Application of Multilayer Hypernetworks in the Context of EEG

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Abstract

This project aims to develop and apply multilayer hypernetworks as a tool for analysis of electroencephalography data (EEG). The approach of network connectivity for neuroscience has pushed the computational sphere forward and multilayer networks can extend this approach to work through time. EEG data was collected from participants during two cognitive tasks (updating and inhibition) embedded with stimuli of different valences (positive, negative, and neutral). The EEG signal was decomposed into the time-frequency domain to focus on alpha (8-12Hz) and theta (4-8Hz) frequency bands. Within-band phase lock values (PLVs) between electrodes (nodes) and a probabilistic analysis was done to determine if high PLVs repeated in certain times or conditions. The results showed that conditional probability is statistically significant between all valence groups in alpha and two valence groups in theta. This suggests that the role of alpha is broader in the context of emotional information in the task. Further research is required to see if these findings extend to power and other metrics. A conditional probabilistic approach was shown to have a lot of potential for further insight into network connectivity. Specifically, hypernetworks can contain this information and be predictive of neural activity across timepoints.

Introduction

- The approach of network connectivity for neuroscience has pushed the computational sphere forward. This can be augmented by the usage of multilayer networks and hypernetworks.
- Multilayer networks stack matrices which can be used for tracking through time.
- Hypernetworks capture relationship between two networks.
- Multilayer hypernetworks can capture relationship between two networks over time.
- Alpha and Theta networks are known to correspond to different functions. Alpha with emotional processing and Theta with working memory.

Hypothesis: Multilayer hypernetworks can capture the overall activity in the brain in a parsimonious way, specifically it would retain Alpha's higher activity in emotionally demanding tasks.

Methodology

Affective N-back:
- Participants were to pick repeat image.
- EEG was collected during this.
- This was done with positive, negative and neutral valence.

PLV:
- Morlet-wavelet decomposition
- In phase values were calculated for all 31 time points for each electrode pairing.

Linkage Matrix:
- 64 x 64 x 31 dimension matrices were taken
- Averaged between the Alpha and Theta PLV matrices.

Filtered Matrix:
- Any value above 0.35 in the linkage matrix with alpha and theta values ± 0.05 were kept.
- Everything else was set to zero.

Binary Matrix:
- All non-zero values in the filtered matrix were set to 1
- Everything else was set to zero.

Matrix Juxtaposition:
- The Alpha, Linkage and Theta matrices were lined up against each other
- Put together in an array of matrices.

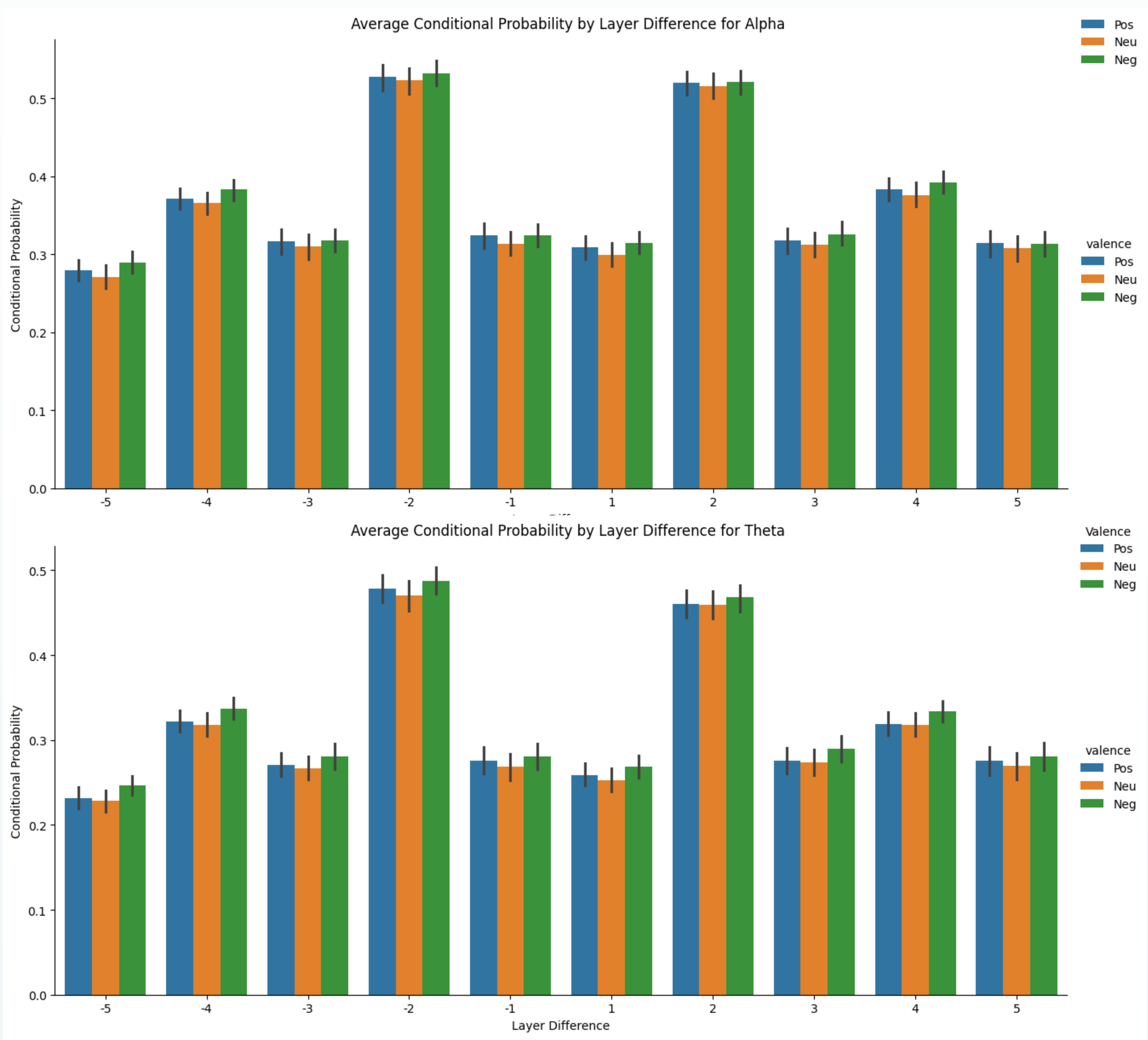
Alpha and Theta Binarization:
- All values above 0.35 in the Alpha and Theta matrix were turned to 1
- Everything else got turned to 0.

