EEG simulation reveals that changes in cortical morphology and global connectivity during development affect neonatal EEG

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1. Background and Purpose

Neonatal Electroencephalogram (EEG)

- Is affected by the maturation of the neonatal brain
- Is used in the diagnosis of neonatal seizures or hypoxic-ischemic encephalopathy

Fetal and Neonatal Brain Maturation

There are many factors in brain maturation, so it is difficult to reveal the effect of each factor to EEG using biological data.

- Factors: Change of cortical morphology [Biagioni+, 2006]
  Change of global connectivity [Honey+, 2009]
  Cortical layer structure,
  Change of E/I balance, Myelination

What is EEG?

- Superposition of electric field potential generated by the postsynaptic current
- Ion distribution -> dipole -> electric field potential

Prior works of EEG Simulation

Fixing of other parameters and investigating the influence of the specific factor

- Frequency coupling [Bhattacharya, 2011]
- Influence of action potential [Mazzoni+, 2010]

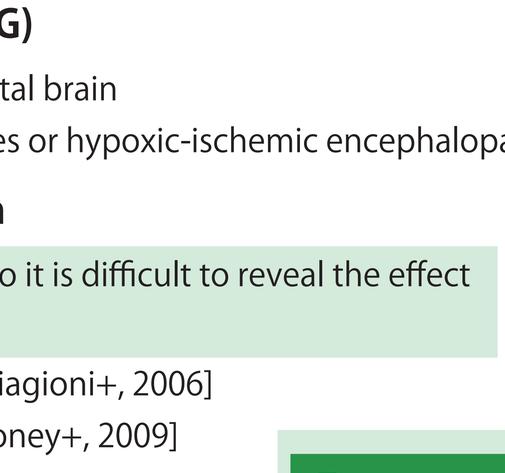
Purpose Reveal how the change of cortical morphology and global connectivity affect EEG signals

2. Methods

We changed each factor (cortical morphology / global connectivity) in brain simulations independently and examine how they affect EEG. The relationships of cortical morphology to EEG signals were first examined with a simple model, then the more biological situation was explored with a large-scale thalamocortical model.

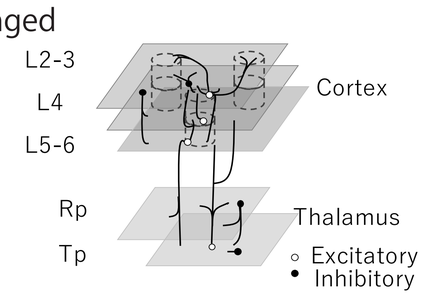
Simple brain simulation

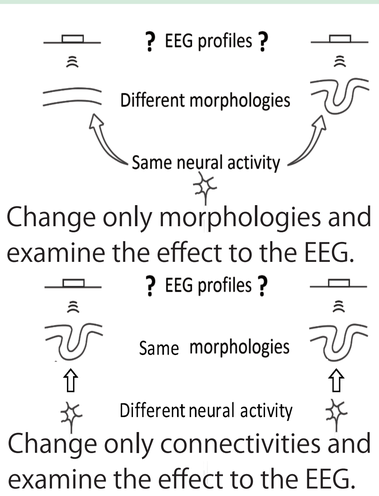
- Neural activity was propagated along a 2-dimensional sine curve
- Spatial frequency and amplitude of curve were changed for investigating the effect of morphology (the number and the depth of sulci)



Thalamocortical brain simulation

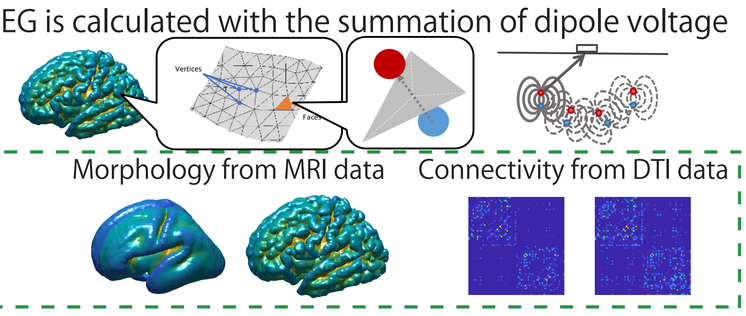
- Spiking neural network is composed of 1M neurons.
- 3 layers, Hill-Tononi neurons [Hill&Tononi, 2004]





Estimation of EEG

- Electric dipoles are placed along with normal vectors at mesh centers
- EEG is calculated with the summation of dipole voltage

