A wearable whole-head "RF-EEG Cap" for concurrent TMS/EEG/fMRI experiments at 3T: a feasibility study

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Motivation

Combining **TMS/fMRI/EEG** offers the next-generation capabilities for causal-functional mapping of the human brain circuits in a non-invasive way. However, the triple combination presents technological challenges especially due to the lack of dedicated hardware (see **Fig.1 Column 1-3**). Feasibility of concurrent human TMS/EEG/fMRI measurements at 3T has been recently demonstrated[1,2].

However, the presented data were acquired either with the body coil (extremely low-sensitivity) or a birdcage coil (**Fig.1 column 2**). Moreover, no parallel imaging acquisition methods[3,4,5] were used due to the lack of multichannel RF-coils, limiting the spatiotemporal resolution of the acquisition. Nevertheless, these results rigorously demonstrate the basic feasibility and safety of the technology.

capabilities/coil	32/64-channel head array	birdcage coil	dedicated thin RF coil array	Proposed "RF-EEG Cap"
commercial TMS compatibility	✗	~*	✓	✓
full head coverage	✓	✓	✗	✓
high sensitivity	✓	✗	✓	✓
parallel imaging capabilities	✓	✗	✓	✓
neuronavigation in bore	✗	✗	✓	✓

***limited applicability in some regions**

Fig. 1. Summary of available instrumentation for MR acquisitions and its capability for online TMS/fMRI acquisitions.

Proof of concept : EEG Acquisition

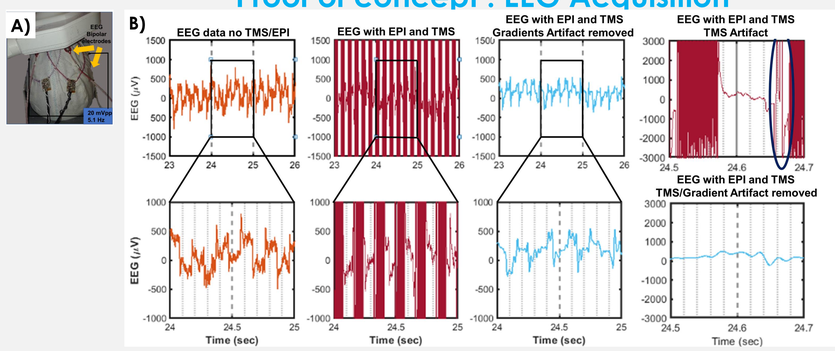
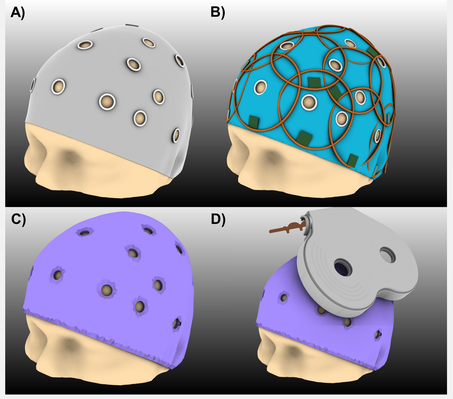


Fig.4. A) Set up used to produce synthetic EEG signal on the phantom. TMS was applied horizontally over the center of the phantom. **B) First column** shows acquired synthetic EEG data from the phantom in the bore when no MR imaging was performed. **Second column** shows acquired synthetic EEG data from the phantom in the bore when MR imaging and TMS stimulation were performed in an interleaved way. The plots show all artifacts contaminating the EEG signal. **Third column** shows acquired synthetic EEG data acquired after removing gradient and TMS artifacts. **Fourth column** shows a more detailed view of the TMS artifact and how it was removed by post-processing.

