In-vivo MRI tCS compatibility

Neuroelectrics White Paper WP201505

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Introduction & Objective

There is an increasing use of non-invasive neuroimaging tools for studying the anatomy and function of the brain at different levels. Modalities such as magnetic resonance imaging (MRI) and near infrared spectroscopy (NIRS) are without significant risk, generally require minimal subject preparation, and are well tolerated when performed by experienced teams.

MRI methods such volumetric T1 imaging and Diffusion Tensor Imaging (DTI) are being used more frequently to determine the gross anatomy and structural connectivity of the developing or neurodegenerative brain (Papadelis et al., 2015). Functional MRI (fMRI) and NIRS are being used to assess the hemodynamic of neurovascular responses and for functional localization (Govindan et al., 2014; Fabiani et al., 2014). Recently, intrinsic functional connectivity MRI (fcMRI) has emerged as a powerful tool for mapping large-scale networks in the human brain. Robust and reliable functionally coupled networks can be detected in individuals that echo many known features of anatomical organization. Features of brain organization have been discovered, including descriptions of distributed large-scale brain networks (Buckner et al., 2013)

Further, electrophysiology can be used to bridge the gap between the changes in brain activity after damage and the construction of efficacious compensating interventions. Recent advancements of transcranial current stimulation (tCS) protocols involved the induction of proper excitation/inhibition effects to selected regional targets (Tecchio et al., 2013). Combining neuroimaging and electrophysiological methods is a useful approach to answer scientific questions and to explore the brain's functional organization to examine if it is altered in neurological or psychiatric diseases.

Here we provide a technical description of different MRI-tCS tests using Starstim (wireless EEG/tCS system from Neuroelectrics Barcelona S.L) and the Neuroelectrics (NE) MRI compatibility kit. The following tests were fulfilled and managed independently in the Göttigen University Medical School, Dept. of Clinical Neurophysiology (Robert-Koch-Strasse 40, 37075 Göttingen, Germany) under the supervision of Prof. Antal (Prof. Paulus Dept.) and Dr. Dechent, Head of the Research Group MR-Research in Neurology and Psychiatry Medical Faculty.

Methods

Weeks before the in-vivo experiment, a thermal safety test was conducted in the *Institut de Diagnostic per la Imatge* (Barcelona, Spain) in order to assess the temperature variations in the sponge stimulation electrodes before and after 10 minutes of an MRI experiment with EPI sequences. The components of the MRI compatible kit for stimulation were assembled and the electrodes were placed in a phantom located inside a 3T Magnetom Verio scanner (Siemens, Erlangen, Germany), as illustrated in Figure 1. Photos were taken with a thermal camera.

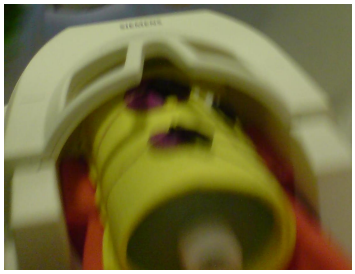

Figure 1. Phantom for safety tests

Starstim stimulation tests (i.e., tDCS, tACS and tRNS) concurrent with MRI scans with different MRI sequences (T1-weighted, EPI) were conducted on a volunteer after obtaining informed consent. The participant was asked to relax and to close his eyes for the whole MRI-tCS resting-state experiment. Thereafter, he was asked to report on his experience in terms of any potential adverse events (e.g., burning sensations, dizziness, etc.) and causally-related stimulation feelings (e.g., itching, induced phosphenes, etc.). Note that the components of the MRI compatible kit for stimulation were tested weeks before. The test consisted on placing the stimulation electrodes in a phantom, connecting all the cables and perform an MRI

Equipment and installation

For the following MRI-tCS tests, Starstim was used in conjunction with the NE MRI compatible kit, which contains specific equipment that makes possible the use of the stimulation channels inside the MRI room. We used a multi-channel kit and montage, as described in the NE_MRIkits_Manual.pdf. The NE MRI kit installation was handled by a NE technical expert on the field, since the MRI filter and the patch panel interface require special attention when installed. The patch panel was properly connected to the ground of the MRI. A metallic L-bracket structure supported the MRI Filter. The L-bracket was attached to the patch panel using a pair of screws. The MRI filter was placed on the side of the patch panel that faces the control room, as shown in detail in Figure 2 & 3. The electrodes cables were connected to the electrodes on the scalp of the subject and run straight, without being coiled or twisted, through the scanner tunnel towards the neck of the subject.

