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Ultrasound holograms to enhance deep-brain neuromodulation

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Transcranial focused ultrasound is widely used for neuromodulation at moderate intensity. To achieve a good treatment, it is important to have a control of the transducer focus location relative to the target of interest, but when ultrasound propagates through the skull it suffers from aberrant and attenuating effects that result in an undesired defocusing and uncertainty of the focus shape and location. Moreover, some nuclei of interest for neuromodulation are symmetrical in both brain hemispheres and current technologies are not capable of producing a simultaneous sonication of these structures.
In this work, we present the capability of acoustic holograms to control the focus shape and location even through the skull. First, time reversal simulations were done to adapt ultrasound focus to deep-brain targets of interest for neuromodulation, such as hippocampus, thalami, putamen and caudate nuclei. Second, holograms were 3D-printed and experimentally validated with an ex-vivo skull in water. We have simulated acoustic holograms to focus on both hippocampi, putamen and caudate nuclei from the parietal bone. Transcranial measurements completely agreed with numerical calculations. We have also created holograms to optimize the covered target volume when sonicating through the temporal bone window while avoiding skull heating, specifically for the thalamic nuclei. Results show that more than 20 % of the volume of bilateral targets within the brain can be covered with a single hologram while minimizing the sonicated non-objective brain tissue.

Acoustic holograms are a robust and low-cost system to focus ultrasound beams through the skull into deep-brain nuclei for precise and selective neuromodulation applications.

