Modelling individual variability across multiple data streams in music listening and at rest

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Highlights

- PLS can be used to analyze multiple data streams in a mixed methods study
- Time spent in specific functional connectivity (FC) states are unique to task condition and are further involved in perceptual tasks
- The number of visits to FC states is linked to self-reported emotional states

Summary

Music is a complex and engaging stimulus that generates subjective responses at the neural and behavioural levels. We can track responses to music using multiple data streams, but how can we combine these data streams to create a more complete description of music listening?

In this analysis, we combine hidden Markov modelling (HMM) and partial least squares (PLS) on three timeseries: brain data collected at rest and during two music listening tasks, continuous behavioural ratings during music listening, and music features.

We found patterns of brain activity unique to rest and music listening. We incorporated behavioural variables and found unique patterns of brain activity corresponding to self-reported emotional states during music listening.

Background: Music is an engaging stimulus that can generate a wide array of subjective experiences. It combines bottom-up sensory processing with top-down cognitive conceptualization, but linking how highly individualistic brain and behavioural states are created from a common stimulus, and how those states are linked, is less than straightforward. In the present study, participants listened to a heterogeneous selection of excerpts from Western art music and provided continuous ratings on induced emotional states while EEG activity was recorded. We used hidden Markov modelling (HMM) and partial least squares (PLS) to describe patterns of within- and between-participant similarity for EEG and continuous perceptual and emotional ratings data.

Methods: We collected EEG data from 14 healthy adults listening to musical excerpts (n = 40). Excerpts were between 40 and 120 seconds in length, and consisted of Western art music from the Renaissance to contemporary periods with varying orchestration, including vocal works. We pre-processed the EEG data in Brainstorm (Tadel et al., 2011) and completed the analysis in Matlab (Mathworks, 2016b). We extracted fractional occupancy (a measure of total time spent in a state), state visits (the number of unique visits to a state), and state lifetimes (the average length of a visit) from HMM (Vidaurre et al., 2018) and used these measures to compare the brain, behaviour, and music data using PLS.

Results: The task PLS on the fractional occupancy returned one significant LV showing a contrast between rest and the experimental task (A). A follow-up PLS was completed incorporating state visits and state lifetimes showing a higher number of state visits in the experimental condition, and longer state lifetimes in the resting state (B). Behavioural PLS showed patterns of state visits and state lifetimes unique to induced emotional states during music listening in the experimental task, and a different pattern of state occupancy during music listening in the perceptual control task (C).

Conclusions: Combining HMM and PLS enables comparison between multiple data streams in space and time. Perceptual and behavioural responses to music are subjective, and the ability to incorporate multiple data sources allows for the identification of patterns within and between these modalities. PLS and HMM provide a sound methodological link between brain and behaviour that is essential to studying naturalistic activity.

References:
Tadel, F., Baillet, S., Mosher, J.C., Pantazis, D., Leahy. R.M. (2011). Brainstorm: A User-Friendly Application for MEG/EEG Analysis. *Computational Intelligence and Neuroscience.*
Vidaurre, D., Quinn, A. J., Baker, A. P., Dupret, D., Tejero-Cantero, A., & Woolrich, M. W. (2016). Spectrally resolved fast transient brain states in electrophysiological data. *Neuroimage, 126*, 81-95.

