Developing a Novel Adaptive Tuning Module for Real-Time Frequency Correction in Radiofrequency Coils During Concurrent TMS-fMRI

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Concurrent transcranial magnetic stimulation-functional magnetic resonance imaging (TMS-fMRI) is a promising neuroimaging approach to visualize brain activity during TMS, improving targeting accuracy and symptoms for neuropsychiatric disorders. However, hardware limitations restrict its clinical translation: electromagnetic interference from the TMS coil shifts frequency of radiofrequency (RF) coils, vital components of fMRI, reducing image quality, while spatial constraints between both coils compromise treatment efficacy. Thus, I engineered a novel adaptive tuning module to optimize RF coil performance and improve image quality, measured by signal-to-noise ratio (SNR), by correcting frequency shifts in real-time during concurrent TMS-fMRI. I constructed an RF coil, integrating a voltage-controlled variable capacitor for real-time tuning and utilized amplitude-based feedback to identify frequency shifts induced by a mock TMS coil positioned 1, 8, and 15 mm from the RF coil. I validated the module using a network analyzer, evaluating two cases at each position: (1) TMS coil; (2) TMS coil with the tuning module. I imaged each case in a 3T-MRI scanner, including one scan, exclusively with RF coils, as an ideal-image-quality control. The 8 mm separation demonstrated a substantial 41.35% SNR increase with the tuning module, corresponding to 69.32% of the ideal image quality, suggesting the module accurately corrects frequency under clinically-relevant coil distance. Furthermore, SNR increases of 31.10% and 23.89% at 1 mm and 15 mm, respectively, demonstrate its ability to improve image quality across multiple separations. Findings from my study may help overcome implementation challenges, enabling widespread clinical use for improved patient outcomes.

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