THE ETERNAL MOVEMENT OF A STILL MIND: EXPLORING THE PROPERTIES OF DYNAMIC BRAIN NETWORKS IN MEDITATION PRACTICES

Roberto Guidotti[1,2]

[1]Deparment of Neuroscience, Imaging and Clinical Sciences, University "G. D'Annunzio" Chieti-Pescara, Italy; [2]Institute for Advanced Biomedical Technologies, University "G. D'Annunzio" Chieti-Pescara, Italy

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Background: Meditation practices are characterized by distinctive qualities including clarity, aperture, stability, and effort. Network control theory (NCT) offers a novel framework to quantify these properties from neural data and to provide insights into the neural mechanisms underlying meditative states.

Aims: The goal is to investigate differences in average controllability of brain networks. Indeed, average controllability measures the ability of the networks to drive the system into easy-to-reach states. Thus, we hypothesize that it changes across different meditation styles and resting states and between expert and novice meditators

Methods: We analyzed fMRI data from expert meditators and novices during Focused Attention (FA), Open Monitoring (OM) meditation, and resting state (RS). Functional connectivity was calculated using the Schaefer parcellation and used as a surrogate for structural connectivity. Average controllability was computed for seven large-scale brain networks. A three-way ANOVA examined effects of group, condition, and network, followed by post-hoc t-tests to identify specific differences. Correlations between average controllability and meditation expertise were assessed in the expert group.

Results: The analysis revealed significant main effects for condition ($F_{1,2}$ =27.77, p<0.001), group ($F_{1,1}$ = 41.45, p<0.001), and network ($F_{1,6}$ = 349.18, p<0.01). Experts showed significantly higher average controllability than novices in the Visual Network across all conditions (RS: t=2.63, p=0.008; FA: t=2.96, p=0.003; OM: t=3.54, p=0.0004). During FA meditation, group differences emerged in the Dorsal Attention Network (DAN) (t=3.36, p=0.0008), Limbic Network (t=2.67, p=0.007), and Somatic Motor Network (t=2.57, p=0.01). In RS, differences were found in the Control Network (t=3.93, p=0.0001), Default Mode Network (DMN) (t=2.74, p=0.006), and Dorsal Attention Network (t=2.56, p=0.01). Years of practice correlated positively with average controllability in the Visual Network for both FA (r=0.67, p<0.01) and OM (r=0.58, p<0.05).

Conclusions: NCT successfully captured meditation-related changes in brain network properties. The observed differences in average controllability, particularly in attention-related networks, align with the literature on the crucial role of the DAN, DMN and Salience Attention Network. These findings suggest that meditation expertise enhances the brain's capacity to flexibly transition between network states, supporting improved attentional control and self-regulation.

Keywords: Control Theory, fMRI, Brain networks, Network Controllability, Meditation

E-mail contact: r.guidotti@unich.it