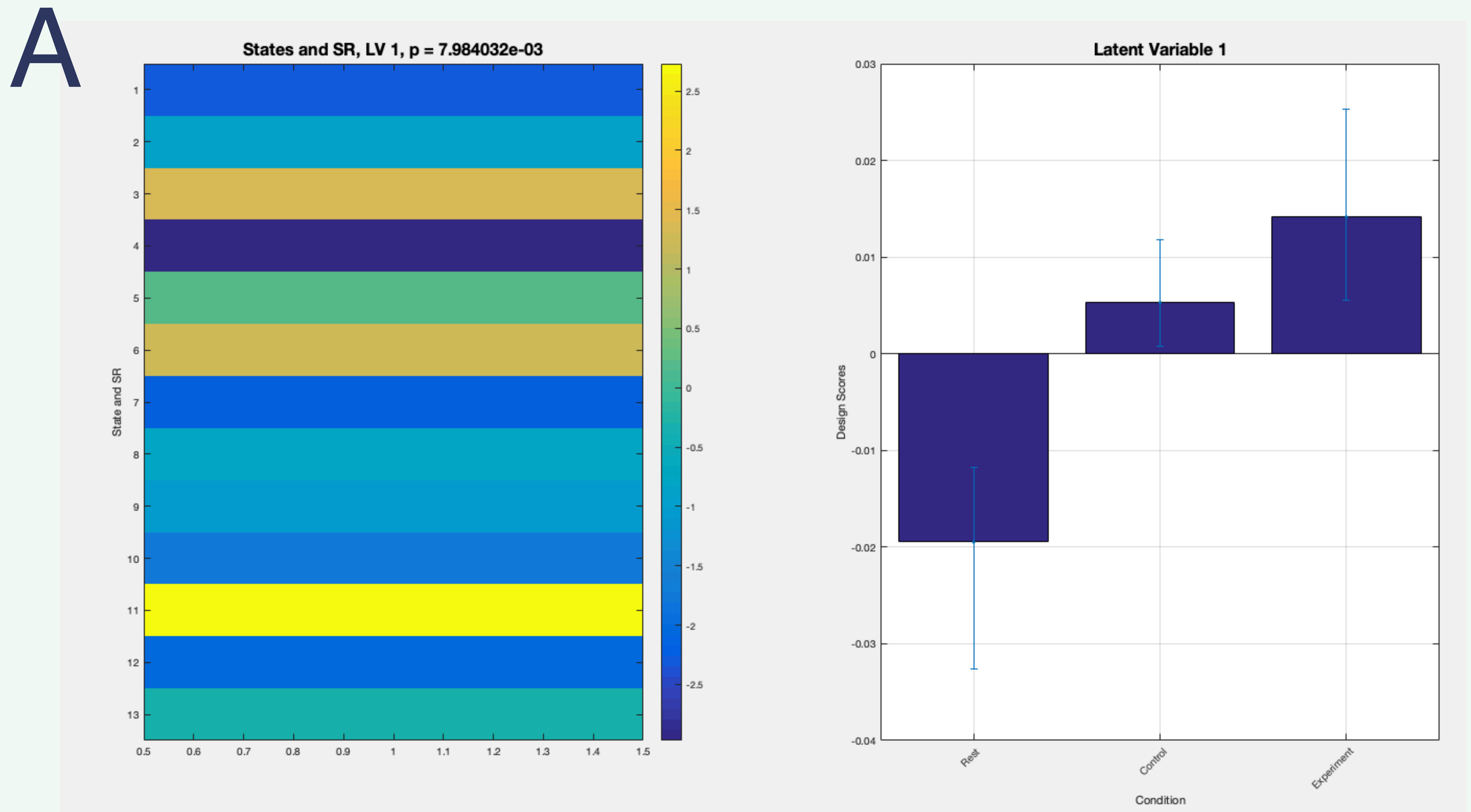
What is HMM?

HMM as a way reduce dimensionality in space while preserving time. The user selects a K value and the analysis finds K discrete functional connectivity states that best describe the data, then combs through the timeseries assigning each window to one of these K states

What is PLS?

PLS describes the relationship(s) within and between between matrices of measurements using singular value decomposition (SVD). It captures covariance in a dataset returning latent variables (LVs) that describe the amount of covariance explained by patterns of input variables.

