

# Best of both worlds: Integrating EEG and fMRI in the study of inhibition

M. Fiona Molloy and Brandon M. Turner

## AIM

### INTRODUCTION

A task commonly used to measure response inhibition is the stop-signal task. Variations of this task have been studied using a wide range of populations and diverse methodologies, which makes it difficult to integrate these findings into a unifying theory. Here, we show how analyses from one modality, such as electroencephalography (EEG), can inform future analyses in a different modality, such as functional magnetic resonance imaging (fMRI).

### Experiments

#### Experimental Details

- fMRI 1: Auditory stop-signal with verbal response (Xue, et al. (2008); n= 17)
- fMRI2: Auditory stop-signal with motor response (Aron, et al. (2007); n = 12)
- EEG 1: Visual stop-signal with motor response (Castiglione et al. (2018); n = 41)
- EEG 2: Visual stop-signal with verbal response (Wagner, et al. (2018); n = 13)

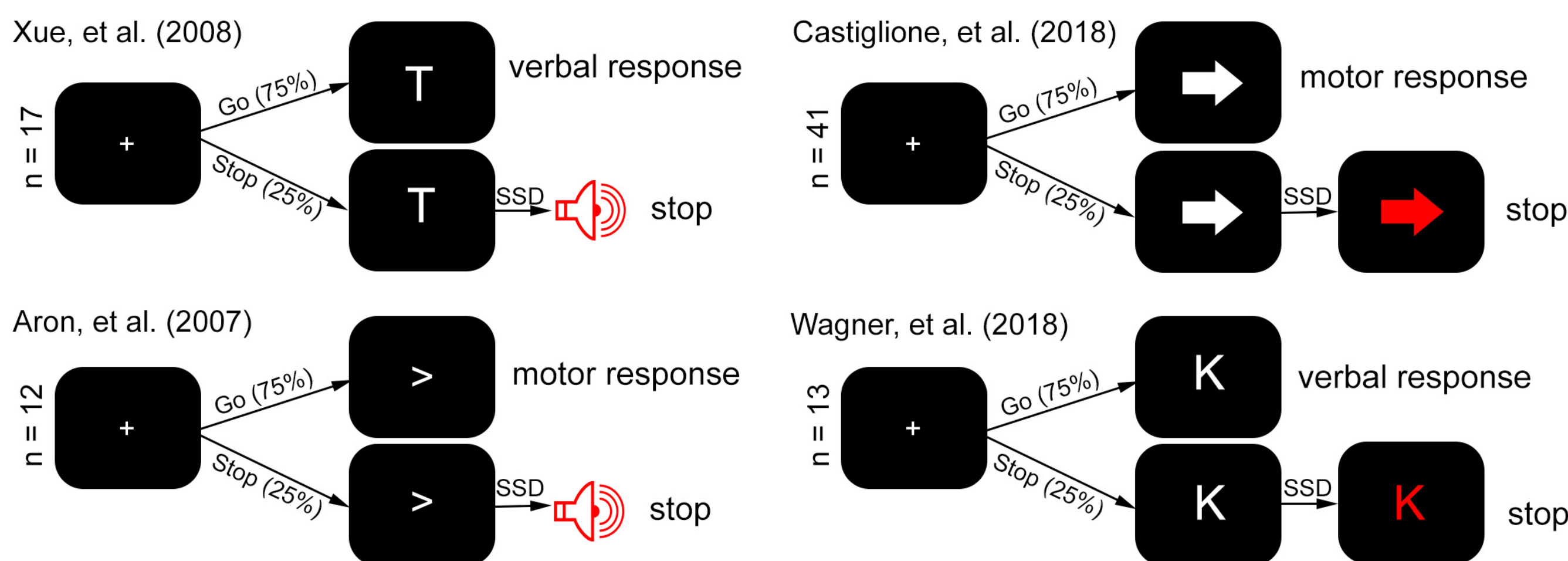


Figure 1. Experiment stimuli.

