A neurovascular coupling model relating habituation of neural response to hemodynamic time course across varying frequency and duration of medial nerve stimuli.

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Abstract
Reconstructing physiologically relevant parameters from multimodal functional neuroimaging data is a highly ill-posed problem. Model-based reconstruction provides a mechanism to exploit the relationships among multimodal data and thus may improve the reconstruction results. The current work aims at capturing the relationship between evoked EEG waveform and the resulting hemodynamic response in a local region of the brain, via a simplified dynamic model (neurovascular coupling). Reconstruction of inputs to a single compartment hemodynamic model which represents the blood vasculature via a Windkessel approach is discussed. Habituation to medial nerve stimuli affects both the evoked responses and changes in blood oxygen concentration in a local region. Variations in the stimulus patterns across different frequencies and durations during experiments have revealed the relationships between amplitudes and the temporal dynamics of the EEG data and the inputs of the hemodynamic model. We exploit these relationships to build a simplified representation of the neurovascular coupling.

The Dynamic Multi-modal Integrated Framework

In this poster we focus on modeling the coupling between the neuronal response and the hemodynamics.

Potential long term research impact
- The dynamic framework [2] uses these models and combines them along with the different lead fields to get relevant information about the brain function.
- Given a neuron model and the hemodynamic model, the neurovascular coupling captures the relationship between the neuronal response and the resulting blood flow in the local vasculature.
- Tools to predict hemodynamic time course from neuronal responses measured by EEG in a local region of the brain, depend on the completion of the development of a neurovascular model.
- Replication of these local low order models over the voxels of the brain volume could provide a robust method to exploit multimodal brain imaging data.
- In the near future these models could be utilized for understanding brain connectivity patterns during cognitive tasks via analysis of brain networks.
- Another purpose of such models is for assisting in diagnosis of brain related diseases.

References

Future work
- Optimize and validate the model on the frequency experiments.
- The model can be tested on its ability to predict the effect of random stimuli.

Data from rat experiment

The data was collected at the MGH-NMR facility at Charlestown, MA, by Dr. Ilkka Nissila.
- Each forepaw is stimulated for 32 seconds, with 4 second breaks in between the stimulus pulses.
- Frequency experiments: Eight 4-second intervals with stimulus frequency of random ordering from {1, 2, . . . , 8} Hz.
- Optical: 9 sources / 16 detectors: Optical signal from the best source-detector pair is used to compute HbO and HbR.

The Hemodynamic model developed by Gagnon/Boas at MGH

- Two model components for 1 compartment (vein):
  - Blood Flow, \( \dot{O}_2 \)
  - \( \dot{O}_2 \) transport
- Inputs: Arterial resistance \( R_a \), metabolic oxygen demand rate (CMRO₂).
- Change in blood volume = flow in - flow out.
- Change in [HbO₂] = [HbO₂ new] - [HbO₂]initial.

Recovering the inputs of the MGH hemodynamic model using optical data
- Total hemoglobin concentration \( \Delta [HbO] \) = \( \nu V \) the Windkessel volume, \( \alpha \) known constant.
- Baseline known/estimated: Can recover \( R_a \) from \( V \), by inverting the flow equations.
- Nonlinearity in the equation impedes recovery of \( \Delta CMRO₂ \).
- Represent \( \Delta CMRO₂ = \sum_{k=1}^{N} a_k B_k(t) \), \( B_k(t) \) are cubic splines.
- Estimate \( a_k \) by matching the optical data to recover \( \Delta CMRO₂ \).

Structure of the neurovascular coupling model

- Low pass filtered neuronal response:
  - Fast Dynamics \( \rightarrow \) slow dynamics.
- SVD the dynamics: \( U S V^T \).
- \( U \) \& \( S \) are bases, \( V^T \) are bases for frequency/duration experiment.
- \( V(t) \) temporal basis.
- Neuronal dynamics = \( U_1 V_1(t) \), Vasculature dynamics = \( U_2 V_2(t) \), \( U_{12} \) for \( \Delta CMRO_2(t) \), and \( U_{12} \) for \( \Delta CMRO_2(t) \).
- Static relation: \( U_{12} = U_{1a} + b_1 U_{a1} + b_2 U_{a2} \) a's and b's are 2 \times 1 vectors.
- \( V(t) \rightarrow \) Temporal dynamics \( \rightarrow V_2(t) \).
- \( V_2(t) \) is the same for both \( \Delta CMRO_2(t) \), and \( \Delta [HbO] \).

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