Characterization and modelling of spatiotemporal features of micro-vascular BOLD responses in humans

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BOLD fMRI is the most widely-used technique to measure brain function non-invasively in humans. A challenge in the interpretation of BOLD signals is that they consist of a mix of hemodynamic changes, some of which relate to neuronal activity via micro-vessels, and some of which relate to purely vascular effects via macro-vessels. Thus, the neurophysiological nature of the signals is unclear due to unknown variability in vascular organization and the spatiotemporal characteristics of the hemodynamic response within the volume imaged.

We report a novel 3D computational model of the vascular organization and hemodynamics that enables discrimination of micro- and macro-vascular BOLD signals. Micro-vessels are represented as a statistical network whose properties (e.g. radius, length, number of connections) match the geometric and rheological characteristics of the human microvasculature. Hemodynamics are simulated as changes in vessel diameter, resistance, and oxygenation levels. BOLD signals are computed as the local magnetic field disturbance induced by the geometry, hemodynamics, and biophysical effects of tissues. We report predictions of the spatiotemporal characteristics of micro-vascular hemodynamic responses and the associated BOLD time course for gradient-echo and spin-echo BOLD fMRI techniques.

To evaluate model predictions, we performed fMRI experiments to obtain neuronally driven (visual task) and purely vascular (gas challenge) BOLD signals from micro- and macro-vessels with spin-echo and gradient-echo techniques respectively. Purely vascular responses reflected variable vessel dilation and blood volume changes elicited with variable CO2 levels, and blood oxygenation changes elicited with O2. Spatiotemporal characteristics (e.g. amplitude, time to peak, width, cortical depth dependence) of macro-vascular responses were significantly affected by both CO2 and O2. Spatiotemporal characteristics of micro-vascular responses did not vary with CO2 levels and were significantly affected by O2. Results suggest that BOLD signals from micro-vessels are not significantly affected by purely vascular processes, and will be compared with against model predictions.