Comparing Neural Activity in the Preparation Stage of Zebra Finch Song and Attempted Human Speech

Background Research

Human-like brain hemispheric dominance in birdsong learning

- This paper found a remarkable **neural parallel** between **birdsong** and **human spoken language**, and how they have important consequences for our understanding of the evolution of auditory-vocal learning and its neural mechanisms.

- Both humans and zebra finches show **left-hemisphere dominance** during early stages of vocal learning.

learning phase and was memory-related. These findings demonstrate a remarkable neural parallel between birdsong and human spoken language, and they have important consequences for our understanding of the evolution of auditory-vocal learning and its neural mechanisms.

(Moorman etc,2012)

Exploring Null-space Hypothesis

nature > nature reviews neuroscience > review articles > article

Review Article | Published: 05 March 2024

Preparatory activity and the expansive null-space

Mark M. Churchland & Krishna V. Shenoy

Nature Reviews Neuroscience **25**, 213–236 (2024) | Cite this article

OUR PROJECT

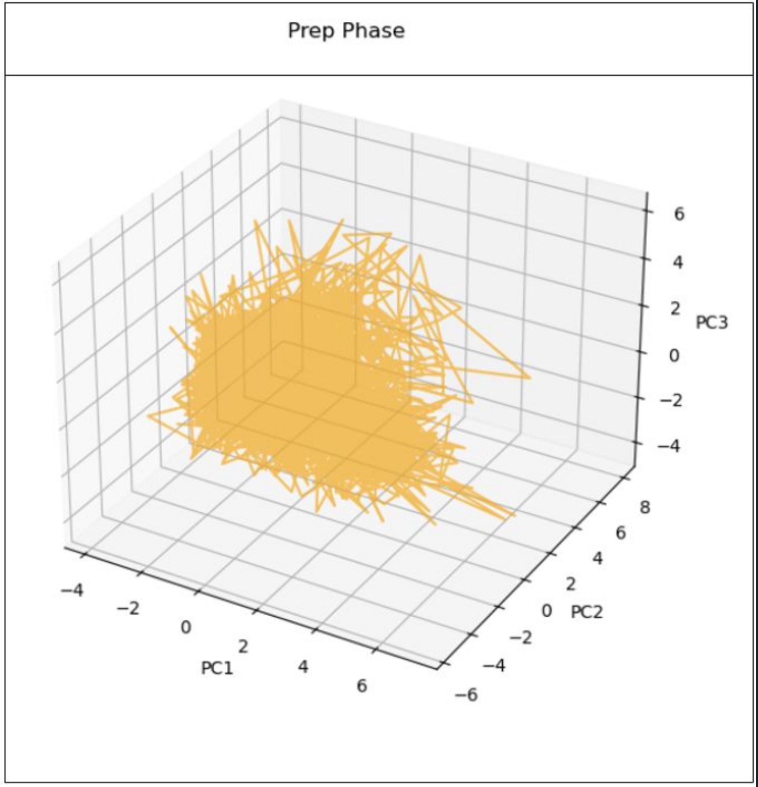
Big Question: Does **comparing neural activity** between **zebra finches** and **human vocal speech** elicit any similarities?

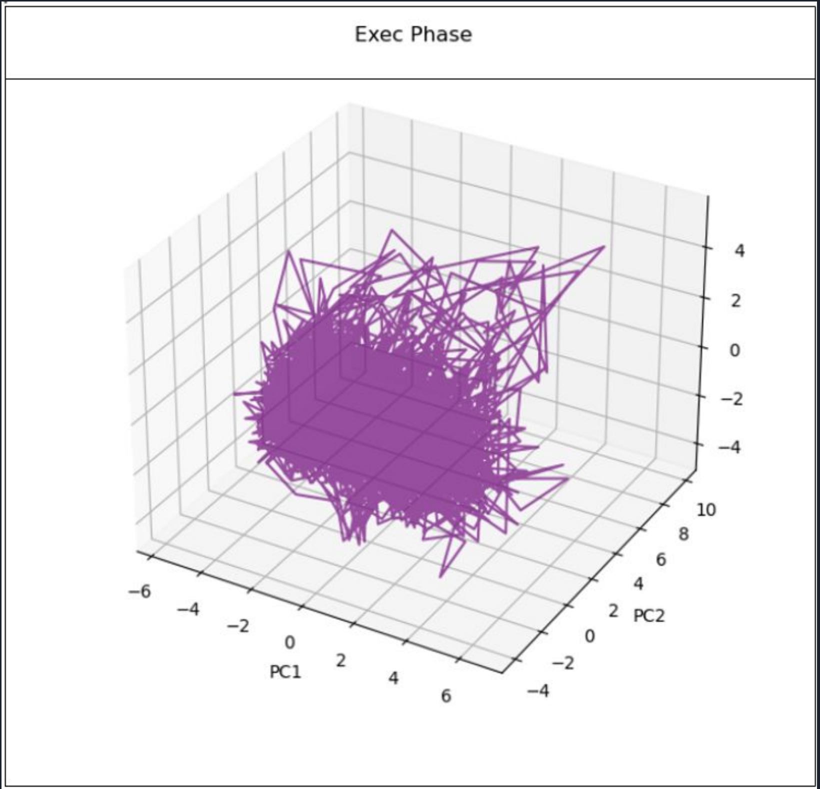
PCA Method for Human Dataset

- Load necessary libraries and toolkits
    - scikitlearn PCA, scikitpreprocessing StandardScaler()
- Load spikePow, delayTrialEpochs, delayGoEpochs, cueList, and trialCues to arrays
- Choose a word and find the timings of the start and end of the trials
- Construct the prep matrix, scale, and conduct PCA

