Modeling Cortical Dynamics in Visually-Evoked Responses Using the Human Neocortical Neurosolver (HNN)

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Introduction

- **V1**: first cortical stage of visual processing; key for transforming retinal input into perception.
- **VEPs (C1: 50–90 ms; N1: 140–200 ms)** reflect early and later visual responses, but their precise neural sources remain unclear.
- In previous work, HNN has been used to investigate ERPs in other sensory areas: A1 and S1 (Jones, 2007; Kohl, 2021).
- While V1 has unique network characteristics compared to other sensory cortices, it shares a common layered structure, pyramidal neurons that span across the layers, and layer specific thalamic and cortical input trajectories.
- **Here, we test whether HNN can reproduce a VEP.**

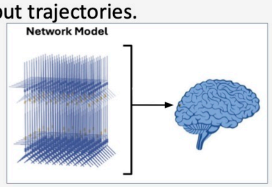


Figure 1 (right): HNN Template Model.

Methods

- **The Human Neocortical Neurosolver (HNN)** simulates the primary current dipoles representing source localized E/MEG signals from the intracellular current flow in pyramidal neuron dendrites, together with corresponding microcircuit information (cell spiking, layer specific LFP/CSD). The network is activated by predefined patterns of thalamocortical (proximal) and cortical-cortical (distal) excitatory synaptic drive.

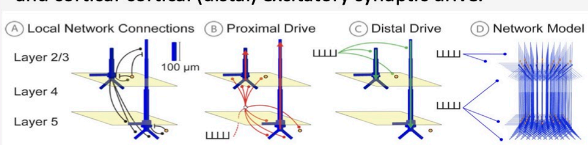
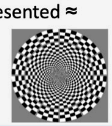


Figure 2: HNN Network Model

- **Experimental Data -** Previously published human EEG measured VEPs source localize to V1 (Inverso, 2016).
  - N = 2 (female 26 y, male 46 y)
  - BIOSEMI ActiveTwo system (74 electrodes, dense occipital coverage)
- **Stimulus:** Multifocal "scaled dartboard" pattern based on cortical magnification factors (84 regions: 7 rings × 12 sectors).
  - 30 ms flashes (3 frames at 100 Hz). Each region presented ≈ 2 ×/s for ~4 min (~484 presentations/region).
- VEP waveforms, averaged across repeated stimulus segments after artifact rejection, were used in modeling.



Results

A Sequence of Thalamocortical Drive can Generate VEP

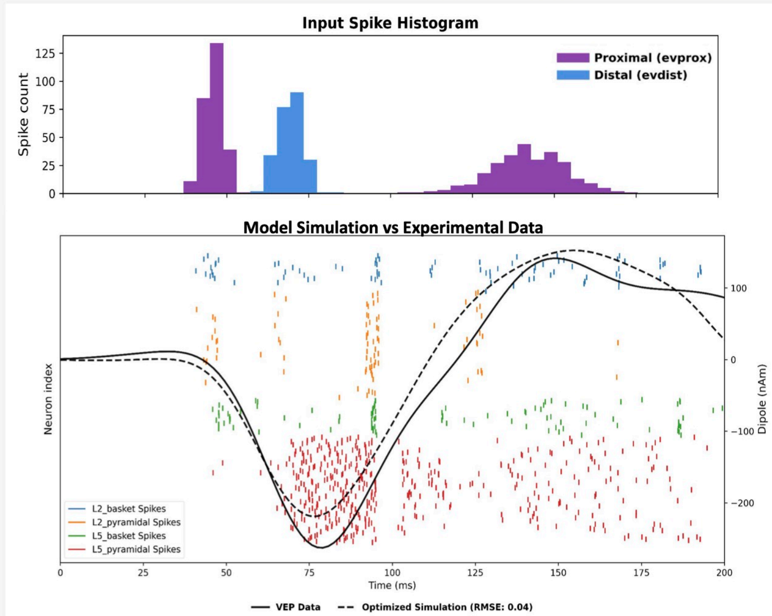
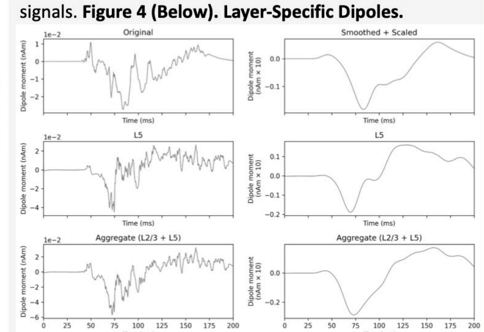


Figure 3 (Left): HNN Simulation of V1 Responses. (Top) Spike histograms showing population activity of exogenous spiking inputs that activate the network through a sequence of feedforward (proximal)– feedback (distal)–feedforward synaptic drive sequence. (Middle) Spike raster from each cell type (dots) overlaid with simulated dipole responses from the HNN model (solid black line) and experimental VEP data (dotted line). Note equal units of measure (nAm) and a scaling factor of 10. When comparing the two dipole waveforms, the root-mean-square error (RMSE) was 0.04, indicating a close match between the simulated and experimental signals. **Figure 4 (Below). Layer-Specific Dipoles.**



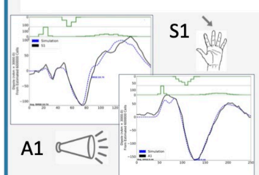


Figure 5: Previous HNN SEP and AEP Modeling.

- HNN successfully reproduced VEPs, capturing major features of C1 and N1 components, using a sequence of **feedforward–feedback–feedforward** drives across cortical layers.
- Previous SEP (Jones, 2007) and AEP (Kohl, 2021) simulations (*Figure 5, Left*) show similar peak timings and orientations, which together with literature motivated the chosen sequence of thalamocortical drive. Parameters were tuned to closely match recorded dipoles, producing multiscale, layer-specific spiking patterns consistent with other studies.
- Ongoing studies are examining the corresponding LFP/CSD.

Discussion

- V1 ERPs were successfully modeled in HNN using a sequence of feedforward–feedback–feedforward drives across cortical layers.
- Multiscale simulations provide several targets for validation of model-based predictions.
- Layer-specific spiking predictions provide mechanistic insight into how different cortical layers contribute to the observed VEP.
- The commonalities with prior SI and A1 evoked response simulations suggest macroscale ERPs are constrained by commonalities in cortical structure and thalamocortical projection patterns, despite finer scale circuit difference.
- Findings suggest that early thalamic input, feedback modulation, and recurrent excitation together shape the major VEP components.

Contact / Funding

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Link to HNN Textbook

Poster PDF

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