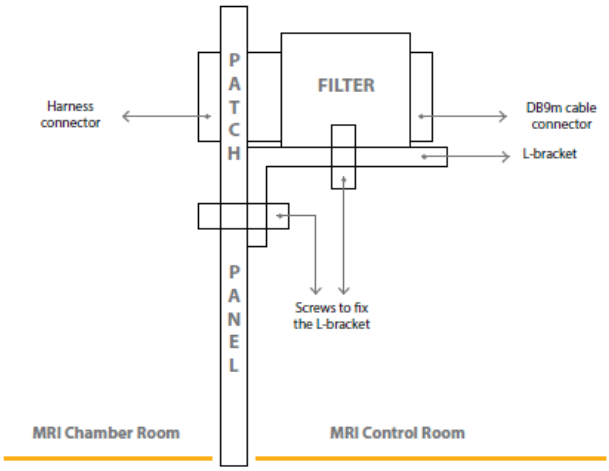

Figure 2. MRI Filter and Patch Panel diagram

fMRI acquisition

Brain images were acquired from on a 3 Tesla Magnetom Tim Trio scanner (Siemens, Erlangen, Germany) using an 8-channel phased-array head coil. Foam cushions were used to prevent head movement, and earplugs were used to attenuate scanner noise. For each of the stimulation tests (tDCS, tACS and tRNS), a high-resolution anatomical T1-weighted MR dataset was acquired covering the whole head at 1 mm^3 isotropic resolution [3D Turbo FLASH, repetition time (TR): 2250 ms, inversion time: 900 ms, echo time (TE): 3.29 ms, flip angle: 9°]. Functional imaging was performed using a T2*-sensitive gradient-echo EPI technique with an in-plane resolution of 3 × 3 mm^2 (TR: 3000 ms, TE: 30 ms, flip angle: 70°, field-of-view (FOV): 192 x 192 mm^2, acquisition matrix: 64 × 64, ipat: 2). Fifty volumes of 56 sections at 3 mm thickness (10 % gap) angulated in an axial-to-coronal orientation covering the whole brain were acquired.

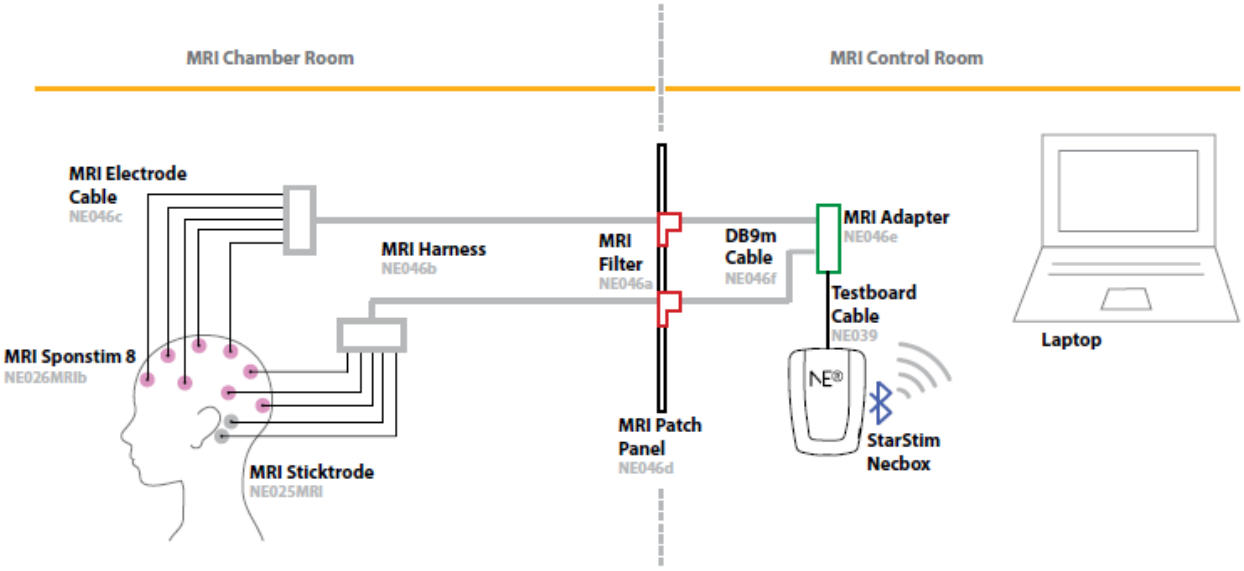

Figure 3. MRI multi-channel montage: Note that for more than 3 stimulation channels 2 MRI harness are required – each with 5 stimulation channels/electrodes. CMS/DRL references need to be connected using 2 channels.