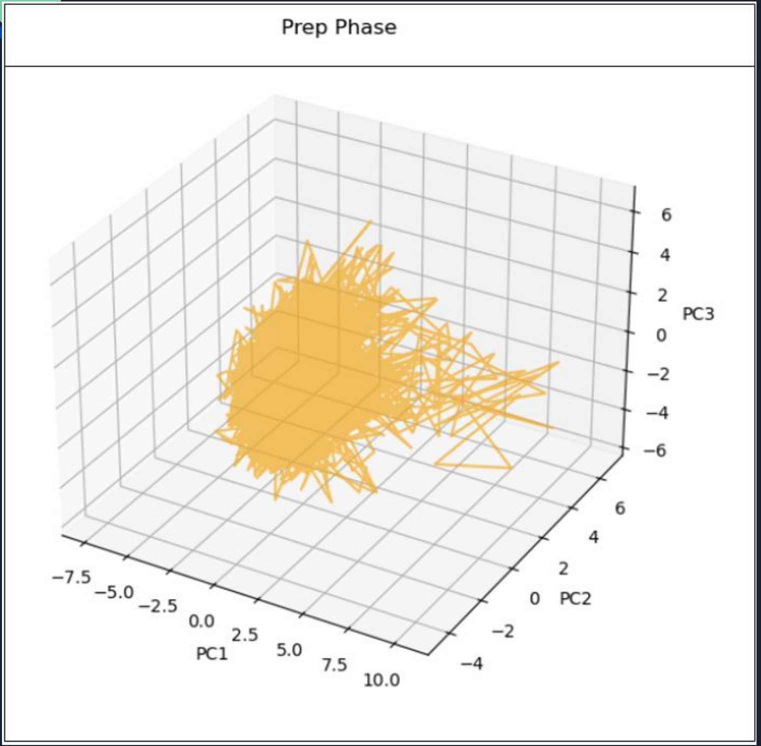
RESULTS

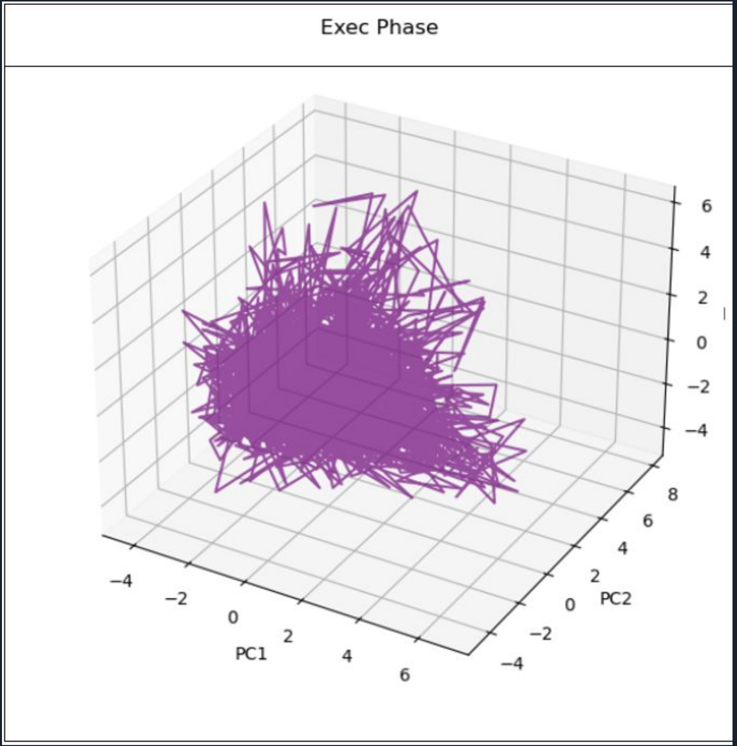
PCA Trajectories when prompted with the word ‘hello’



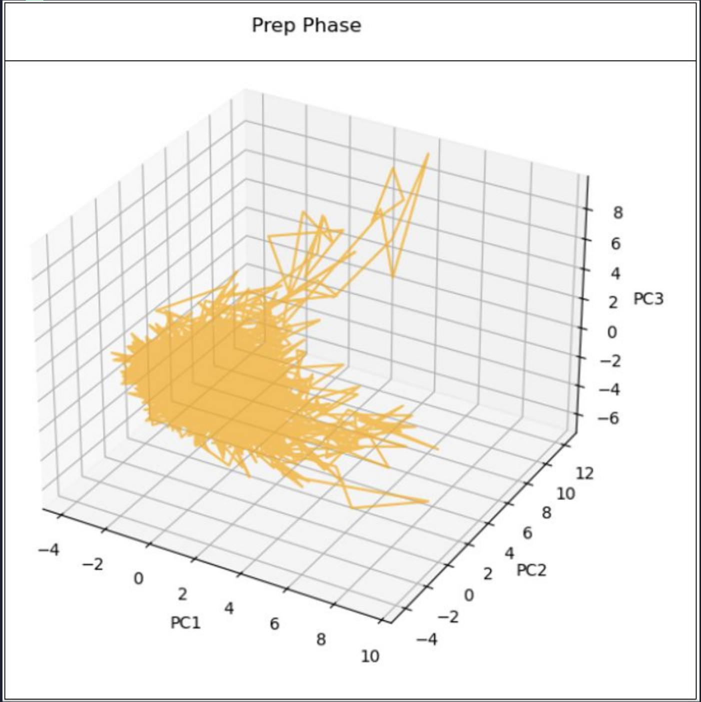


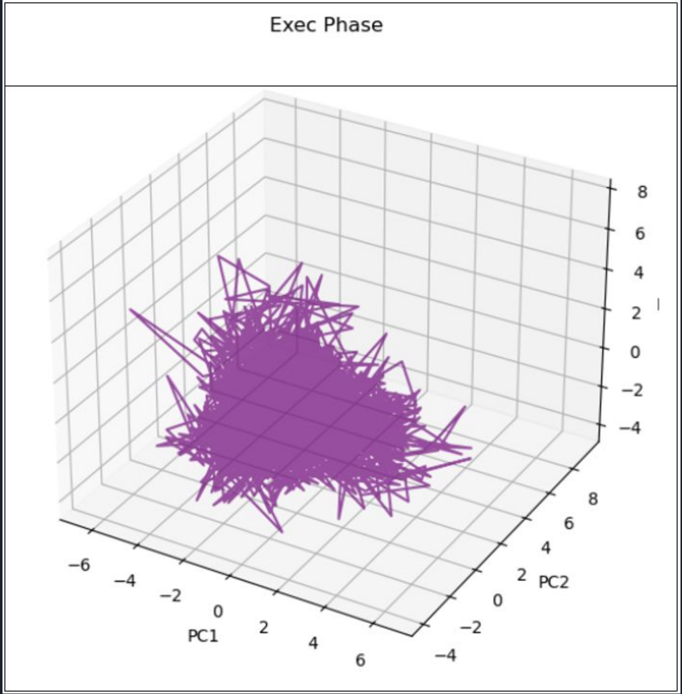
PCA Trajectories when prompted with the word ‘bad’



