A Hierarchy of Timescales in the Brain: From Mechanisms to Cognition

A hierarchy of timescales in the brain is a fundamental organizational principle linking brain structure to neural dynamics and cognition. Here, we investigate the mechanisms that give rise to a gradient of intrinsic timescales across brain regions, whereby temporal integration windows systematically increase along anatomical and functional hierarchies, enabling higher-order regions to integrate information over longer durations than sensory areas. We characterize the contributions of several factors to this organization, including neuronal and circuit heterogeneity, modular and hierarchical network topology that supports optimal dynamics without fine-tuning, and axonal delays and oscillatory processes that together shape a robust temporal scaffold. Using a combination of abstract and biorealistic computational models together with empirical neuroimaging data from resting-state and task-based conditions, we show that this gradient of timescale is not merely structural but support adaptive computation, playing a central role in higher cognitive functions such as predictive coding. Within this framework, temporal hierarchies provide a substrate for hierarchical inference, allowing the integration of sensory evidence over progressively longer timescales at higher processing levels. This perspective offers a unifying account in which the brain's temporal architecture supports flexible, context-sensitive processing across multiple scales, from microcircuits to behavior.