pulses up to 1000-V capacitor voltages on top of a rat brain phantom, inside a 9.4-T MRI scanner.

We recorded concurrent mTMS–fMRI using a Multi-Band SWIFT (MB-SWIFT) radial sequence [Paasonen et al., NeuroImage, 2020] and computed the power spectrum of the MRI free induction decay signal.

Figure 1. Illustration of the mTMS transducer placed in the MRI bore



Results

Result #1: mTMS transducer

We developed an mTMS transducer for rats (Fig. 2) that allows electronic control of the stimulus orientation inside the MRI scanner.

The developed transducer is MRI-compatible (except for the fracturing at 1000 V, Fig. 3) and had low signal in an anatomical scan (Fig. 4).

Figure 2: The manufactured 2-channel mTMS transducer with bottom and top coils.

Figure 3: mTMS transducer inside the MRI, which fractured after a 1000-V stimulus.

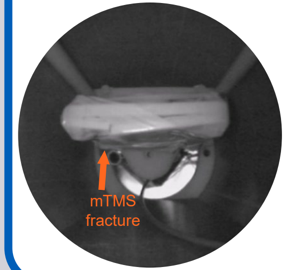
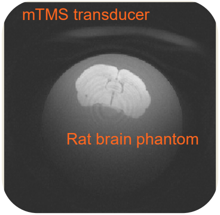


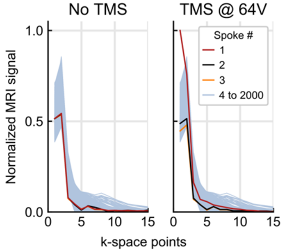
Figure 4: Anatomical MRI of the mTMS transducer and the brain phantom.



Result #2: Concurrent mTMS–fMRI

mTMS pulse at 64 V destroyed only 1/2000 spokes in k-space leading to negligible artefact in the SWIFT image.

Figure 5: SWIFT spokes without TMS (left) and while applying TMS pulses (right). The first spoke (red line, right chart) was affected by the TMS pulse, but the others show similar amplitude and waveform than those without the TMS pulse.



MRI signal spectrum was affected up to 3–4 ms after the TMS pulse with two coils simultaneously.

Figure 6: Frequency spectrum power of the MRI signals recorded at 1-ms intervals after the TMS pulse. The light orange lines (up to 3-4 ms) have substantially different frequency spectrum than the reference signal without the TMS pulse (dashed blue line). The resonant frequency is represented as 0 Hz.