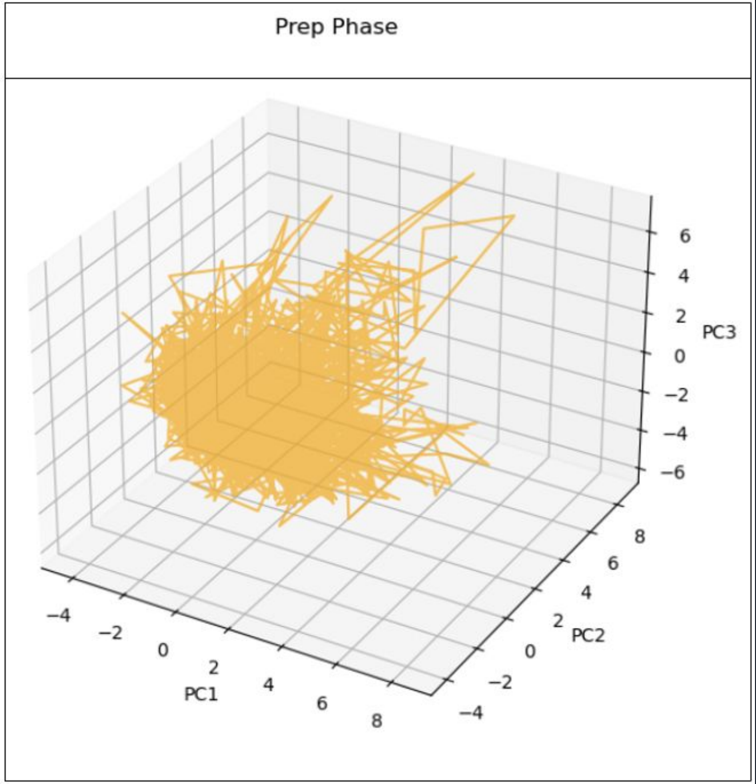


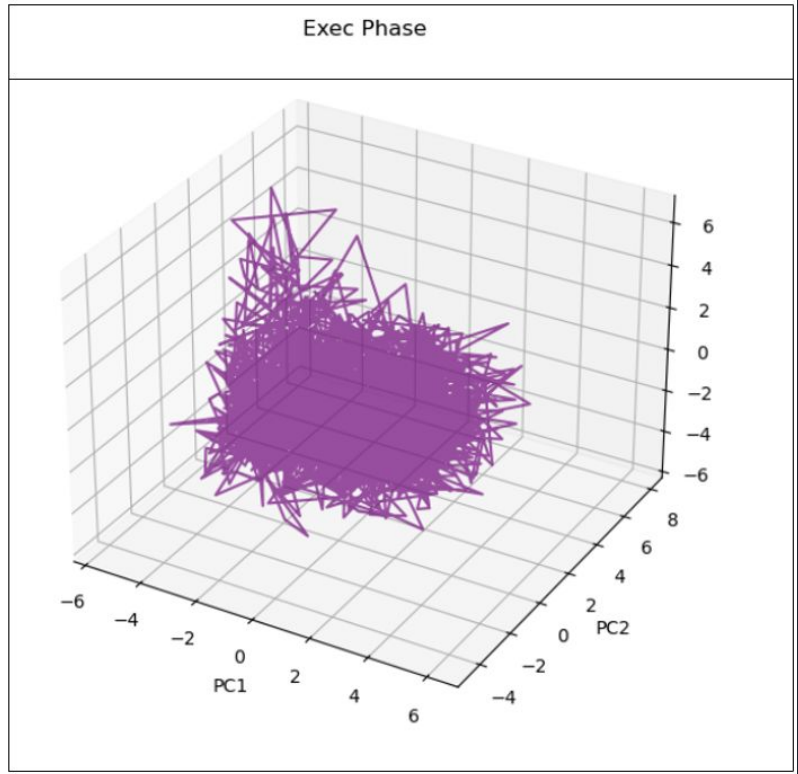
We tested a few words such as “Tired”





We tested a few more words such as “hungry”



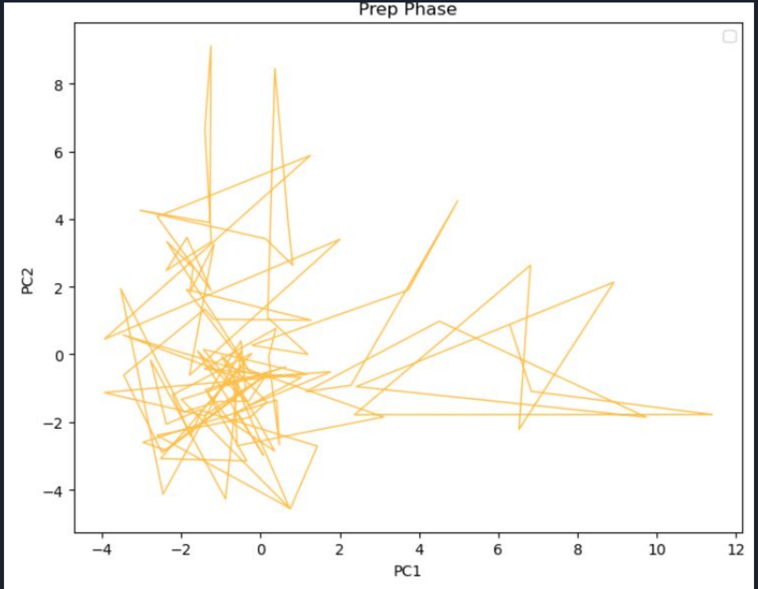


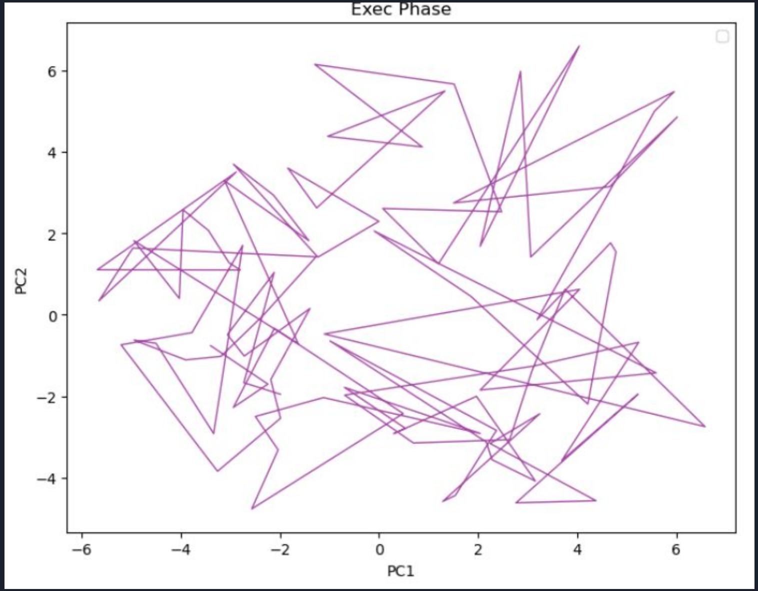
Analysis

- **Lots of activity** in both the preparation and execution phase
- Difficult to extrapolate trends

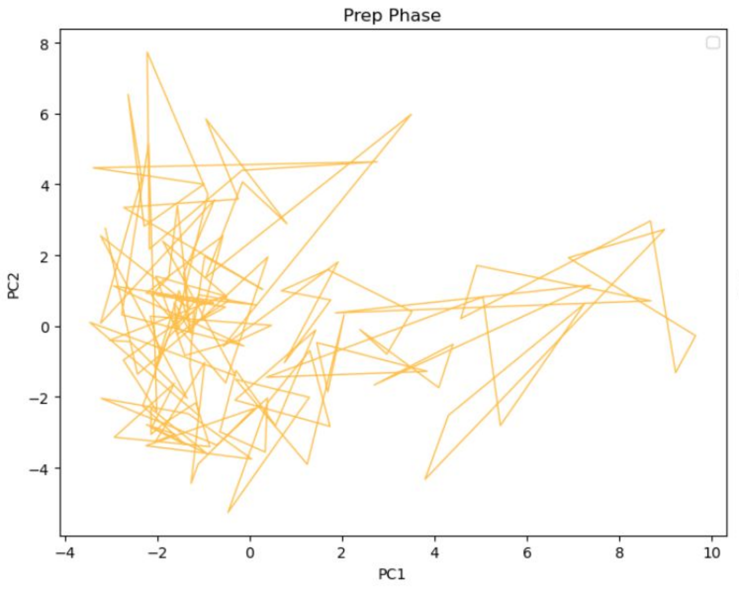
- We decided to do further analysis on **single trials**

