Published in final edited form as:

Clin Neurophysiol. 2016 October ; 127(10): 3341–3342. doi:10.1016/j.clinph.2016.08.011.

3D-printed head models for navigated non-invasive brain stimulation

Eran Dayan*, Ryan M. Thompson, Ethan R. Buch, and Leonardo G. Cohen*

Human Cortical Physiology and Neurorehabilitation Section, National Institute of Neurological Disorders and Stroke, National Institutes of Health, United States

Recent years have seen considerable interest in the clinical use of noninvasive brain stimulation (NIBS), including transcranial magnetic stimulation (TMS) and transcranial electrical stimulation (tES) (Hummel et al., 2005; Dayan et al., 2013; Fox et al., 2013; Dunlop et al., 2016; Otal et al., 2016). One promising avenue of research that advances towards minimizing interindividual differences in patients' responses to NIBS integrates brain imaging data, particularly functional and structural brain connectivity, to provide personalized, guided stimulation in clinical contexts (Fox et al., 2013; Dunlop et al., 2016; Otal et al., 2016). However, integrating imaging datasets into neuronavigation systems while simultaneously searching for the optimal stimulation site(s) in the clinic is a time-consuming process which requires operator training and may not be well-tolerated by some neurological and neuropsychiatric patient populations. Here, we propose a strategy to optimize operator training and allow for individualized, pre-intervention planning offline, which does not require the patient's participation.

Our protocol combines a commercially-available neuronavigation system (Fig. 1A) together with 3D printing, an emerging technological innovation that allows users to fabricate 3D objects. We propose to use 3D printing technology to generate full-size head models, reconstructed using subjects' magnetic resonance imaging (MRI) data, which can then be used in neuronavigation sessions. To describe and validate the protocol, we used data from a healthy volunteer (female, 42 years old), applying procedures approved by the local Institutional Review Board. We first imported the subject's structural MRI (based on a T1 weighted MP-RAGE sequence) into the ITK-SNAP software (v3.4.0-rc1), segmented the head/scalp surface, and exported the head surface volume as a surface mesh. The mesh was then smoothed in Blender software (v2.73) and the orientation of its surface normals were reversed using MeshLab software (v1.3.3). We then cropped the model to fit the printer build volume using Netfabb software (Basic v6.4.0 252). The final model was loaded into CatalystEx software (v4.4) to be sliced and formatted for printing, and was then printed on a uPrint SE Plus Stratasys printer with a layer resolution of 0.254 mm. We next performed 20 neuronavigation sessions using the Brainsight system (v2.2.7; Rogue Research), half of which with the 3D head model (Fig. 1B) and the remaining with the actual subject. In short, the subject's structural MRI was first imported into Brainsight and was used to perform a 3D

*Corresponding authors. eran_dayan@med.unc.edu, (E. Dayan), cohenl@ninds.nih.gov (L.G. Cohen).

Conflicts of interest: None disclosed.

reconstruction of the brain and to segment the skin surface of the subject's head. Landmarks were selected and then used for subject (or model)-image registration. We then assessed how well the registration of the model and subject matched by using 3 scalp reference points (Cz, Fz and Pz) based on the international 10/20 system of electrode placement. As a measure of the match between the registration of the 3D model and the MRI image in comparison to that of the real subject's head and the MRI image, we calculated the Euclidean distance between each of the model's and the subject's reference point coordinates. We report that the two registrations were indeed well-matched along the three reference points (Fig. 1C), with a mean distance of 3.83 mm (3.11 mm for Cz, 2.82 mm for Fz and 5.56 mm for Pz), well beneath previously-reported intersession variability in stimulation-site positioning based on the 10-20 system (Herwig et al., 2003).

The protocol described here can allow clinicians and operators of NIBS technologies to conduct extensive neuronavigation-based, pre-treatment planning sessions as needed for each individual subject. This approach will allow integration of multiple imaging modalities into the neuronavigation environment of an individual subject without prolonging the patient's treatment time in the clinic. This technique may also be suitable for training purposes. Neuronavigation sessions in which multiple imaging modalities are integrated and the optimal stimulation trajectory is determined may last 45 min to an hour (and longer in the context of training). Thus, the approach described here may ideally facilitate individualized neuronavigation in frail populations that may not otherwise tolerate lengthy pre-treatment procedures.

Acknowledgment

We wish to thank Ms. Verma Walker for her help and expertise. This work was supported by the Intramural Research Program of the National Institute of Neurological Disorders and Stroke.

References

- Dayan E, Censor N, Buch ER, Sandrini M, Cohen LG. Noninvasive brain stimulation: from physiology to network dynamics and back. *Nat Neurosci.* 2013; 16:838–44. [PubMed: 23799477]
- Dunlop K, Woodside B, Olmsted M, Colton P, Giacobbe P, Downar J. Reductions in cortico-striatal hyperconnectivity accompany successful treatment of obsessive-compulsive disorder with dorsomedial prefrontal rTMS. *Neuropsychopharmacology.* 2016; 41:1395–403. [PubMed: 26440813]
- Fox MD, Liu H, Pascual-Leone A. Identification of reproducible individualized targets for treatment of depression with TMS based on intrinsic connectivity. *Neuroimage.* 2013; 66:151–60. [PubMed: 23142067]
- Herwig U, Satrapi P, Schönfeldt-Lecuona C. Using the international 10-20 EEG system for positioning of transcranial magnetic stimulation. *Brain Topogr.* 2003; 16:95–9. [PubMed: 14977202]
- Hummel F, Celnik P, Giraux P, Floel A, Wu WH, Gerloff C, Cohen LG. Effects of non-invasive cortical stimulation on skilled motor function in chronic stroke. *Brain.* 2005; 128:490–9. [PubMed: 15634731]
- Otal B, Dutta A, Foerster A, Ripolles O, Kuceyeski A, Miranda PC, Edwards DJ, Ilic TV, Nitsche MA, Ruffini G. Opportunities for guided multichannel non-invasive transcranial current stimulation in poststroke rehabilitation. *Front Neurol.* 2016; 7:21. [PubMed: 26941708]

Fig. 1.

Neuronavigation with 3D-printed head models. (a) The protocol utilizes a commercially-available neuronavigation system and 3D-printed head models reconstructed based on subjects' MRIs. (b) The full-size head models can be registered to subjects' structural MRIs in the neuronavigation system, which may then allow for lengthy pre-treatment planning sessions in the absence of subjects (or patients). (c) We assessed the registration of the model to a subject's MRI by repeating the registration with the actual subject and using 3 scalp reference locations (Cz, Fz and Pz) localized according to the 10/20 system. Each registration session was repeated 10 times. The two registrations were well-matched with a mean Euclidean distance of 3.83 mm. Representative registrations are shown. Panel A reproduced with permission by Rogue Research.