Design and production of a 5-coil multi-locus TMS transducer

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Introduction

Conventional transcranial magnetic stimulation (TMS)

- Manual coil positioning is slow and has variable accuracy.
- Nearby cortical regions cannot be stimulated simultaneously as the coils are large.

Multi-locus TMS (mTMS)

- The overlapping-coil mTMS technology introduced by Koponen et al. [1] solves these limitations, allowing electronic control of the stimulus location.
- We developed a practical and manufacturable five-coil transducer to control the stimulus orientation and rotation within a circular region.

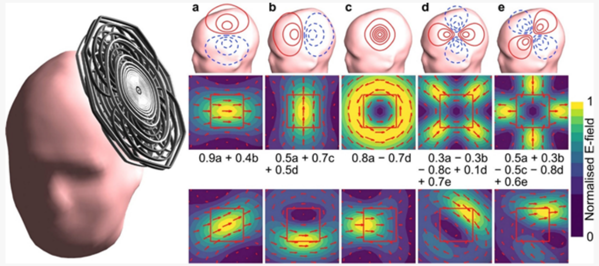

Fig. 1. 1st row: Schematics of previously proposed five coils for controlling the stimulus location and orientation within a 3 × 3 cm diameter rectangle. **2nd row:** The induced electric field distribution on a spherical cortical surface for each coil. **3rd row:** Electric field distribution resulting from the linear combination of multiple coils changing the stimulation location and orientation within a 3 × 3 cm region (red square). Figure reproduced from [1].

Methods

- The coil windings were designed using a minimum-energy optimization algorithm [1] and a set of initial parameters.
- **Critical initial parameters:** transducer dimensions, coil stack order, number of winding turns, and the area under the coil where the stimulation location can be controlled.
- The optimized coil windings were finalized and modeled into formers with Fusion 360 (Autodesk, USA). The formers were 3D-printed, and the coils were hand-wound using Litz-wire.

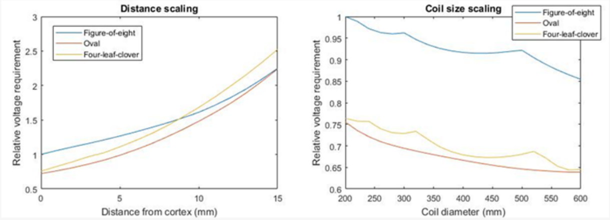

Fig. 2. Left: Coils require more power when further away from the head, however, each coil type scales differently. **Right:** size decreases power requirements.

Fig. 3. 3D model of the wire paths in a figure-of-eight coil. The wires were arranged in partially overlapping turns to induce an electric field in the brain with desired voltage, energy, inductance, and electric current requirements.

Results

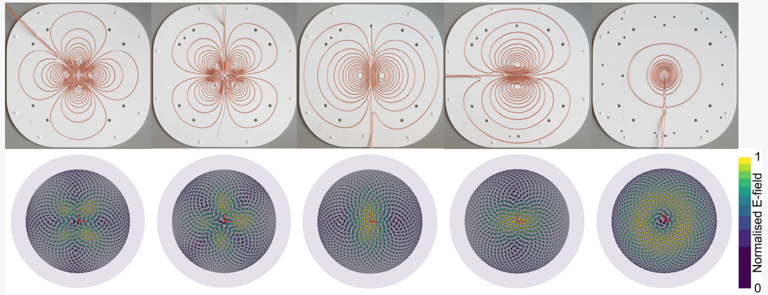

Fig. 4. Top row: The manufactured 5-coil transducer: two four-leaf-clover coils, two figure-of-eight coils and one round coil stacked on top of each other from closest to furthest from the head. The rectangular transducer is 2.6-cm thick and has a side length of 30 cm. **Bottom row:** The induced electric fields were measured on a 70-mm radius spherical cortex model using an electric field characterization device [2] and the measured electric field distributions resemble closely the simulated distributions in Figure 1.

Conclusions

The manufactured mTMS coils will allow the electronic control of the stimulation location and orientation in a 3-cm-diameter circular region. Further calibration and experimental validation of the transducer is needed. The device will allow moving the stimulation site faster and more precisely than a human or robot could do with a conventional TMS coil. The system will be useful, e.g., for studying brain networks, compensating head movements, and developing automated algorithms for brain stimulation.

References

[1] Koponen, L.M., Nieminen, J.O. and Ilmoniemi, R.J., 2018. Multi-locus transcranial magnetic stimulation—theory and implementation. *Brain Stimulation*, 11(4)

[2] Nieminen, J.O., Koponen, L.M. and Ilmoniemi, R.J., 2015. Experimental characterization of the electric field distribution induced by TMS devices. *Brain Stimulation*, 8(3)

Acknowledgements

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