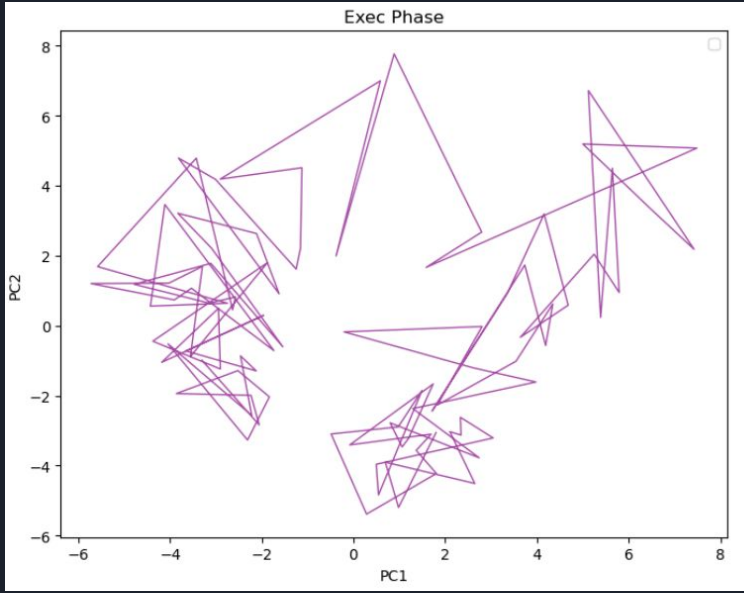
Single trial: ‘hello’



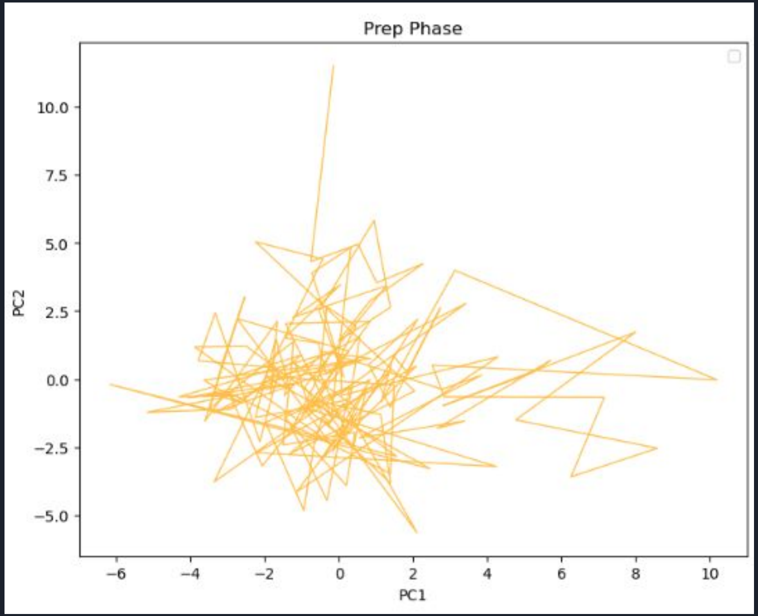


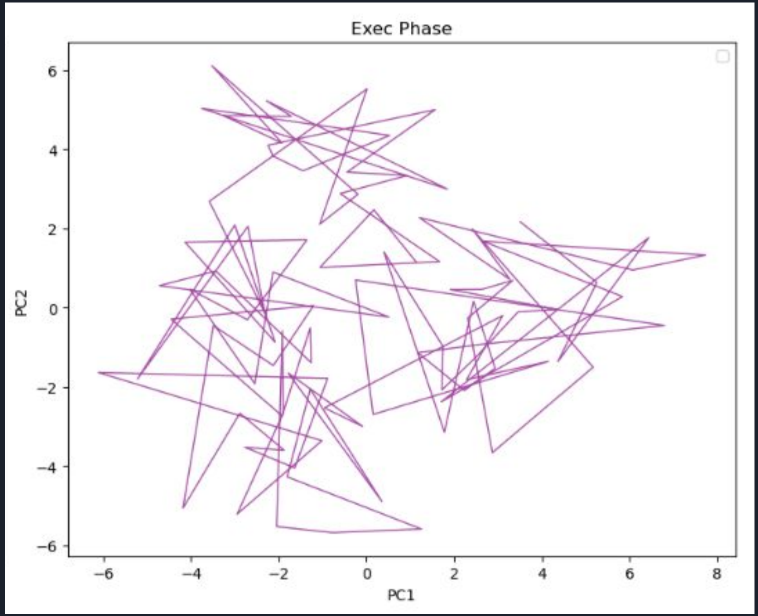
Single trial: ‘tired’