Montage. MRI-tCS multichannel electrode positions

We first checked the NE neoprene cap for MRI compatibility and artefact-free acquisition. During all battery tests, the NE neoprene cap was used to fix the five NE MRI-sponges (8 mm^2) covering the multi-channel MRI-tCS montage. The MRI-sponges were placed over AF3, CP5, FC1, AF4 and FC5 of the international 10-10 EEG system. The sponges were soaked with saline solution (NaCl 0.9%) to improve the scalp-electrode impedance. NE references (CMS/DRL) using MRI sticktrodes were placed on the mastoid, as usual (see Figure 2). For an illustration of the specific montage using Starstim's Neuroelectrics Interface Controller (NIC) software see Figure 4. Basic settings were used showing here the main stimulation electrode on AF3 (anode) and the "return" electrode on the remaining positions. Note that this set-up is valid for tDCS whereas for tACS and tRNS, anode and cathode alternate in time. Return percentages were equally set to 25%.

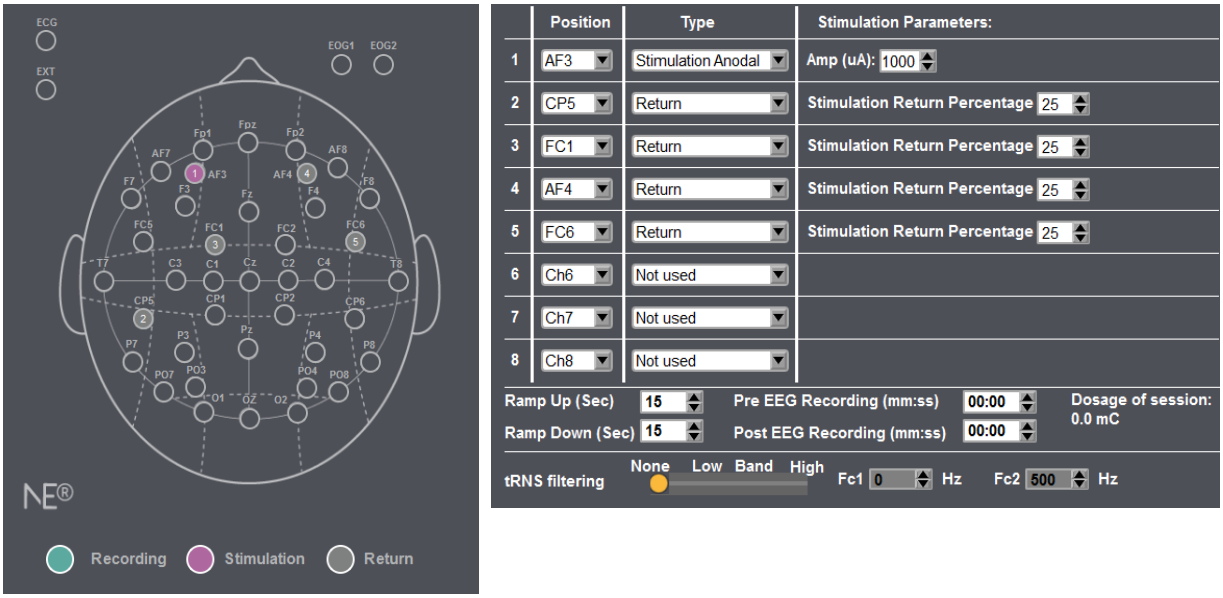

Figure 4. NIC Montage and configuration set-up

Set-up. MRI-tCS protocols

We run a battery of MRI-tCS tests with tDCS, tACS and tRNS protocols at a current intensity of 1 mA. Each of the MRI-tCS protocol tests was programmed for 10 min with 15 sec ramp-up and ram-down times. No EEG was performed during the experiments. The frequency of the tACS protocol was set to 10 Hz for the in-vivo experiments. No filtering was used during tRNS tests.

