

A computational model relating changes in the BOLD (Blood Oxygen Level Dependent) signal to neural activity in cortex

W.G. Gibson¹, L. Farnell¹, and M.R. Bennett²

¹School of Mathematics and Statistics, University of Sydney, NSW, Australia,

²The Brain and Mind Institute, University of Sydney, NSW, Australia

Brain imaging methods, and in particular fMRI (functional Magnetic Resonance Imaging), do not detect neural activity directly, but rather changes in the blood flow and oxygenation in neighbouring blood vessels, this being the BOLD (Blood Oxygen Level Dependent) effect. It is still an open question as to how increased neural activity transmits a signal to nearby arterioles causing them to dilate and thus provide more oxygenated blood to the region. However, there is an increasing consensus that the type of glial cells known as astrocytes are vitally involved [1].

We have constructed a computational model of the steps leading from increased glutamate release at neuronal synapses to vasodilation in nearby arterioles. This incorporates a mathematical model of an astrocyte that we have previously used to account for calcium (Ca^{2+}) waves in two-dimensional arrays of astrocytes [2]. The steps in the present model are: (1) neural activity leads to glutamate release at synapses; (2) glutamate overspill at these synapses acts on metabotropic receptors on astrocyte processes that surround these synapses, leading to the production and release of EETs (epoxyeicosatrienoic acids) from the astrocytes, particularly from their endfeet which are in close proximity to arterioles; (3) these EETs diffuse in the extracellular space and act to hyperpolarize the smooth muscle cells that form the walls of the arterioles; (4) this hyperpolarization propagates electrotonically along the smooth muscle cells of the arteriole; (5) this in turn causes the closure of L-type Ca^{2+} channels in the smooth muscle cell walls and the subsequent decrease in cytosolic Ca^{2+} results in vasodilation and hence increased blood flow.

The model successfully accounts for the main observed changes in blood flow in cat visual cortex following stimulation by high-contrast drifting grating [3] and in rat somatosensory cortex following single whisker stimulation [4]. Using an extension of the balloon model [5] to multiple compartments, we are also able to predict changes in the BOLD signal that are in agreement with experiment.

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References

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