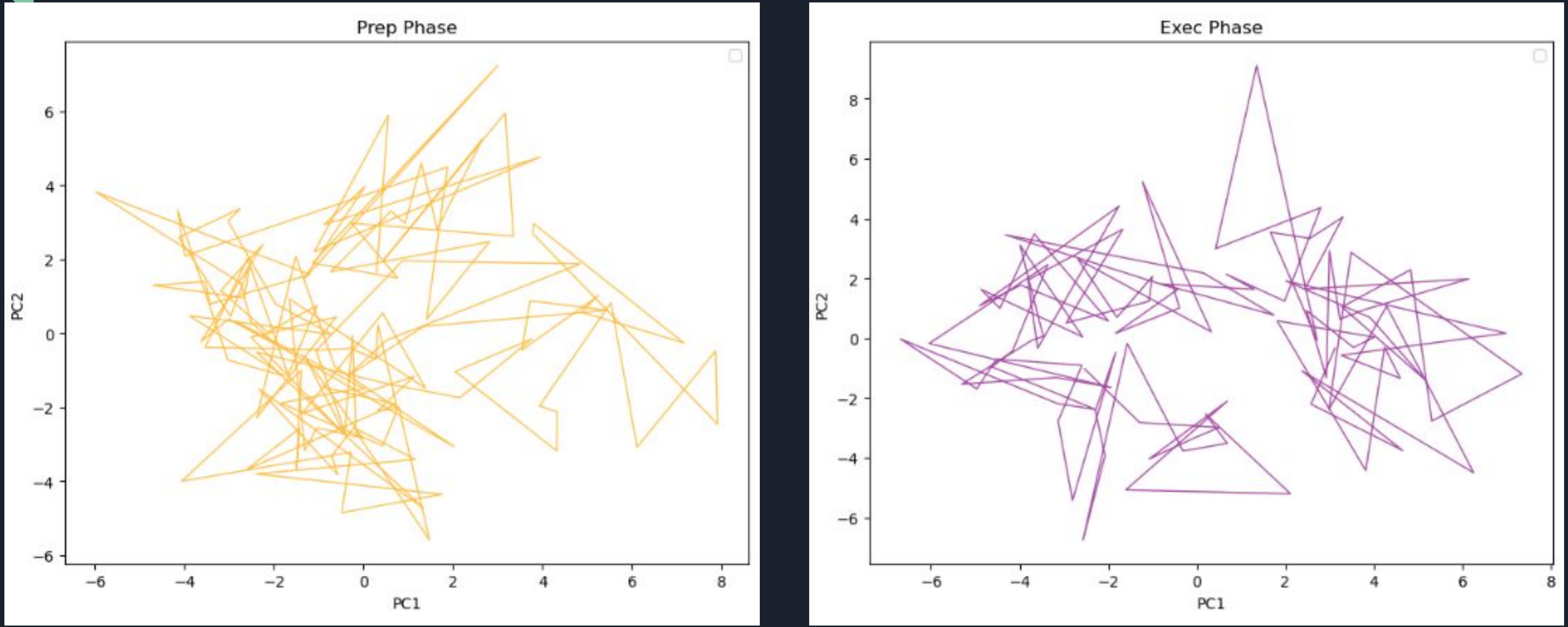


Single trial: ‘hungry’





Single trial: ‘bad’