The "RF-EEG Cap" Concept



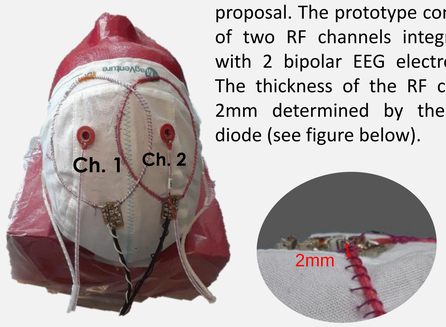


Fig. 3. We have built a 2-channel prototype (shown in the picture) to assess the feasibility of the proposal. The prototype consists of two RF channels integrated with 2 bipolar EEG electrodes. The thickness of the RF coil is 2mm determined by the PIN diode (see figure below).

Fig. 2 The proposed RF-EEG Cap (in blue (B)) is thought to be attached to a commercial EEG Cap (above in grey, (A)). We plan to use flexible self-resonant coaxial cables[6,7] as technology to build the RF loops, having 24 channels. The RF Elements should be covered with another cap (in purple (C and D)) to isolate all components from the subject. The thickness of the whole assembly should be about 5mm.

Proof of concept : MR Imaging

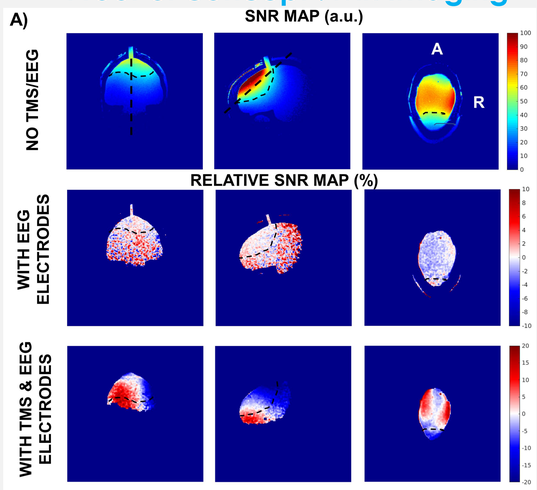


Fig 5. A) Top SNR maps of 3 slices of the phantom using the prototype **without EEG-electrodes and TMS**. The black dashed lines in the coronal slices indicate the position of the transversal slice. **Center**. Relative change of the SNR in percentage when **placing the EEG-electrodes** on the prototype. **Bottom.** Relative change of the SNR in percentage when **placing the electrodes and the TMS coil** on the prototype**.** Dashed lines show the region where the built prototype has an acceptable SNR.

Conclusion

From the results of theses experiments and additional ones such as benchmark testing, B0 maps and fMRI timeseries stability (not shown here) we conclude that :

- the flexible coaxial RF technology is a feasible choice to build the proposed "RF-EEG Cap". The detuning effect of the TMS on the resonance of the RF elements was found to be less than 0.4MHz compared to 4-5MHz when using standard copper wire coils[8].
- Observed SNR effects are minimal when applying the EEG electrodes and only TMS B_1^+ effect is visible when applying both.

The minimal effects observed on the SNR, B0 maps, EEG quality signal and fMRI volumes and timeseries justify the further development of the "RF-EEG Cap" to enable high quality data acquisition for concurrent TMS/EEG/fMRI experiments.

References: **1**: *Peters et al.* , J. Neurophysiol. 109, 1214–1227 (2013) **2**: *Peters et al.* , Commun. Biol. 3, 1–11 (2020); **3:** *Pruessmann et al.*, Magn. Reson. Med. 42, 952–62 (1999) **4:** *Griswold et al.*, Magn. Reson. Med. 47, 1202–10 (2002) 5: *Auerbach et al.*, Magn. Reson. Med. 69, 1261–7 (2013).*6: Zhang et al.* Nat. Biomed. Eng. 2, 570–577 (2018)*; 7: Ruytenberg et al., Magn. Reson. Med. 83 (3), 1135-1146 (2020), 8: Navarro de Lara et al,* Magn. Reson. Med. 74, 1492–1501 (2015) Funding: **R01MH111829.** MGH/Martinos : **P41EB015896**, **S10RR019307**, **S10RR019254**, **S10RR023043**.