MINDFULNESS MEDITATION STATE AND TRAIT THROUGH THE EYES OF BRAIN COMPUTATIONAL MODELLING

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Background: Meditation offers a unique window into how consciousness, attention, and neuroplasticity arise from dynamic brain processes. Over the past two decades, neuroimaging studies have shown that it actively reshapes large-scale brain network interactions. Different styles — focused attention, open monitoring, and non-dual awareness — engage distinct neural circuits and alter the balance between attention, salience, and default mode networks (Malinowski, 2013; Marzetti et al., 2015). This makes meditation a powerful model for studying flexible brain reorganization.

Aims: This project aimed to uncover how different modes of attentional engagement shape large-scale brain network dynamics, providing mechanistic insights into how meditation alters consciousness, attention, and self-referential processing. We combined a cross-sectional approach in expert practitioners and a longitudinal approach in meditation-naïve individuals to disentangle state- and trait-related features.

Methods: Twelve expert Theravada Buddhist meditators (virtuoso group) were recorded with MEG and fMRI during rest, focused attention meditation (FAM), and open monitoring meditation (OMM). In parallel, twenty meditation-naïve adults took part in an 8-week Mindfulness-Based Stress Reduction (MBSR) program, with EEG and behavioral assessments before and after training. We analyzed functional connectivity, spectral power, EEG and MEG microstate dynamics, and criticality metrics (Hurst exponent, Lempel–Ziv complexity). To bridge data and theory, we also developed computational models of network synchronization and criticality.

Results: Distinct neural signatures emerged for the two meditation styles in the virtuoso group. FAM enhanced fronto-parietal connectivity and stabilized microstate patterns, reflecting sustained focus. OMM, in contrast, engaged broader brain networks and showed higher neural complexity, with more diverse microstate sequences. Across meditation states, we observed reduced long-range temporal correlations and increased complexity — signatures of a system moving closer to criticality. In the meditation-naïve group, after MBSR, participants showed improved processing speed, lower stress, and measurable shifts in EEG microstate dynamics, echoing expert patterns on a smaller scale.

Conclusions: Microstate and criticality measures emerged as powerful biomarkers of both expertise and rapid training effects, offering new insight into how contemplative practices shape the brain.

Keywords: Mindfulness meditation, Mindfulness Based Stress Reduction Therapy, Non-invasive electrophysiology, Microstates, Complexity

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