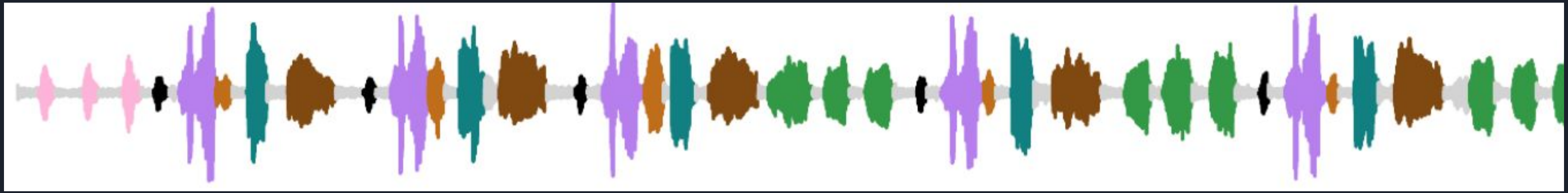


PCA Method for Zebra Finch Dataset

Gray: Silence

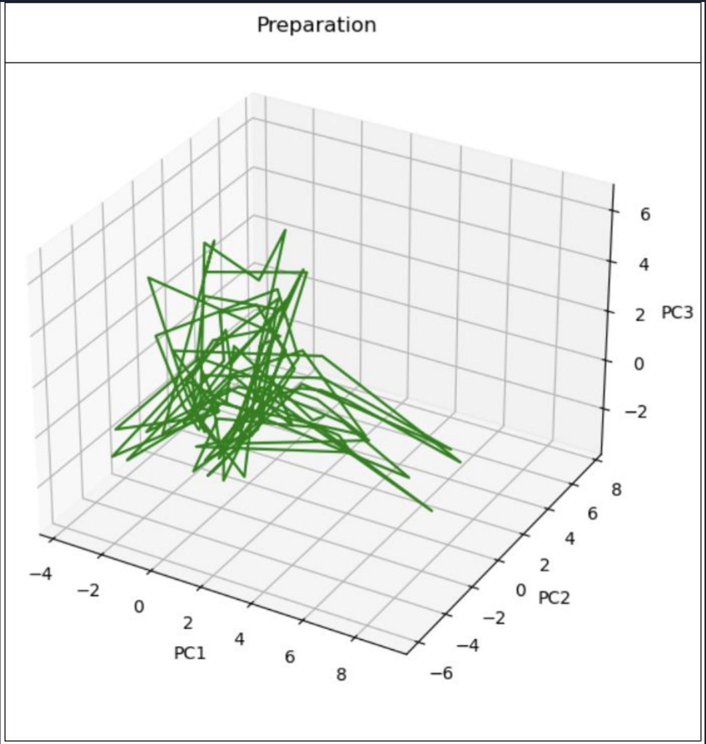
Pink: intro note

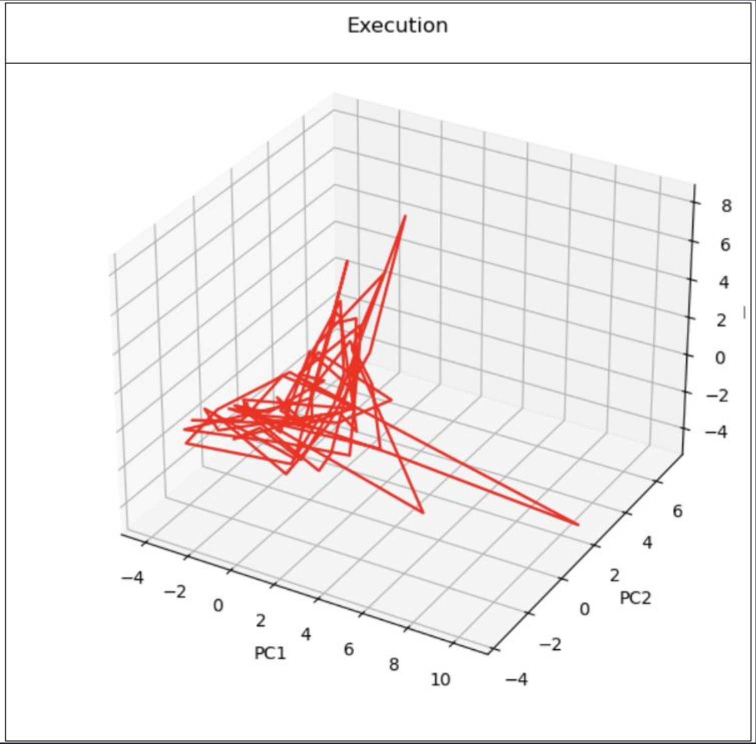
Black: syllable 1



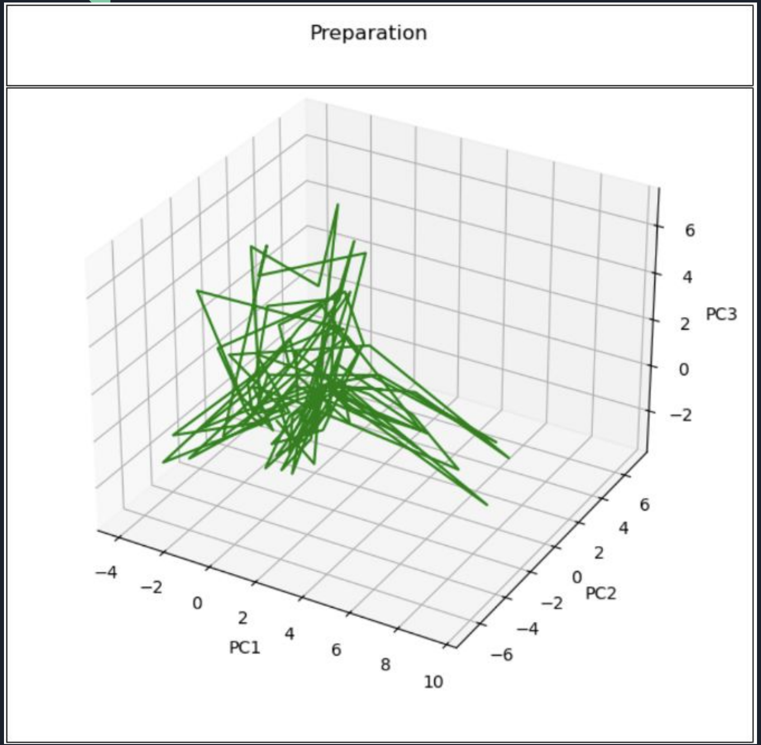
- Dataset contains neural recordings from the songbird motor nucleus RA and audio recordings of birdsong
- Sectioned out sections for silence (preparation) and notes (execution)
- PCA on each section

