Rhythms across scales: from rhythmic cells to neural oscillations in the EEG

What do you notice?
Electroencephalography (EEG) is a primary method for non-invasively measuring neurophysiological signals in humans. Do you think it is possible to infer neural spiking activity and circuit interactions from an EEG signal?
What are the potential cellular and local circuit contributions to large-scale neural oscillations?
Slow-Wave Sleep:

- Slow-waves and K-complexes (<1 Hz)
- Delta waves (1-4 Hz)

Delta waves are nested in slow-waves

Neurons in the thalamus and cortex engage in slow-wave activity:

Crunelli and Hughes, *Nature Neuroscience*, 2010
Mechanisms of the Cortical Slow Wave (<1 Hz):

Slices of mouse visual cortex:

Intrinsically bursting cells in the cortex produce an UP state.

Layer 5 Pyramidal Cell  Layer 2/3 Pyramidal Cell  Layer 5 Interneurons  These interneurons have an intrinsic rhythm or resonance at >1 Hz, which can pace this activity.

Mechanisms of the Cortical Slow Wave (<1 Hz):

Intact Cortex

Isolated Gyrus

Which rhythms are present in the isolated cortex?

Which rhythms missing?

A synchronized **slow rhythm** is observed in large sections of isolated cortex.

How are **spindles** and **delta rhythms** generated?

Timofeev et al., *Cereb. Cortex*, 2000
Mechanisms of the Delta Rhythm (1-4 Hz):

*Resonance* in thalamocortical neurons:

Inject a **ZAP current**: oscillating current spanning a range of frequencies

Guinea pig thalamus:

- + 10mV
- -66mV (rest)
- - 10mV
- - 20mV

What is happening here?

Larger amplitude voltage response at lower frequencies

Puil et al., *Journal of Neurophysiology*, 1994

Thus, these neurons have a preferential response at lower frequencies (2-4 Hz) when hyperpolarized.
Mechanisms of the Delta Rhythm (1-4 Hz):

1. Cortical neurons excite thalamic reticular neurons.

2. Thalamic reticular neurons hyperpolarize thalamocortical neurons.

3. Thalamocortical neurons project back to cortex.

Crunelli and Hughes, *Nature Neuroscience*, 2010

Thalamocortical neurons have a preferential response at delta (2-4 Hz) when hyperpolarized.
Slow-waves and K-complexes (<1 Hz)

Delta waves (1-4 Hz)

Delta waves are nested in slow-waves

Thalamocortical neurons produce the delta wave through projections back to cortex

Mechanisms of Sleep Spindles:

Cortical activity during UP states causes prolonged period of hyperpolarization in reticular thalamic neurons, causing them to intrinsically burst at a spindle rhythm.

Fuentealba et al., PNAS USA, 2004
The resonance properties (frequency preference) of neurons in the thalamus and cortex contribute to rhythms in slow-wave sleep:

**Slow-wave**: cortical neuron resonance  
**Delta rhythm**: thalamocortical neuron resonance  
**Spindles**: reticular thalamus neuron resonance

The observed rhythms are also dependent upon *connectivity* within thalamocortical circuits:

**Slow-wave**: relies on cortical connections  
**Delta rhythm**: relies on connections between the cortex, reticular thalamic neurons, and thalamocortical neurons  
**Spindles**: relies on connections between reticular thalamic neurons, thalamocortical neurons, and cortex
Electroencephalography (EEG) is a primary method for non-invasively measuring neurophysiological signals in humans. Do you think it is possible to infer neural spiking activity and circuit interactions from an EEG signal?

Assuming you could infer neural spiking activity and circuit interactions from an EEG signal, what might be some ways that the data could be used to advance medicine or technology?