Results

Thermal Safety Tests

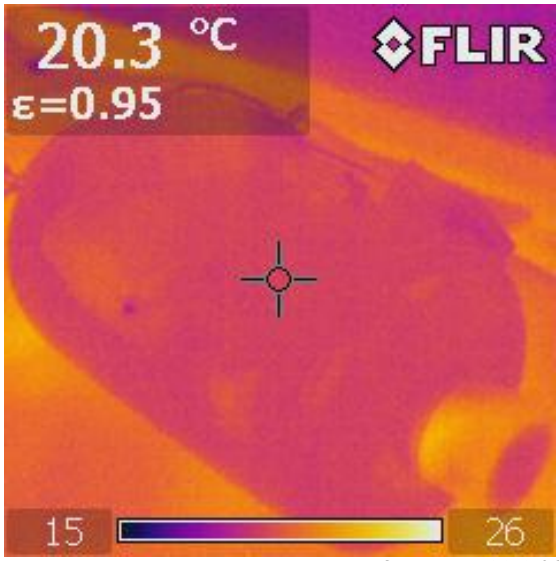

Figure 5. Electrode temperature before MRI: 20.3 ºC

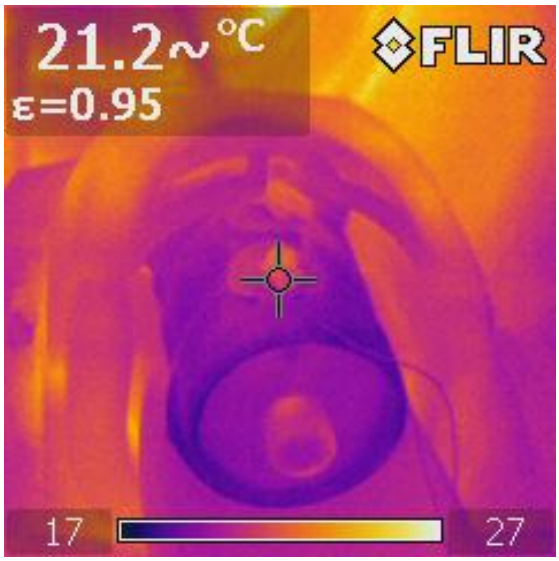

Figure 6. Electrode temperature after 10 min of MRI with EPI sequences: 21.2 ºC

tDCS tests: MRI T1 & EPI sequences