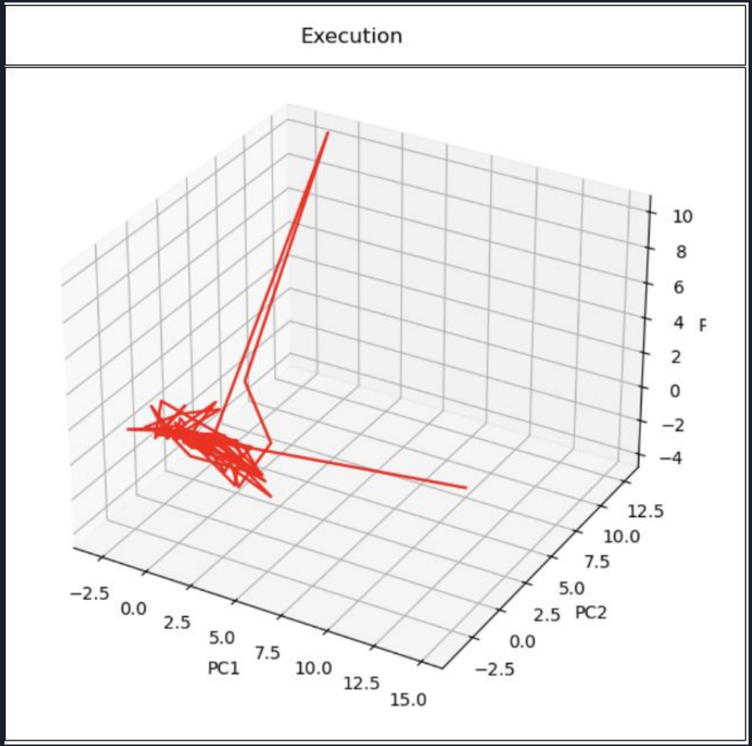
PCA Zebra Finch First Intro Note



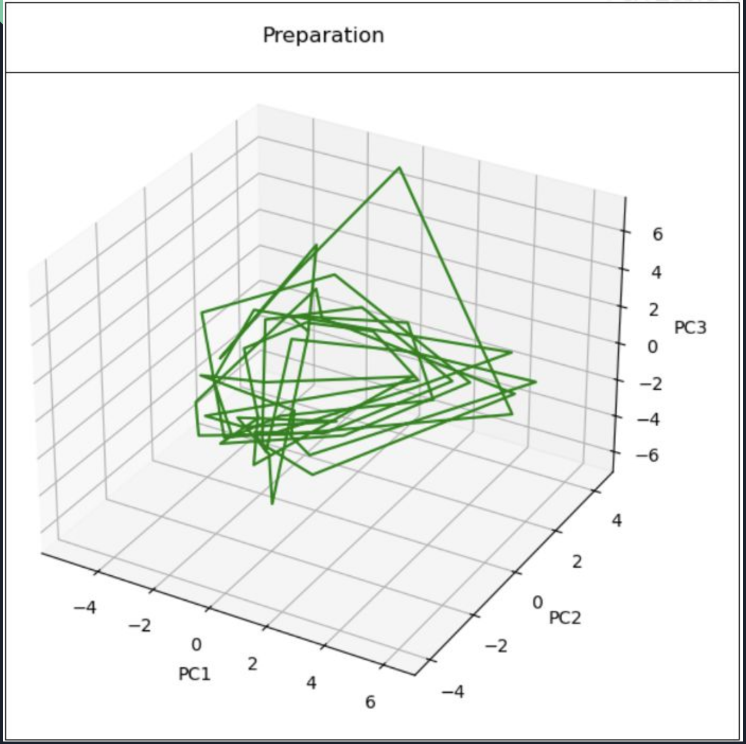


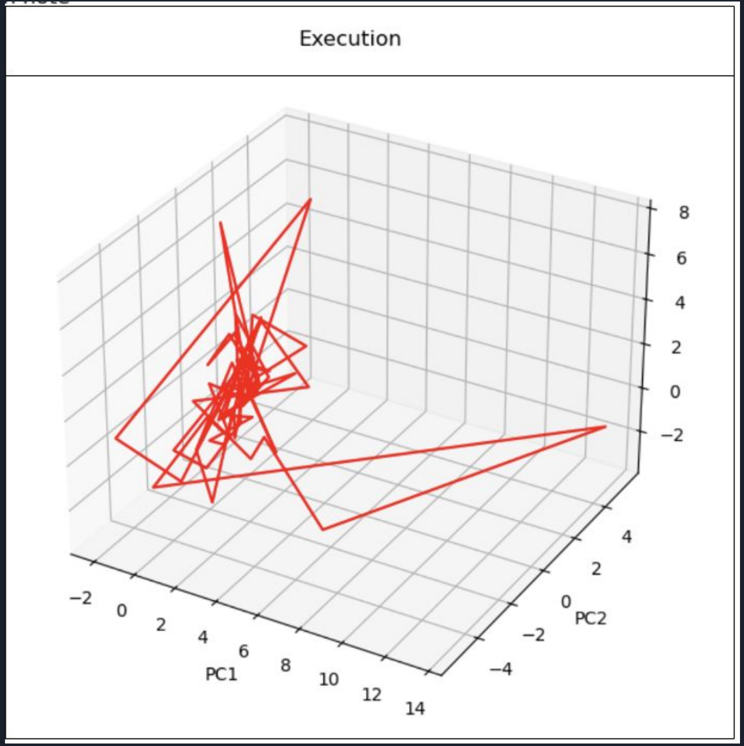
PCA Zebra Finch Second Intro Note





PCA Zebra Finch fourth note





Analysis

Preparation

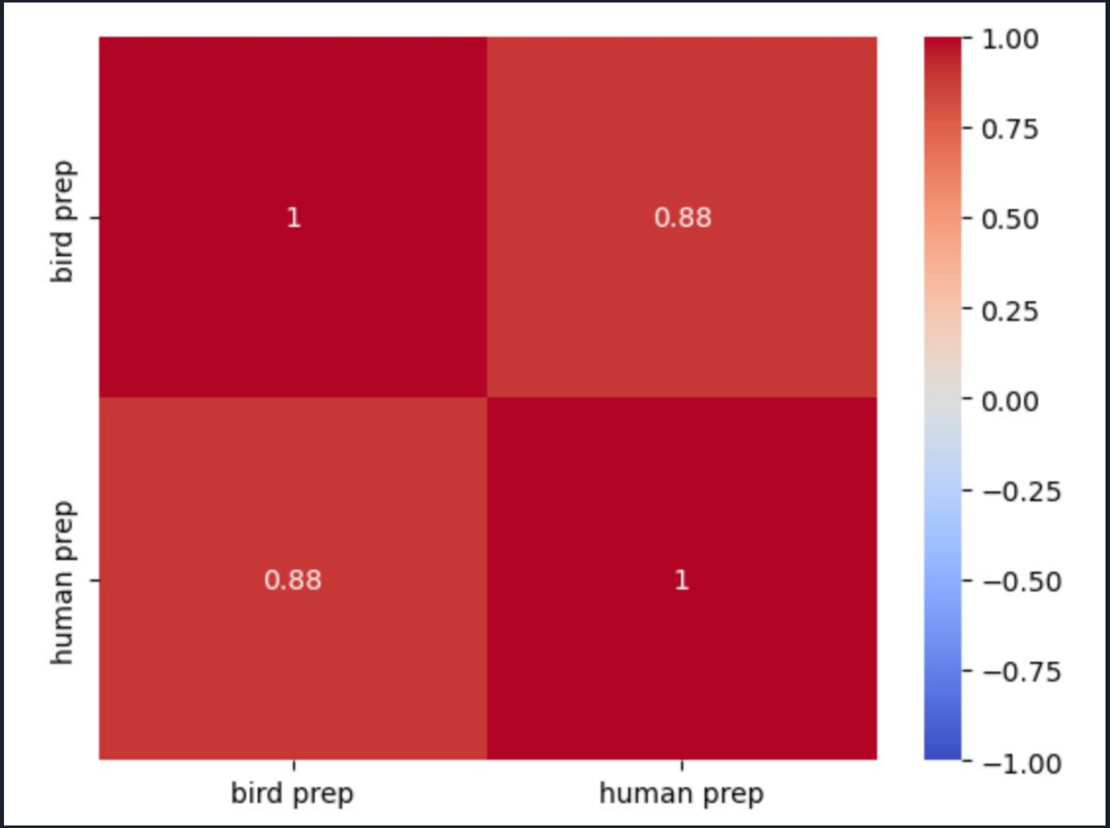
- more consistent
- more centered

Execution

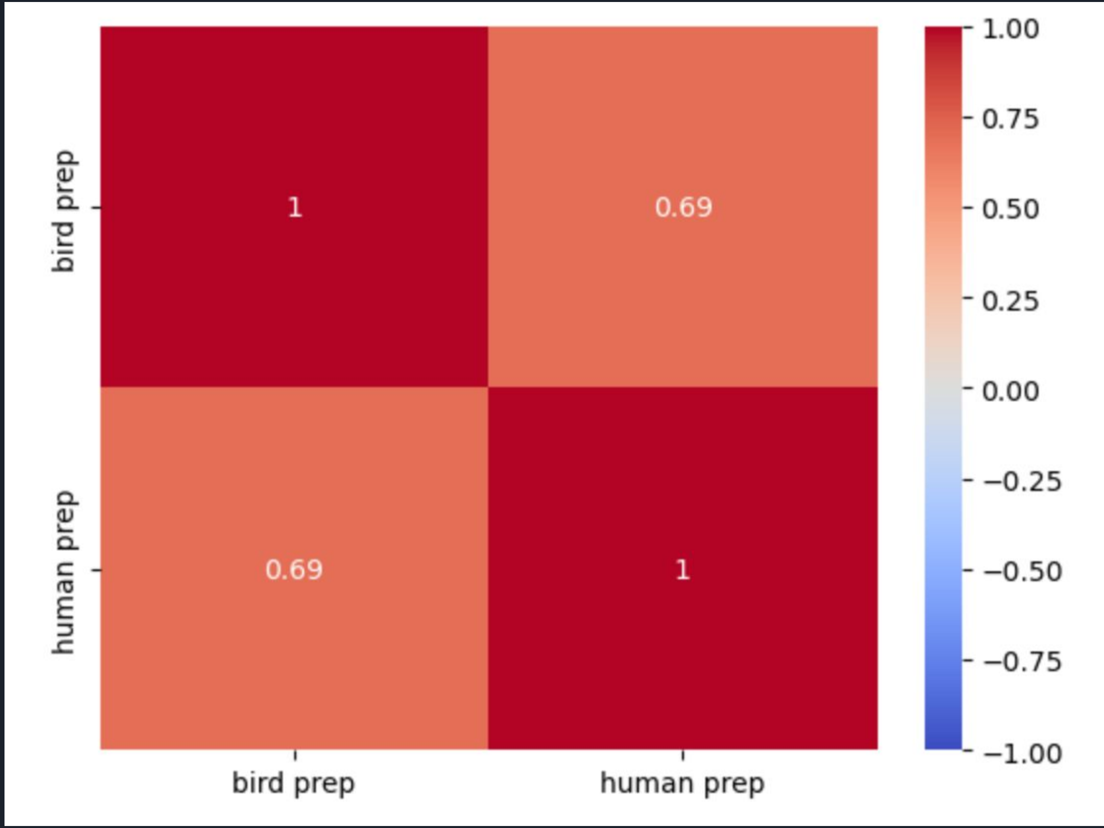
- less activity
- gathered more in the corner

Correlation Matrices for Bird Preparation Phase vs Human Preparation Phase

Correlation Heatmap for the word: ‘hungry’