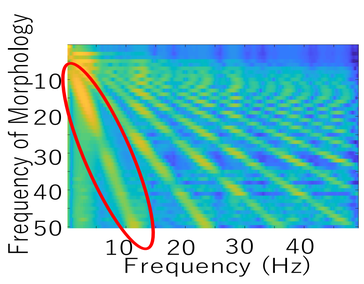


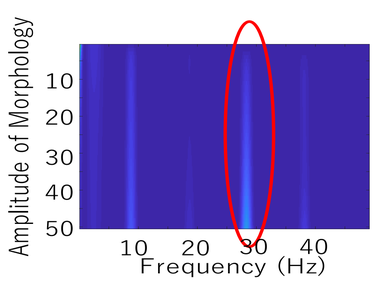
3. Experiments & Results

Experiment 1: Morphology and EEG in the simple model

Setting: Change the frequency (the number of sulci) and amplitude (depth of sulci) of the simple cortex and calculate EEG

Result: the peak of EEG frequency ↑ when the num. of sulci ↑
the absolute value of Power Spectrum Density ↑ when the depth of sulci ↑





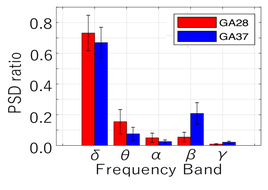
In the development of the neonatal brain, the cortex gets more folded and morphology gets complicated, and the peak frequency of EEG gets higher. These results show the relationship between the morphological & EEG development.

Experiment 2: Validation of the thalamocortical EEG simulation

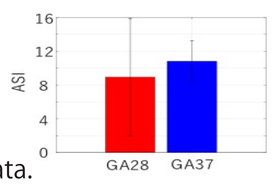
Setting: Use MRI and DTI data of 28 & 37 weeks after conception and compare EEG

Result: Verified in three features:

1) Power Sectrum Density (PSD)
2) Activation Synchrony Index (ASI): for synchronization of 2 electrodes
3) Graph network indexes: for analysis of global EEG network



PSD ratio of GA28 > GA37 in the delta-theta band.
PSD ratio of GA28 < GA37 inthe beta-gamma band.
That is similar to the biological data.

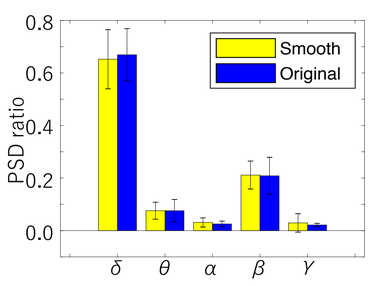


In ASI, GA28 < GA37.
The prior work shows the developmental increase of ASI, and this result accords to the report.

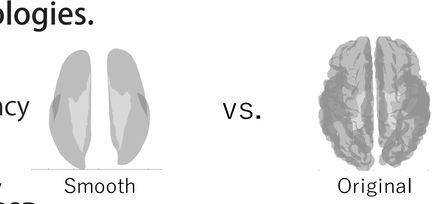
Experiment 3: Morphology and EEG in the thalamocortical simulation

Setting: With the same connectivity, compare EEG of Original & Smooth morphology

Result: There is no differences in PSD between two morphologies.



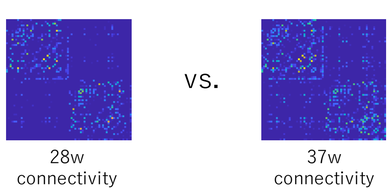
In the thalamocortical simulation, there are no differences in frequency distribution between smooth and original morphology, but in Exp. 1, there is the relationship between PSD and morphology.
The differences in Exp. 1 & Exp. 3 are neural connectivity, complexity of signals, or complexity of morphology.

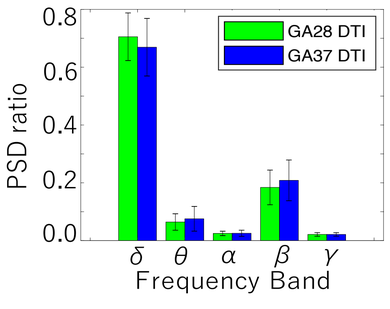


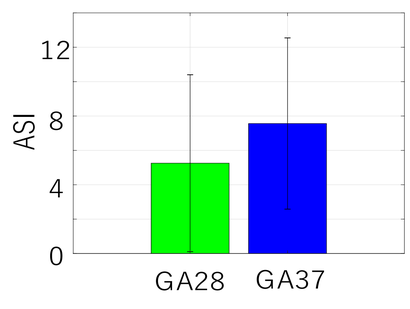
Experiment 4: Global Connectivity and EEG in the thalamorotical simulation

Setting: In the same morphology, compare EEG of 28 & 37 weeks global connectivity

Result: ASI value increased as the connectivity changed from 28 to 37 weeks.







With the change of global connectivity,
there is no difference in EEG frequency, but GA37 DTI is higher ASI than GA28.
The development of connectivity affects the synchronization of the global EEG network.

4. Conclusion

- Implement brain simulations and EEG estimation systems that can be utilized to understand changes in EEG signals during development.
- Show that the change of brain morphology in neonates affects the development of EEG from low-frequency dominant to high-frequency dominant.
- Show that the development of global connectivity affects the index of the synchronization of electrodes in EEG that is reported in the developing brain.