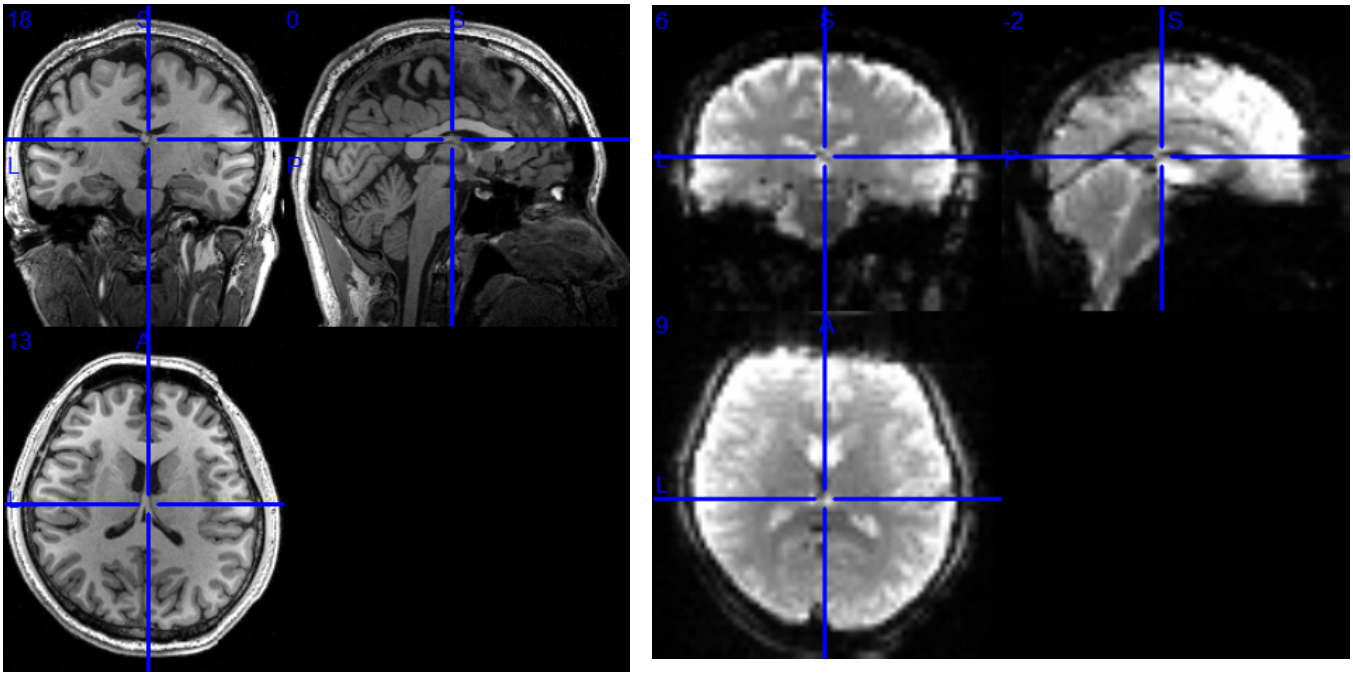

Figure 7. tDCS (1 mA) results – MRI T1 (left) & MRI EPI (right)

tACS tests: MRI T1 & EPI sequences

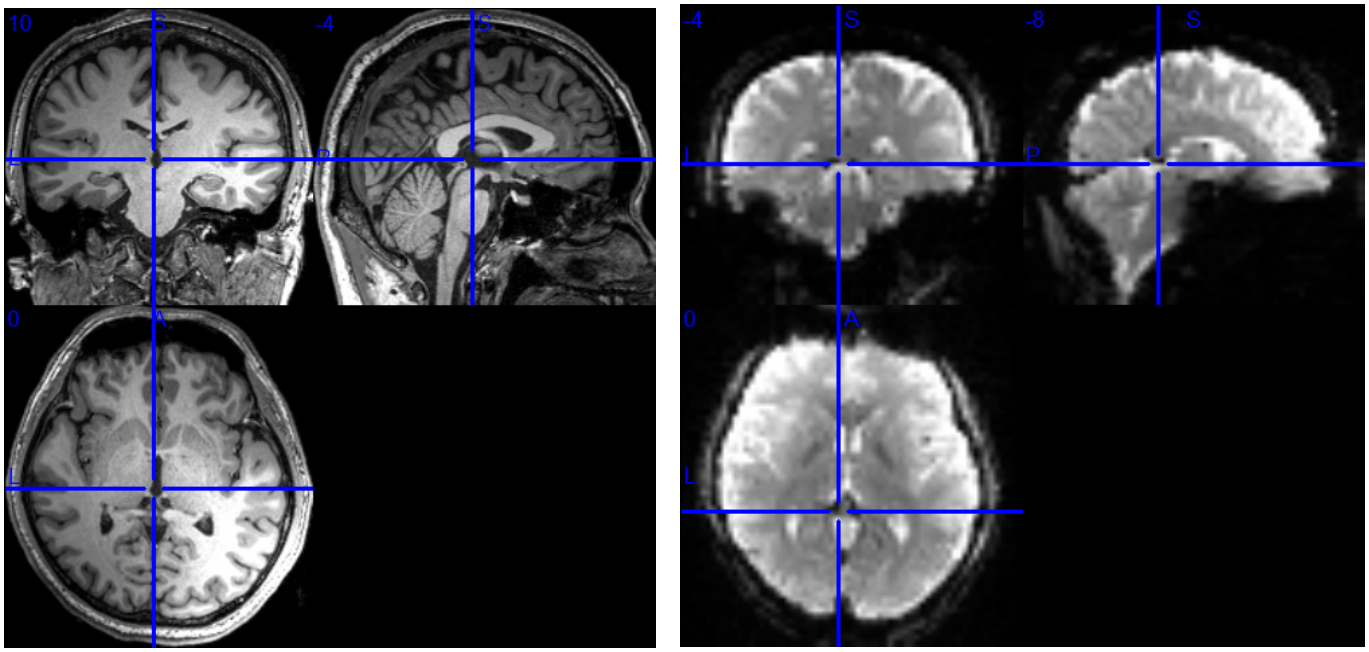

Figure 8. tACS (1 mA, 10 Hz) results – MRI T1 (left) & MRI EPI (right)