### ROI specification

- Using the EEG studies (Castiglione, et al. (2018), Wagner et al. (2018)) identified eight clusters of stopping, including bilateral inferior frontal areas, using temporal and spatial properties of independent components
- These clusters were converted into fMRI masks based on the probabilistic dipole densities
- List of regions of interest:
  - right lingual
  - right inferior frontal gyrus (rIFG)
  - right precentral (rPrecentral)
  - left inferior frontal gyrus (lIFG)
  - precuneus
  - right temporal (rTemp)
  - left occipital (lOcc)

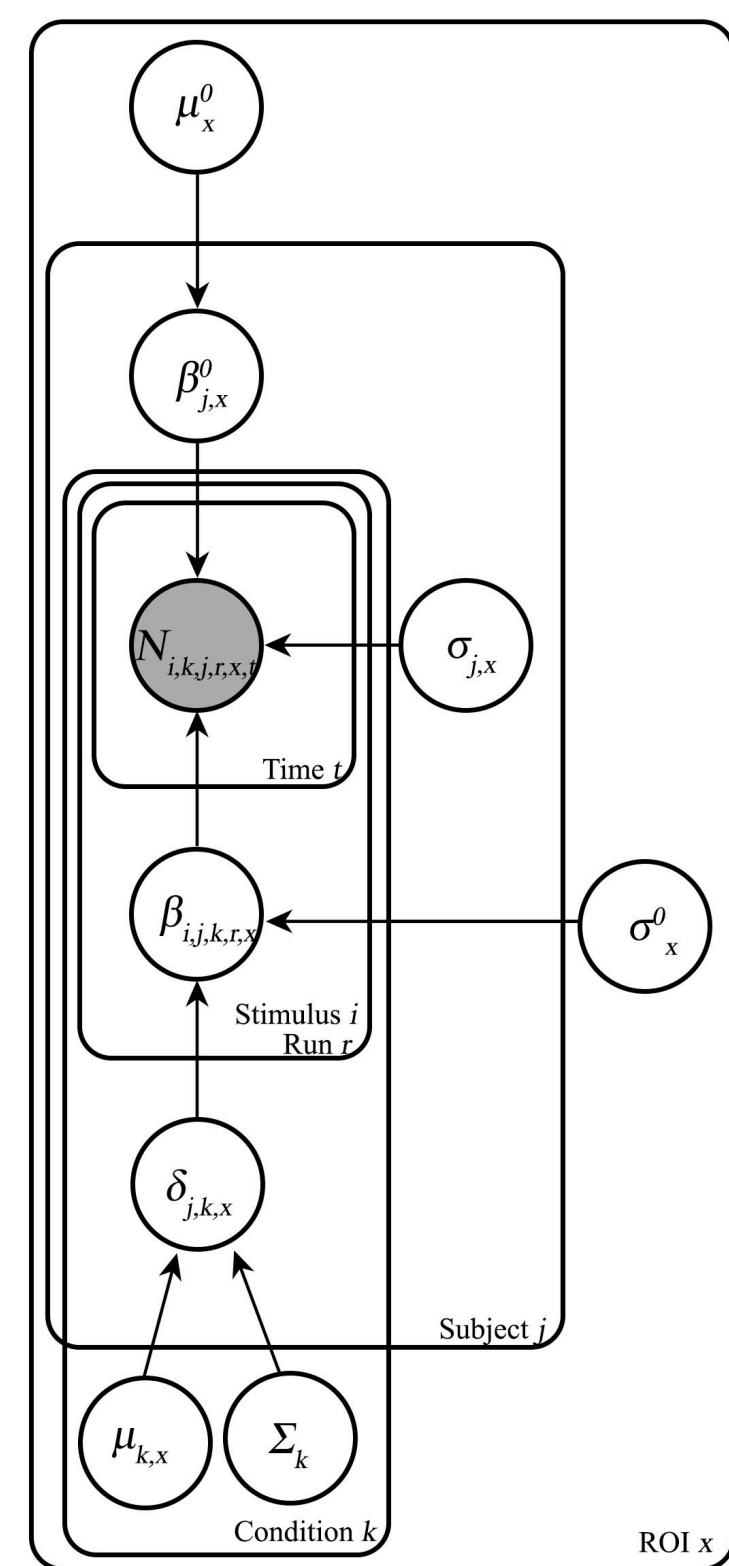
### ERSP

- Event-related spectral projection (ERSP) calculated for two clusters corresponding to frontal areas. Code adapted from Wagner, 2018.