Conditional Probability by Layer Difference:
- For every layer, the conditional probability of a cell being 1 based on a reference layer was collected.
- This was done for all layer pairings to see if time difference held any predictive ability.
- All layer pairings with the same difference were averaged.

Conditional Probability Histogram:
- The distribution of conditional probabilities across all layers were graphed for all emotional valences.
- Done for alpha and theta separately.

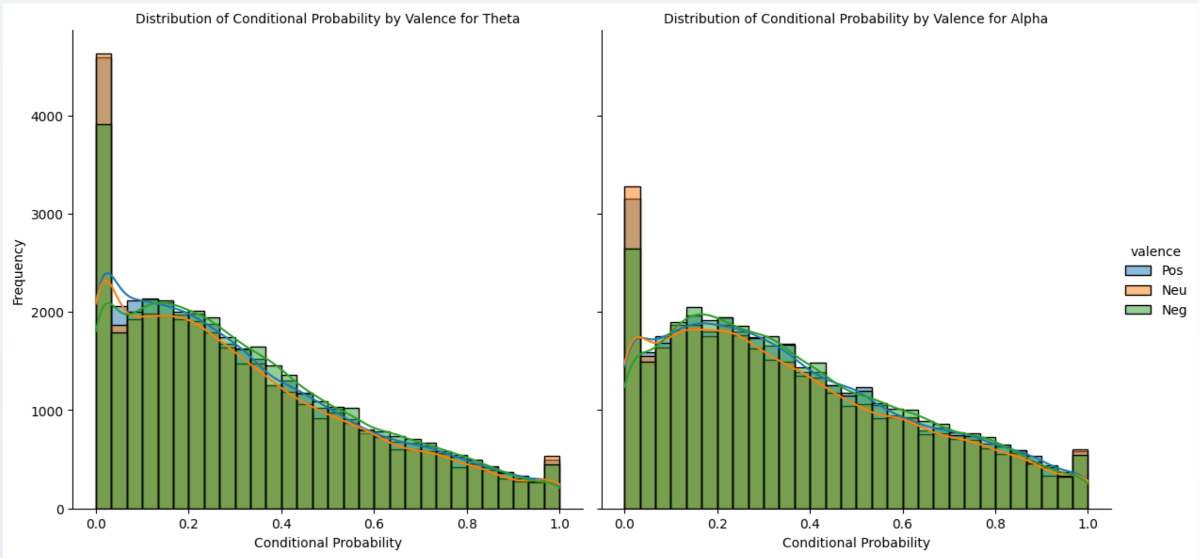
Results

Conditional Probability Across Layers:



Layer ± 2 has markedly higher conditional probability. This is seen in Alpha and Theta. The amount of data going into every average is lower at the further edges. Only layer differences ± 5 is shown here for visibility.

Conditional Probability Distributions:



Alpha	Neg	Neu	Pos
Neg	1	3.14E-13	0.00159
Neu	3.14E-13	1	0.00003
Pos	1.59E-03	3.03E-05	1

Theta	Neg	Neu	Pos
Neg	1	5.82E-20	5.74E-15
Neu	5.82E-20	1	1.50E-01
Pos	5.74E-15	1.50E-01	1

Conditional probabilities were all significantly different from each other in alpha. Only negative emotional valences were significantly different in theta. P-value of 0.05 was used as cutoff for distribution differences.

Discussion and Conclusion

Conditional Probability Over Layers:
- The layer difference analysis: time difference is major factor in how predictive phase locked nodes are phase locking in the future.
- High values at layer differences of two may suggest that alpha or theta often times lag each other by a that time point.
- This would be 200ms in this study.

Conditional Probability Distribution:
- The distributions had significant differences.
- While all emotional valences were significantly different from each other in alpha, only negative was different in theta.
- This reflects the idea that alpha is more active in emotional processing.
- Theta is not as involved so this lines up.
- Negative emotions cause more activity that is measured by EEG.
- Supports that this probabilistic approach maintains important features of the original EEG data.

Limitations and Future Directions:
- This study was only done on PLV
- Still questions on whether this can be done with more basic metrics such as power correlation.
- The conditional probability over layers is not reliable further out but showed high predictiveness in layer differences of +31 and -31.

Conclusion:
- This method has potential to capture whole brain activity in a condensed manner.

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