

# Coupling of cortical hemodynamic response and neural activity in cortex and thalamus

Anna Devor, Istvan Ulbert, Andrew K Dunn, Suresh N Narayanan, Mark L Andermann, Stephanie R Jones, David A Boas and Anders M Dale  
 MGH-NMR Center, Harvard Medical School, Charlestown, MA

## Summary and conclusions

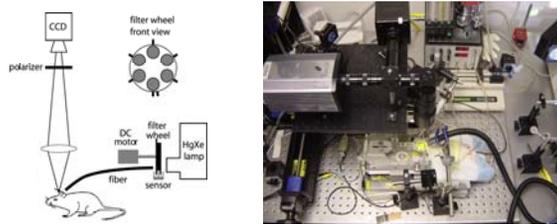
Accurate interpretation of functional magnetic resonance imaging (fMRI) activation requires knowing the relationship between changes in the hemodynamic response and the neuronal activity that underlies it.

We used simultaneously measurements of spiking and synaptic electrical activity and optical imaging of hemoglobin concentration and oxygenation in rodent somatosensory (Barrel) cortex in response to a single deflection of one whisker. We demonstrate that the hemodynamic response is a supra-linear function of neuronal activity measured from the principal cortical column (barrel) as well as from a corresponding location in the thalamus (a corresponding barreloid). Increase in neuronal activity in neighboring columns beyond saturation of the principal barrel column provides explanation for monotonically increasing hemodynamic response.

These results demonstrate that (*in Barrel cortex using a brief stimulus*):

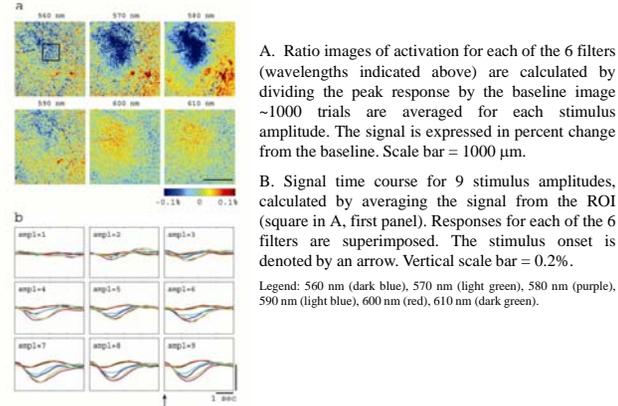
- Vascular responses do not have a single column resolution
- A point measurement of neuronal response does not reflect point hemodynamic activity. However, the relationship between local hemodynamic activity and neuronal activity in the same area is supra-linear
- Antagonistic center-surround hemodynamic activation does not correspond to surround neuronal inhibition

**Figure 1. The instrument for multi-wavelength imaging of blood volume and oxygenation**

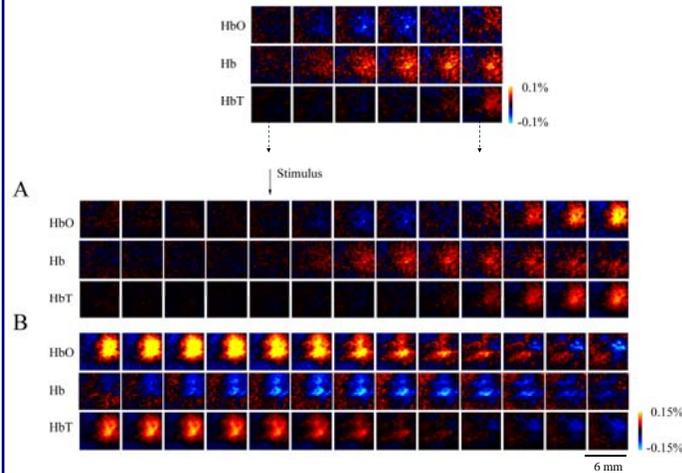


An imaging instrument that provides spectroscopic imaging of intrinsic signals using a rotating filterwheel. A schematic representation is shown on the left, a close-up image of the experimental setup is on the right.