### fMRI Bayesian Model

- fMRI model fit using a Bayesian hierarchical model (across conditions, runs, subjects, and regions of interest) in JAGS

Figure 2. Graphical diagrams of the five models. Each node represents a variable in the model, where filled nodes are observed data and white nodes correspond to latent variables. The only filled node pictured in each model is  $N_{ijk,x}$ , the neural data. The design matrix (information about stimuli condition and onset time) were not included in this diagram for visual clarity. Arrows represent relationships between variables and plates represent replications across dimensions (e.g., conditions or subjects).



## RESULTS

### EEG replication

- Combined study: increased beta band activity in successful stopping compared to failed stopping following stop-signal
- Replicates expected results

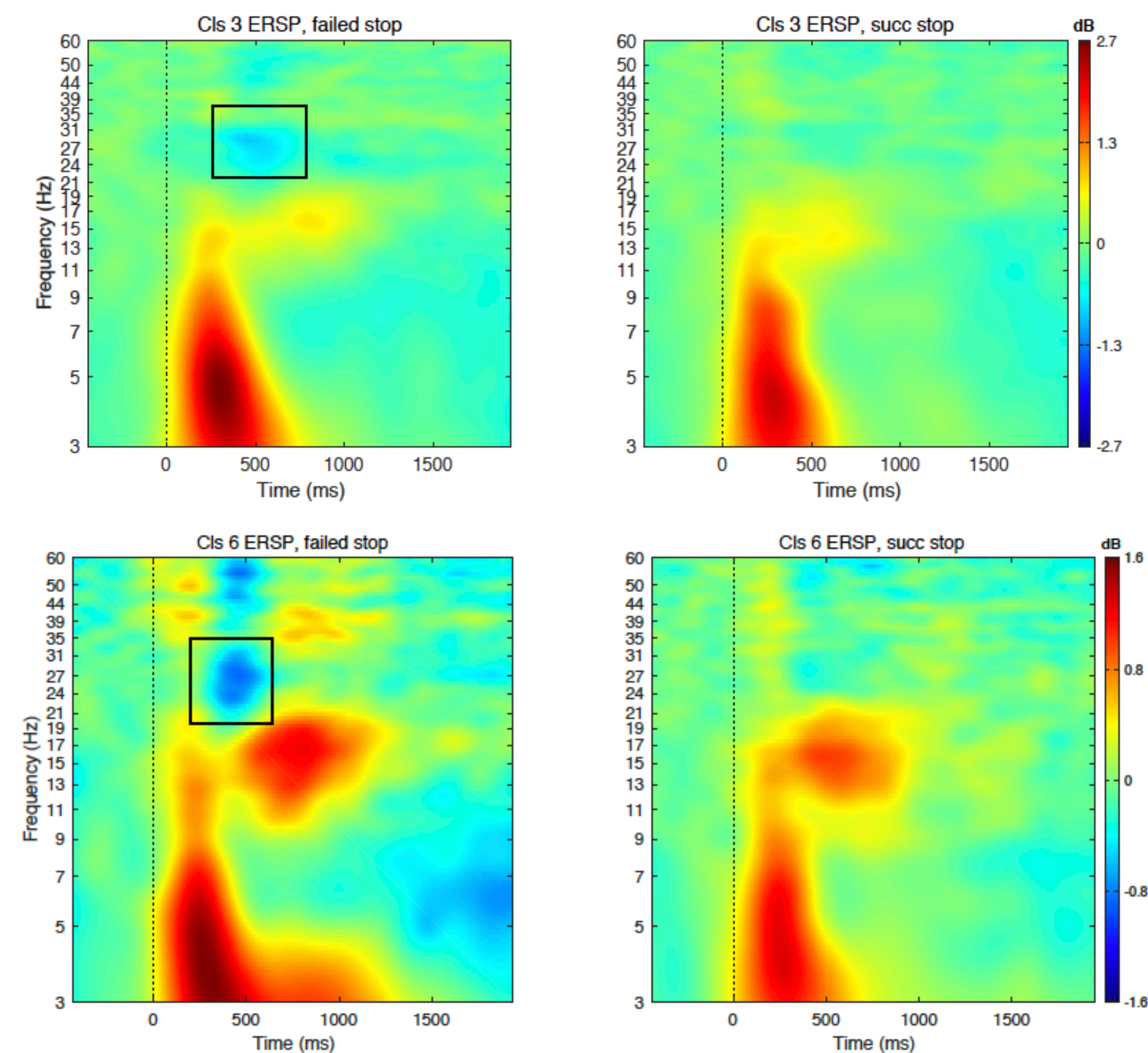


Figure 3. Event related spectral projections (ERSP). Top row shows cluster corresponding to right inferior frontal gyrus, and bottom row corresponds to the left inferior frontal gyrus. The left column shows the ERSP for failed stopping and the right column shows the ERSP for successful stopping. The frequencies corresponding to beta-band are between 12.5 and 30 Hz.

### fMRI analysis

- Increased pair-wise coactivation in all ROIs for successful and failed stopping over going
- Overall pattern was the same in the two fMRI datasets, but successful and unsuccessful stopping had different signatures