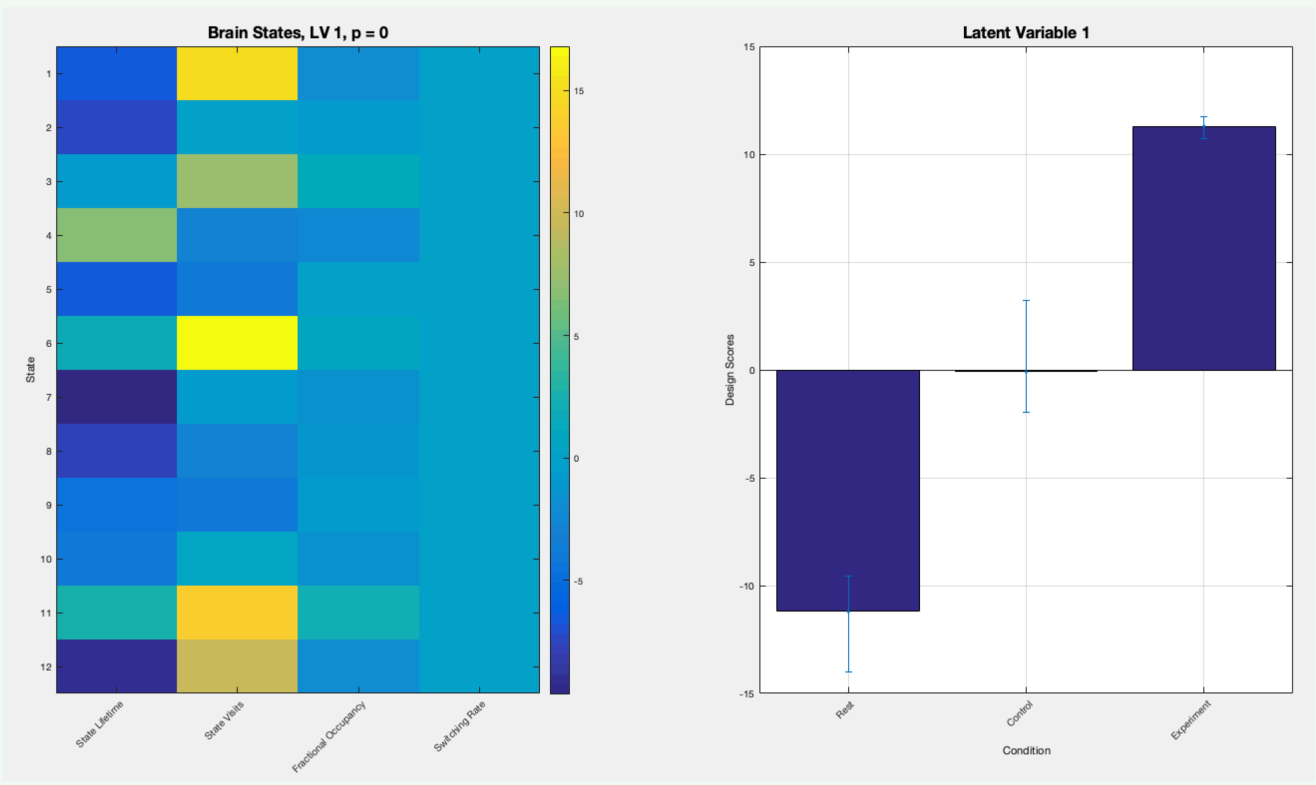
A



Here, participants are spending more time in brain state 4 in the resting state, and more time in states 3, 6, and 11 during music listening.

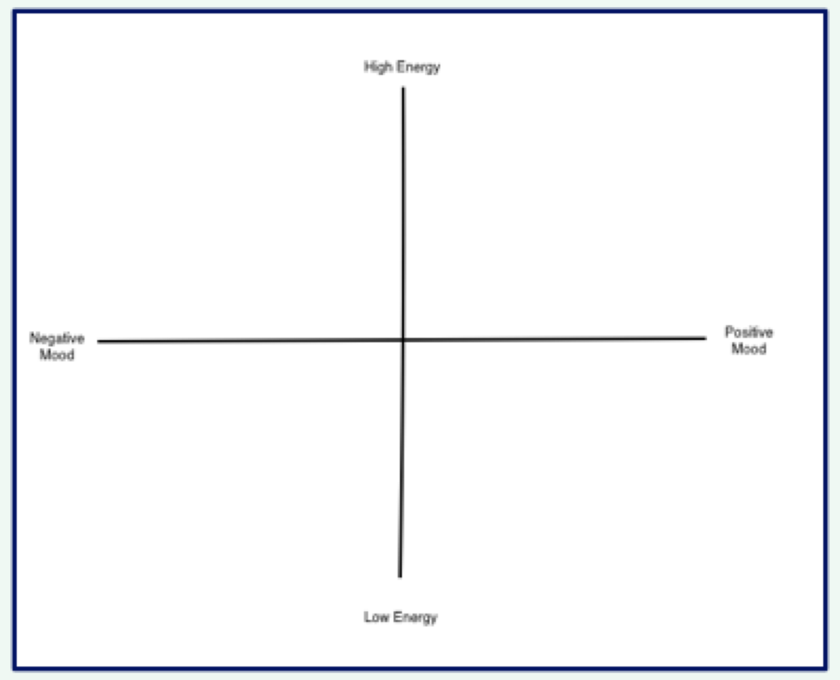
State 4 is of particular interest as it involves many regions in the default mode network. More time is spent in this state in resting state trials than in music listening trials (see section D for brain plots).