**Figure 2. Multi-wavelength imaging in rat Barrel cortex using event-related stimulus presentation paradigm**

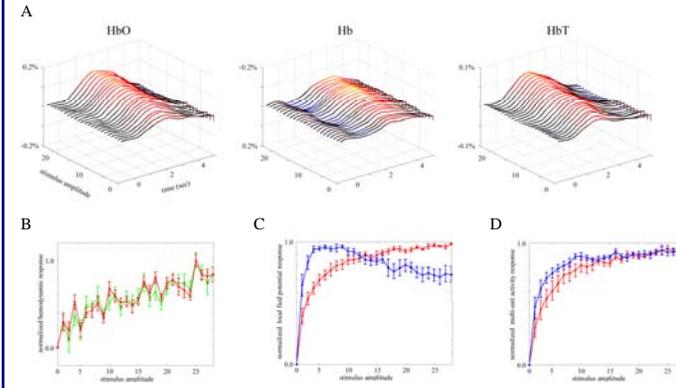


**Figure 3. Spatiotemporal evolution of HbO, Hb and HbT**



Each image represents an individual frame (average of ~1000 trials). Time between consecutive images is 200 msec. Panel B is a continuation of the time series shown in panel A. The signal for Hb and HbO is expressed in percent change relative to its own baseline concentration (40 and 60  $\mu$ M respectively). HbT was calculated as a sum of Hb and HbO. The time series showing the region of the "initial dip" is re-plotted on top on a different scale. Note a surround decrease in HbO (increase in Hb). These correspond to regions outside Barrel cortex where no change in neuronal activity was detected (data not shown). Scale bar = 6000  $\mu$ m.

**Figure 4. Hemodynamic signals monotonically increase throughout the range of stimulus intensities while cortical local field potentials (LFP) and multiunit activity (MUA) saturate with increase in stimulus intensity**



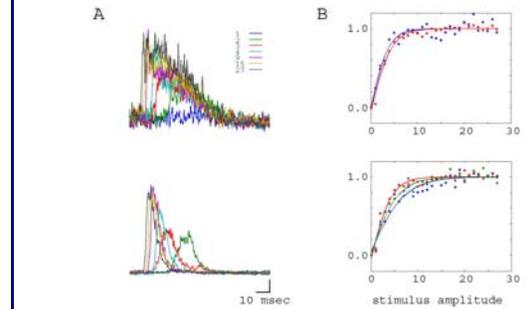
Hemodynamic signals monotonically increase (close to linear) throughout the range of stimulus intensities.

A. Signal timecourses of HbO, Hb, and HbT averaged from 8 animals. The original data using 27 stimulus amplitudes was smoothed using a sliding window of 5 amplitudes. Note that the Hb scale is inverted.

B. Integral of HbO (red) and HbT (green) responses averaged from 8 animals as a function of stimulus amplitude. The integral was calculated using rectified timecourses 0-4.5 sec following the stimulus. All 27 amplitudes are shown.

C-D. LFP (C) and MUA (D) responses averaged from 8 animals as a function of stimulus amplitude. Peak amplitude (red) and integral (blue) were calculated.

**Figure 5. Pre- and post-synaptic activity saturate to the same extent**

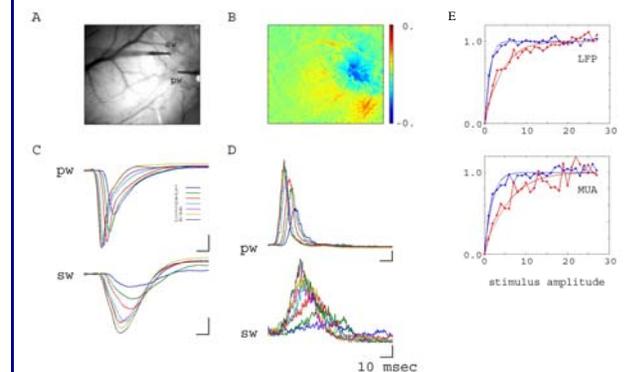


Laminar recordings from the principal barrel were performed simultaneously with recordings from the corresponding thalamic barreloid.

A. Thalamic (top) and cortical layer IV (bottom) response to one deflection of a single whisker. Responses using different stimulus amplitudes are superimposed.

B. Peak response amplitude as a function of stimulus intensity. Top: cortical layer IV response (red) follows that of the thalamus (blue). Bottom: supra- and infragranule layers (green and blue) saturate at a slower rate than layer IV (red).

**Figure 6. Hemodynamic response might be influenced by neuronal activity in neighboring cortical columns**



Simultaneous recordings from two neighboring cortical barrels show that the response in surrounding barrels as a function of stimulus intensity saturates at a slower rate.

A. An image of the vasculature with two electrodes recording from the principal (pw) and surround (sw) barrels.

B. A ratio image of the response at 580 nm.

C-E. LFP (C) and MUA (D). E. Peak amplitude of LFP (E, top) and MUA (E, bottom) in the principal (blue) and surround (red) barrel. Note that red curves do not reach an asymptote.

**Figure 7. Neurovascular transfer function  $y(t) = F(u(t)) \otimes h(t)$ ?**