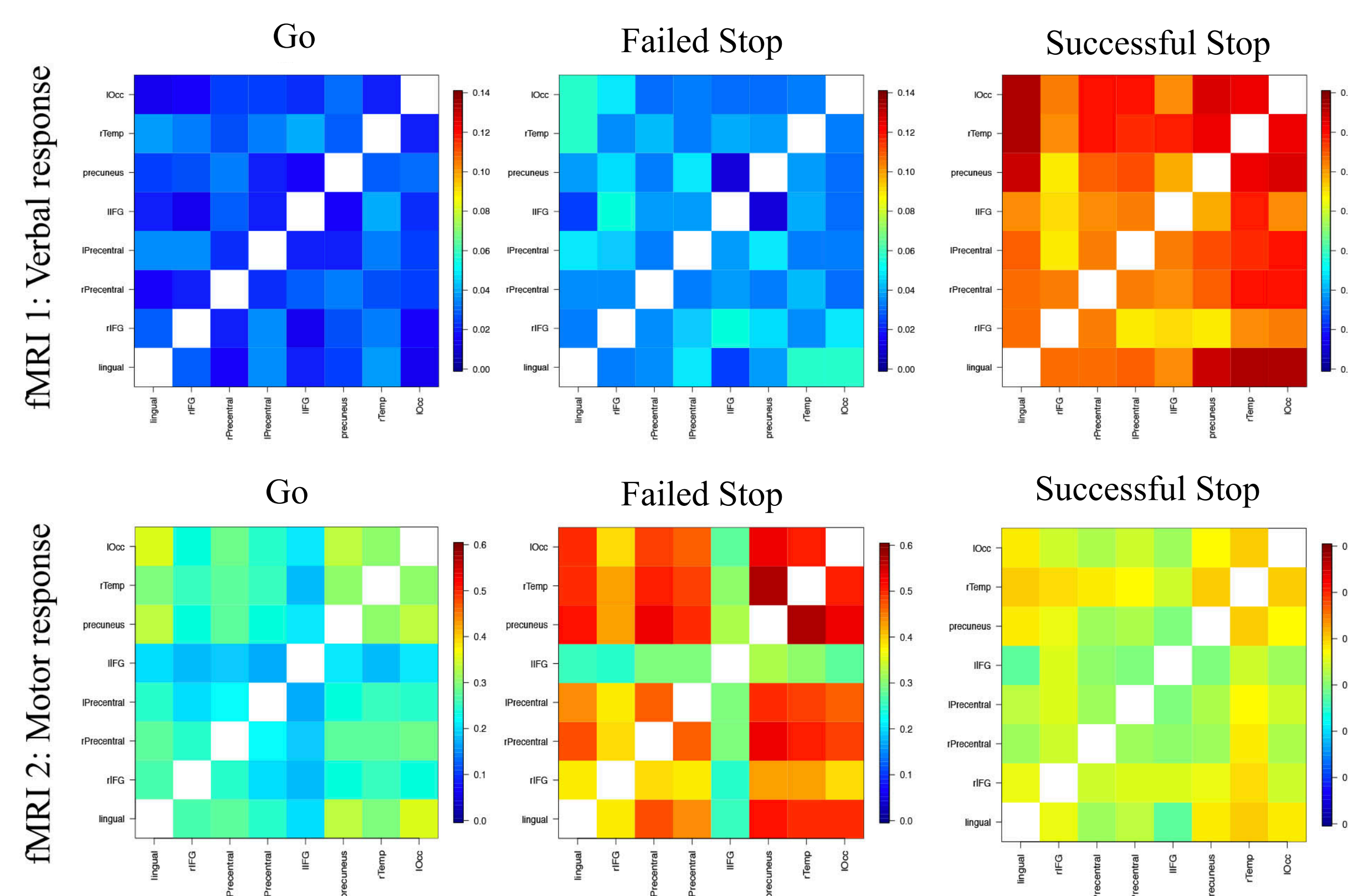


Figure 5. Coactivation matrices for fMRI. Pairwise coactivation matrices for the two fMRI studies, where the top row shows the fMRI study with a verbal response (Xue et al., 2008) and the bottom row shows the fMRI study with a motor response (Aron et al., 2007). A coactivation matrix was estimated for each condition (rows): go, failed stop, and successful stop. Higher (more positive) correlations are denoted by red-orange colors and lower correlations are denoted by blue-green colors.

$$S(t) = S(t - 1) + h\{\theta[\mu - S(t - 1)] + C(i)S(t - 1) + DU(t)\} + \sqrt{h}W(t)$$