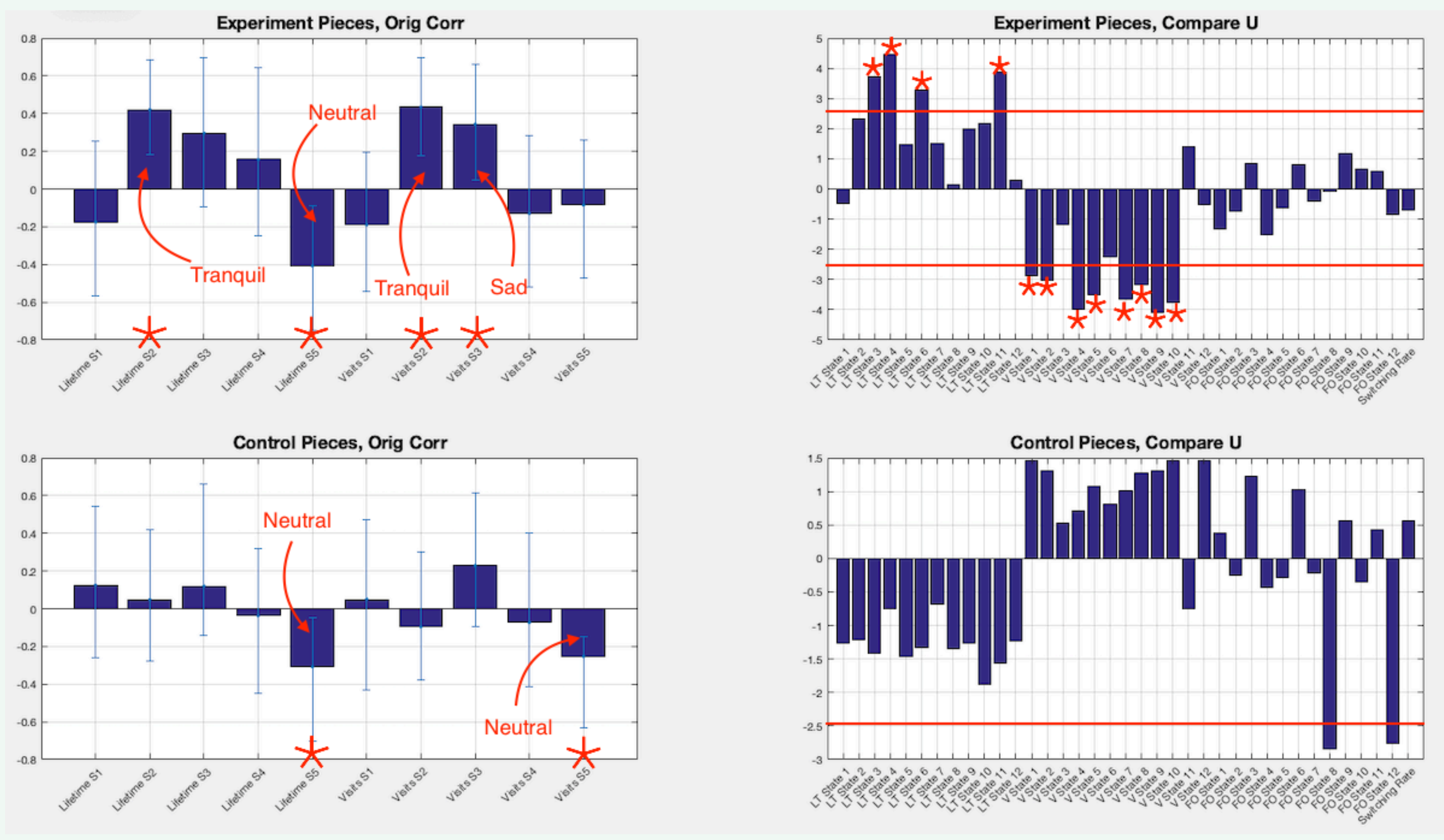
B



The temporal variables are coming out here more than the spatial variables with participants spending less time on average in states 7 and 12 during the experiment task with more visits to states 1, 6, 11, and 12 (see section D). Participants have longer visits to states 7, 8, and 11 in the resting state. Fractional occupancy's contributions are much weaker here.