tRNS tests: MRI T1 & EPI sequences

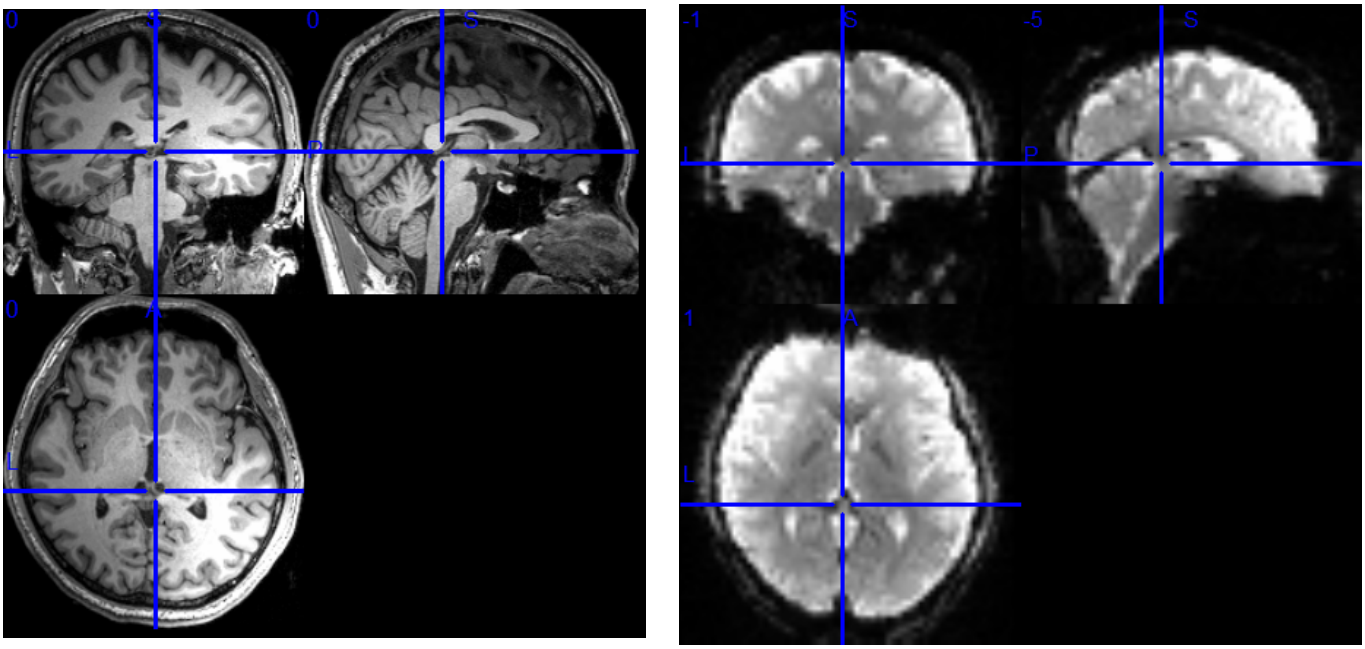

Figure 9. tRNS (1 mA, no filtering) results – MRI T1 (left) & MRI EPI (right)

Phantom MRI-test

Prior to in-vivo testing, there was a phantom MRI test considering all previous depicted MRI-tCS protocols. For every setup/protocol, SNR values for the EPI sequences (usually reported for fMRI) were calculated.

Table 1: SNR Results – phantom MRI-test

Protocol	SNR	Comment
No stim	792	Baseline (NE MRI wires in the room)
No stim	768	Baseline (with NE neoprene cap)
No stim	851	Dual-MRI electrodes (Ten20 conductive gel)
tDCS (1mA)	818	Dual-MRI electrodes (Ten20 conductive gel)
tACS (1mA, 10Hz)	784	Dual-MRI electrodes (Ten20 conductive gel)
tACS (1mA, 200Hz)	756	Dual-MRI electrodes (Ten20 conductive gel)
tRNS (1mA)	850	Dual-MRI electrodes (Ten20 conductive gel)
No stim	876	Multi-channel 5 MRI electrodes (Ten20 conductive gel)
tDCS 650uA	877	Multi-channel 5 MRI electrodes (Ten20 conductive gel)
tACS (1mA, 10Hz)	775	Multi-channel 5 MRI electrodes (Ten20 conductive gel)
tACS (1mA, 200Hz)	877	Multi-channel 5 MRI electrodes (Ten20 conductive gel)

Conclusions

The thermal photos show the temperature of the electrodes has risen 0.9 ºC during 10 minutes of MRI with EPI sequences. This let us assume that the simulation equipment, including electrodes, is not subjected to over-heating caused by MRI that could compromise the safety of an individual undergoing an MRI simultaneously with non-invasive brain stimulation session using the same equipment.

All tests were performed successfully with no appreciable SNR degradation or subsequent artefacts. Further, the subject reported no adverse events after taking part in this experiment, in which participation was free and without any retribution.

Starstim can thus provide in-vivo MRI-tCS compatibility using Neuroelectrics MRI kit in the here depicted scenarios.

Acknowledgements

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