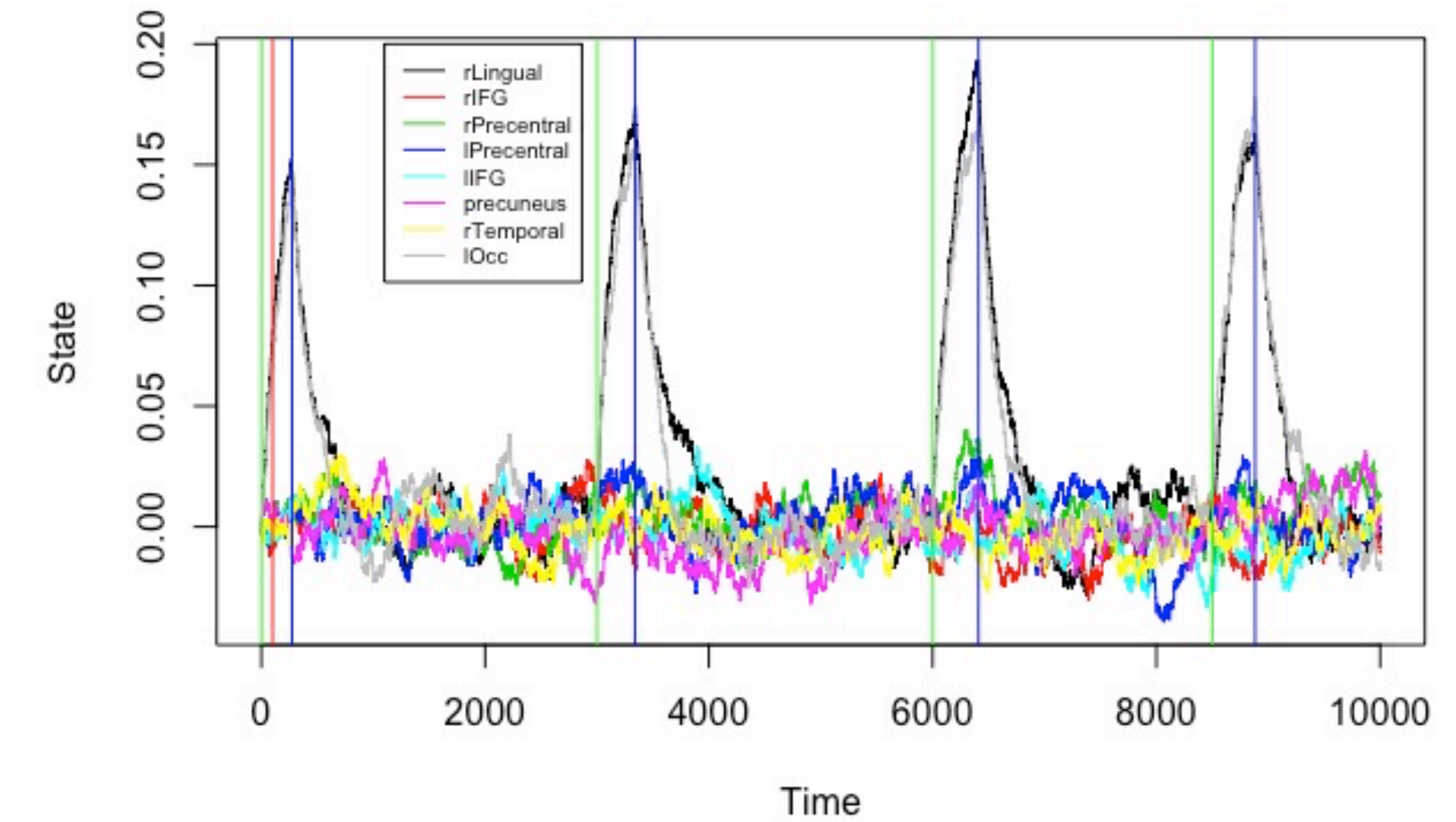


Figure 6. Simulated state space used extended MDS framework. Trace plot of the simulated states for the 8 ROIs (different colored lines). Latent states are on the x-axis and time (in ms) is on the y-axis. The vertical lines depict details from the experimental design of the first 4 trials, using real stimuli from Aron et al., 2007. The green lines denote trial start, the red lines denote stop-signal onset, and the blue lines denote trial end.

### Integrative Model

- While these modalities can be informed using common regions of interest, this type of analysis has many limitations
- Extension of Multivariate Dynamical Systems (MDS) to predict both fMRI and EEG data with a common underlying generative model (latent states; above figure)