C

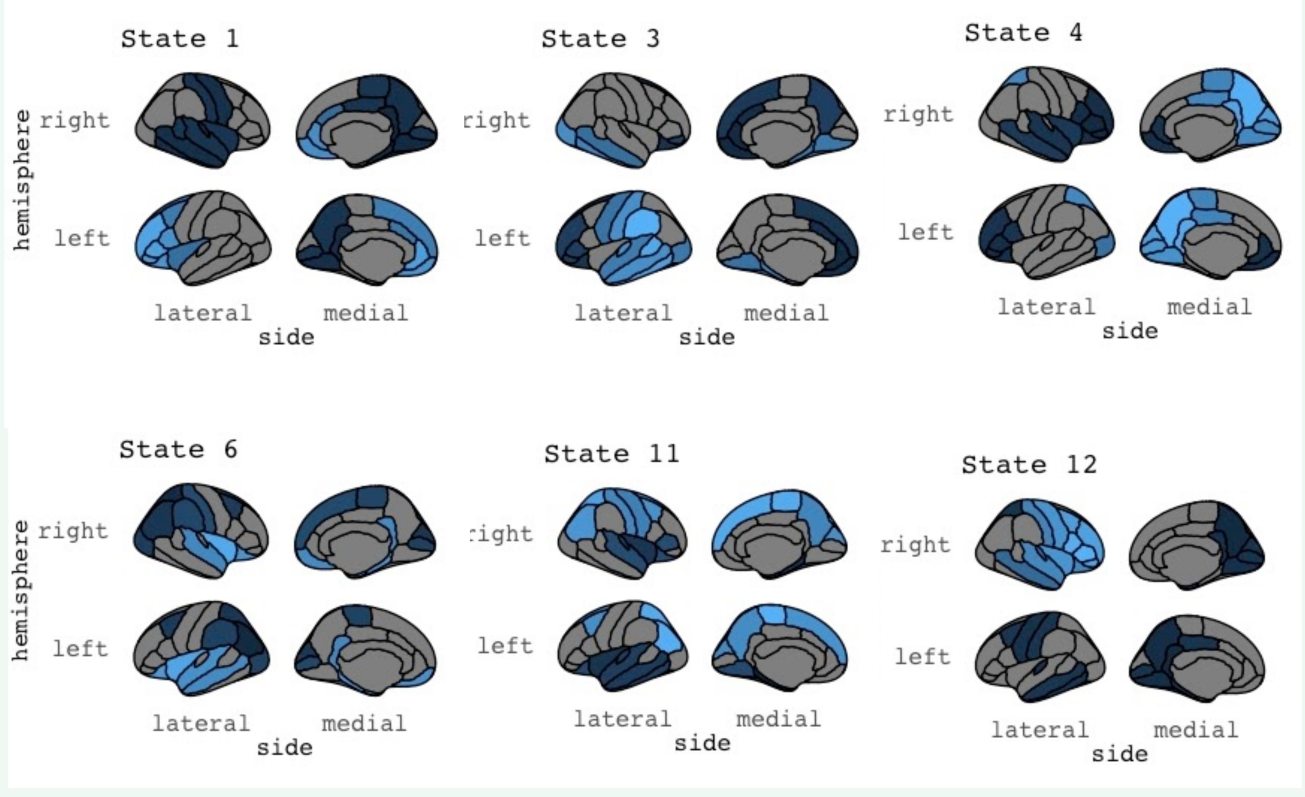




Here, we have a positive relationship between time spent in the tranquil behavioural state and visits to the tranquil and sad behavioural states with the average visit length in brain states 3, 4, 6, 11; and a negative relationship between these behavioural quadrant states and visits to brain states 1, 2, 4, 5, and 7-10. This relationship was inverted for time spent in the neutral behavioural state, which was positively associated with visits to brain states 1, 2, 4, 5, 7-10; and negatively associated with average visit length in brain states 3, 4, 6, and 11.

We do see an interaction with fractional occupancy in the control condition where fractional occupancy (total time spent) in brain states 8 and 12 is positively associated with visit length in and number of visits to the neutral behavioural state.

D State brain plots



E Future directions