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Behavior-dependent layer-specific oscillations, phase-amplitude coupling and spike-to-LFP coupling in a data-driven model of motor cortex circuits

Exploring the primary motor cortex (M1) is crucial for understanding motor functions, as well as for developing new treatments for motor disorders. Neural oscillations, a universal hallmark of brain activity, exhibit specific patterns within M1, related to motor control. During movement, gamma activity increases and beta activity decreases, reflecting active motor engagement. During immobility, an opposite pattern is observed ‒ decrease of gamma and increase of beta activity. Theta and delta oscillations orchestrate higher-frequency activities along the cortex, which manifests as cross-frequency coupling between theta/delta phase and beta/gamma amplitude. Previously, we built a biophysically detailed model of the M1 circuit validated against in vivo experimental data. The model spontaneously generated delta, beta, and gamma oscillations, with gamma increase and delta decrease during the movement state. Interestingly, beta and gamma were both locked to the delta cycle and occurred at opposite delta phases. To further test our modeling results, we analyzed multi-layer LFP data recorded from the M1 of mice engaged in a reaching task, where they had to move a joystick following an auditory cue and maintain its position for a certain time period. Following the cue, we observed an overall low-frequency power decrease (below 25 Hz) in deep layers, except for the theta activity, which remained unchanged. High-frequency power increased in superficial and middle layers, with stronger gamma during the initial ballistic movement phase and stronger high-beta during the subsequent maintenance of joystick position. The amplitudes of gamma and beta were locked to theta cycle, with various depth profiles and preferred theta phases. Despite the discrepancies in the frequency bands between the model and the experiment, a common pattern was observed: movement-related gamma, holding-related beta, and low-frequency activity that modulates both of them in a phase-dependent manner.