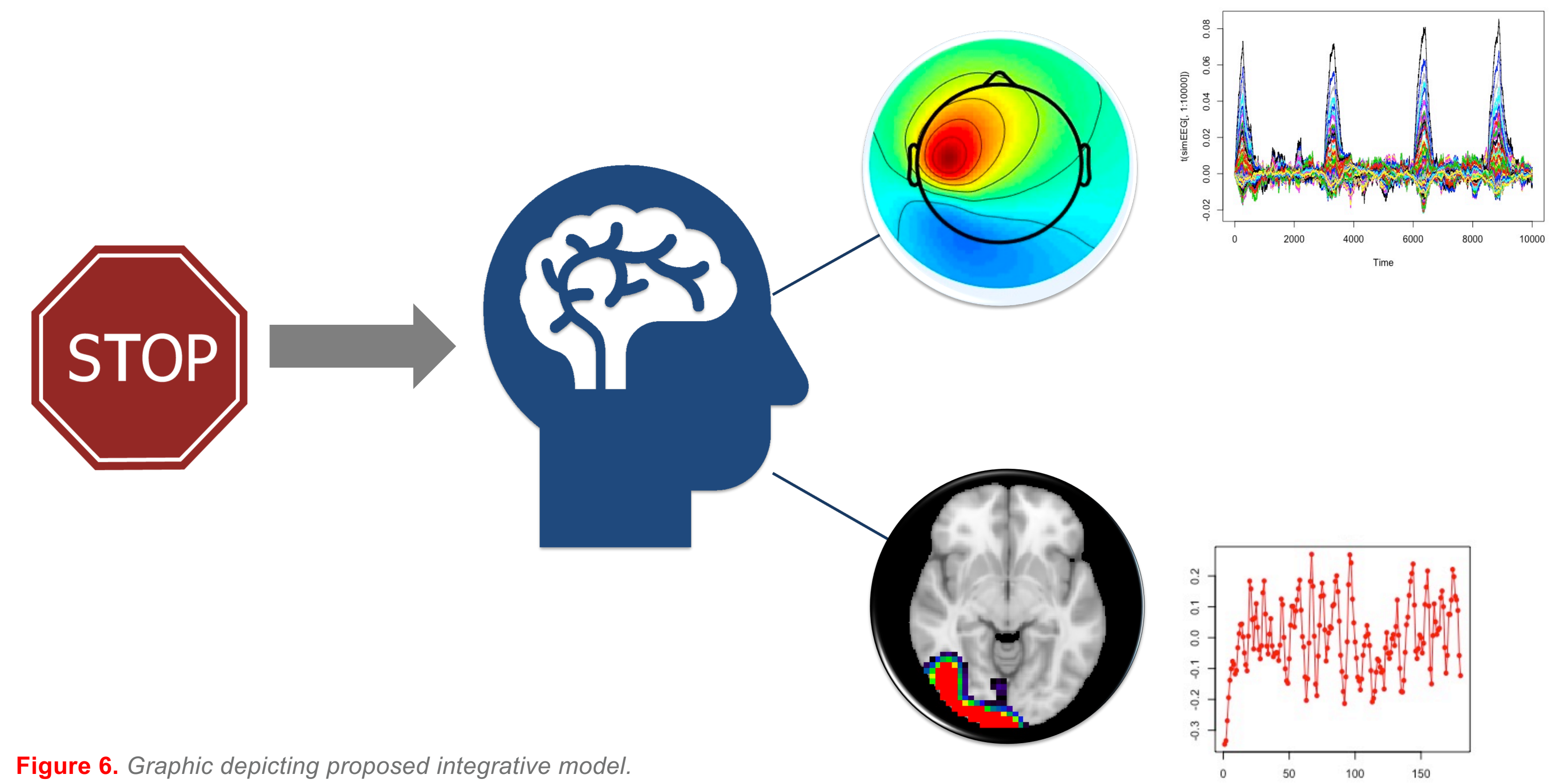


Figure 6. Graphic depicting proposed integrative model.

## CONCLUSIONS

- EEG data can inform analyses of fMRI data to aid in fully understanding response inhibition, but they lack mechanisms for causality.
- Further research using dynamical models is needed to determine causality and allow full integration of these modalities.

### BIBLIOGRAPHY

- Xue, G., Aron, A.R., Poldrack, R.A. (2008). Common neural substrates for inhibition of spoken and manual responses. *Cereb Cortex*, 18(8):1923-32.
- Aron, A.R., Behrens, T.E., Smith, S., Frank, M.J., Poldrack, R.A. (2007). Triangulating a cognitive control network using diffusion-weighted magnetic resonance imaging (MRI) and functional MRI. *J Neurosci*, 27(14):3743-52
- Wagner J, Wessel JR, Ghahremani A, Aron AR (2018). Establishing a right frontal beta signature for stopping action in scalp EEG: implications for testing inhibitory control in other task contexts. *Journal of Cognitive Neuroscience*
- Castiglione, A., Wagner, J., Anderson, M. & Aron, A.R. 2018. Preventing a thought from coming to mind elicits increased frontal beta just as stopping action does