Neuronal excitatory and inhibitory balance in neuron-astroglia-vasculature coupling and BOLD fMRI signal: A computational simulation study

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Keywords:
Neuron-Astroglia-Vasculature, Model, BOLD-fMRI

Abstract

Functional magnetic resonance imaging (fMRI) is used to study human brain activity by measuring changes in blood flow. This technique relies on the coupling between neuronal activity and cerebral blood flow, a process previously known as neurovascular coupling. While this relationship is well-established, the underlying cell signaling mechanisms, particularly the role of astrocytic calcium signaling, are still debated. We have previously developed a model to address the relationship between neuronal excitatory and inhibitory drives and the effects seen in astroglial and vascular activity (Tesler et al. 2023). This study demonstrates that calcium signaling primarily transmits information through frequency coding. Additionally, it shows that calcium activity predicts the BOLD fMRI responses, including the post-stimulus undershoot, and captures the effects of neuronal adaptation. In the present work, we explored the role of excitatory and inhibitory drives to BOLD signal. One of the key findings from our simulations is that variations in the excitatory/inhibitory ratio directly influence the amplitude and duration of the BOLD signal's post-stimulus undershoot, with an increase in the inhibitory component leading to a prolonged undershoot and suggesting stronger neuron-astroglia-vasculature activity post-stimulus. This framework allows integration into large-scale whole-brain simulators, such as The Virtual Brain, to simulate comprehensive brain activity. The Virtual Brain is an open-source brain simulation platform that allows for large-scale brain network modeling and the integration of multimodal data for simulating whole-brain activity. Our research introduces a framework that models and monitors neuron-astroglia-vasculature activity by emphasizing calcium signaling in astrocytes, linking neuronal excitability with vascular dynamics.

Funding:
101147319 (EBRAINS 2.0 Project)/European Union's Horizon Europe Programme, Eye and Neuroscience Bequest for Tampere University.