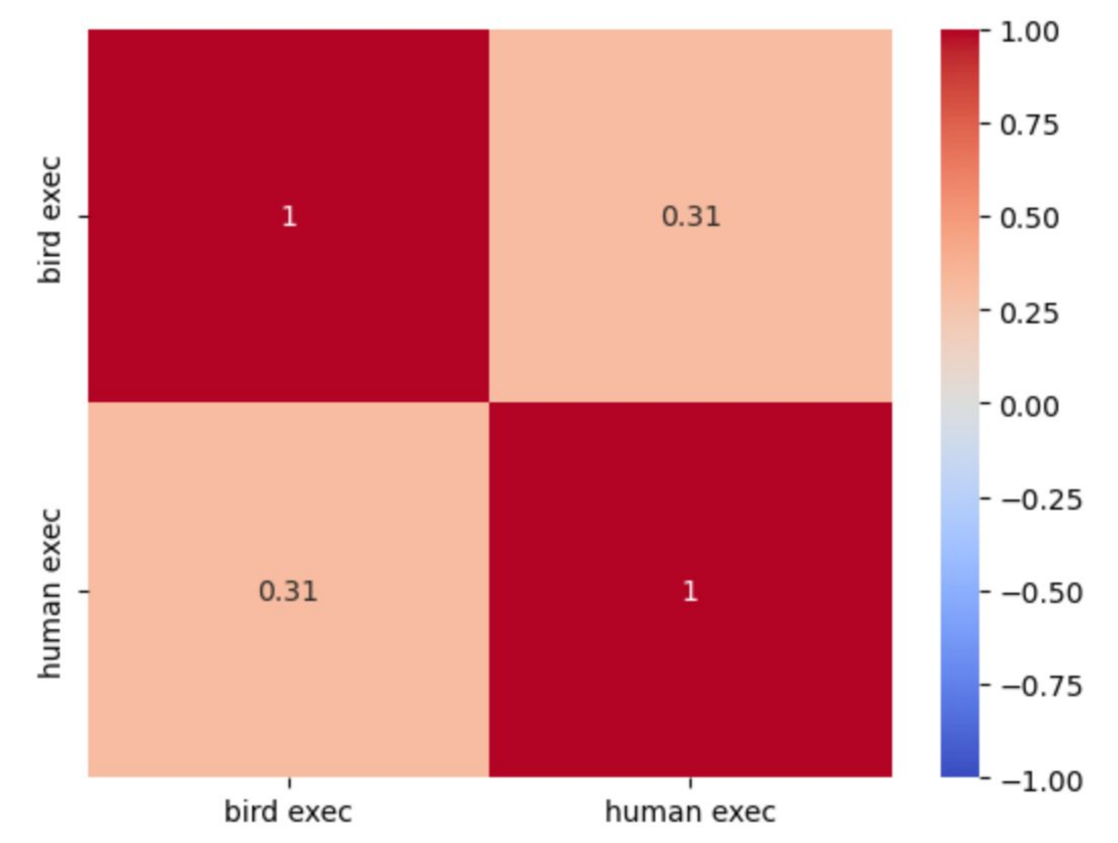


Correlation Heatmap for the word: ‘bad’

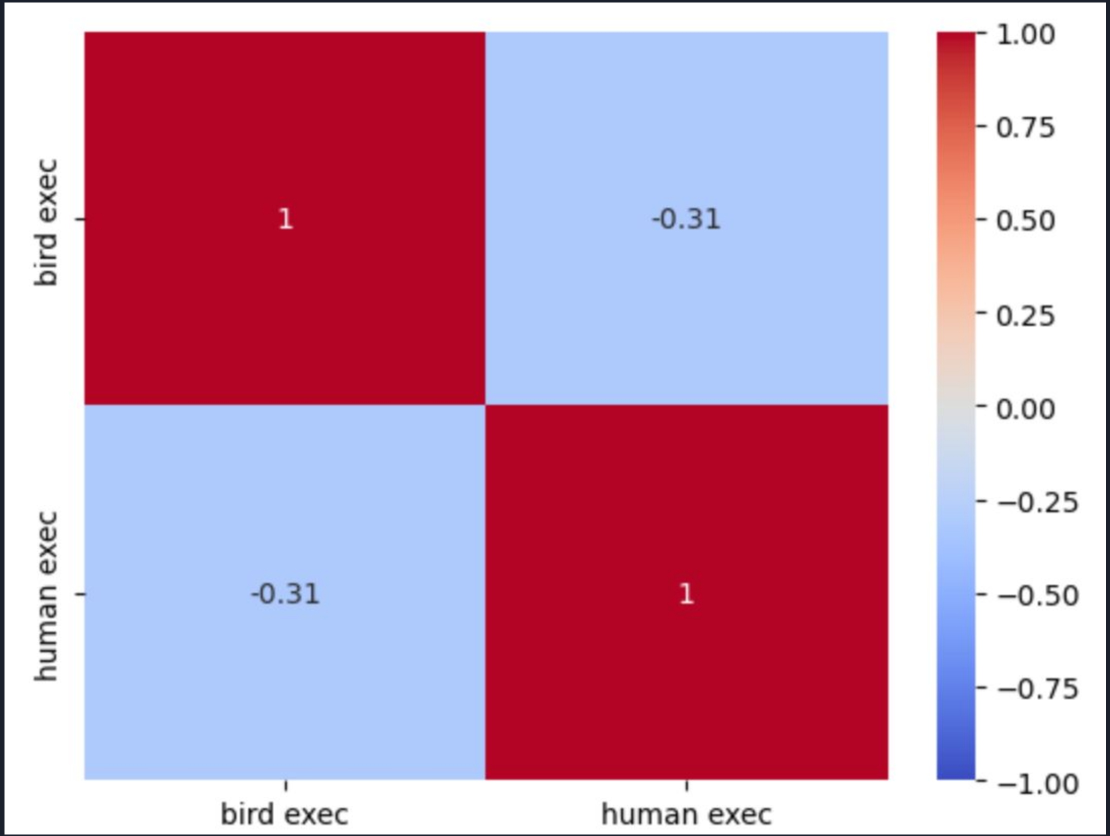


Correlation Matrices for Bird Execution Phase vs Human Execution Phase

Correlation Heatmap for the word: ‘hungry’



Correlation Heatmap for the word: ‘bad’



Future Directions - ML models

inputting PCA plots to match trajectories to possible behavior/syllables

=> since this means aiming for discrete op (syllable, word, behavior), we could train two SVM models that matches PCA trajectories to probability clusters of different syllables/words

Compare 2 models: performance, weight maps, etc.

Then, could try cross-implementation and derive how similar the prep/execution stages are by analyzing prediction accuracy

Could even try :

nonlinear models like RNN to analyze temporal differences in prediction

Future Directions - Information Theory

building a prediction model using IT approaches and the zebra finch dataset, then applying that to the human dataset

Compute and compare encoding efficiency via bps

Calculate Snoise to evaluate how much neural activity is actually caused by stimulus; also, could compare the amount of “transmitted information” in different datasets from neural activities by calculating Stotal-Snoise

On the Application of Information Theory to Neural Spike Trains

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$$\text{Bits/Spike} = \frac{\text{Transmitted Information Rate } (R_{\text{Info}})}{\text{Average Firing Rate } (\bar{R})}$$

Discussion

Preparation similar across trials for both humans and zebra finches; moderately similar in preparation process across humans and zebra finches

Neural activity for humans during preparation is different across word trials, suggesting that semantics may influence neural activity at preparation stage

In humans, there were higher neural activity during execution compared to birds

In the future, datasets could be compared with ML models and other approaches