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TRR 295 ReTune

Learning how network structure shapes decision-making for bio-inspired computing.

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Why do some people solve more problems on intelligence tests than others? Based on strong correlations between reaction times and intelligence a prevailing theory is that higher intelligence is related to a faster brain. Indeed, some problems can be easily solved quickly (e.g., hitting the brake at a red light) while others require a certain amount of time for thinking deeply (e.g., writing an abstract). What are neurobiological underpinnings of fast versus deep thinking?

We developed a learning algorithm that we used to build personalized brain network models for 650 Human Connectome Project participants from which multimodal MRI (structural, functional, diffusion) and extensive intelligence test results (fluid intelligence, g-factor, processing speed, ...) were available. In the empirical data, we reproduced the long-standing result that participants with higher intelligence scores were faster to solve simpler problems. However, unexpectedly, people with higher intelligence took more time to correctly solve difficult problems than the participants with lower general and fluid intelligence. In the simulated part, we used the learning algorithm to closely fit the simulated functional connectivity of each participant to its empirical counterpart. Importantly, the learning algorithm tunes functional connectivity based on a smooth relationship that we identified between excitation-inhibition balance and functional connectivity that allows to precisely set the synchrony between each pair of brain areas based on their relative balance of excitatory and inhibitory coupling. Analyzing simulation results, we identified a mechanistic link between functional connectivity, intelligence, processing speed and brain synchrony for trading decision-making accuracy with speed in dependence of excitation-inhibition balance. We found that simulated brain activity of each subject-specific model correlated with the empirical performance of the participant. By coupling decision-making and working memory circuits to the large-scale brain network model the model was used to explain the differences in underlying decision-making. Reduced synchrony led decision-making circuits to quickly jump to conclusions, while higher synchrony allowed for better integration of evidence and more robust working memory. Strict tests were applied to ensure reproducibility and generality of the obtained results. Here, we identify links between brain structure and function that enable to learn connectome topology from noninvasive recordings and map it to inter-individual differences in behavior, suggesting broad utility for research and clinical applications. Excitation-inhibition balance not only controls functional connectivity but also switches depths versus speed of decision-making in our model, which appears like a scale-free mechanism that governs intelligent behavior across all scales and explains how decision-making speed is traded with decision-making accuracy based on the large-scale hierarchical organization of a system. The algorithm appears as a general-purpose method to modularize systems of exciting and inhibiting elements into organized and hierarchical functional subsystems with explicitly tuned functional coordination and prescribed interaction, which may help increase artificial intelligence or to better simulate human intelligence.

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