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Tracing the Gating Role of Oscillation in V4 Spike Generation

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Introduction

In cognitive processes, communication between regions of the brain is paramount in order to incorporate the intricacies of high-level neural processes. It has been previously established that oscillation between brain regions is a method of communication, by modulating the temporal pattern of spike activity, while not changing the overall firing rate of neurons [1-3] .

Our project is to determine if there exists an optimal phase of oscillation for neural transmission between the prefrontal frontal eye field (FEF) and posterior V4. Initial analysis will serve to determine the possibility of a relationship between phase and neural transmission efficacy, then later and future analysis will build upon that determination to construct a mathematical model to predict firing patterns based on a combination of input stimulus, V4 oscillation phase, and FEF oscillation phase.

Methods

Neural activity from a male rhesus macaque was used from both FEF and V4, in areas with overlapping receptive fields. Recordings were taken from a memory guided saccade task with a 9x9 array of probes presented during the trial. Local field potential (LFP) data was recorded from both locations and spiking activity was recorded from V4. A single electrode was used in FEF, and a 16-channel Plexon S-probe was used in V4.

Recordings were Hilbert transformed to determine signal oscillation phase across 12 different frequency ranges: 4-8 Hz, 8-12 Hz, 12-16 Hz, 16-20 Hz, 20-24 Hz, 24-28 Hz, 28-30 Hz, 30-38 Hz, 38-46 Hz, 46-54 Hz, 54-62 Hz, and 62-70 Hz. Signal phases were separated into eight bins, numbered from 1-8: $-\pi$ - $\frac{-3\pi}{4}$, $\frac{-3\pi}{4}$ - $\frac{-\pi}{2}$, $\frac{-\pi}{2}$ - $\frac{-\pi}{4}$, $\frac{-\pi}{4}$ - 0, 0 - $\frac{\pi}{4}$, $\frac{\pi}{4}$ - $\frac{\pi}{2}$, $\frac{\pi}{2}$ - $\frac{3\pi}{4}$, $\frac{3\pi}{4}$ - π.

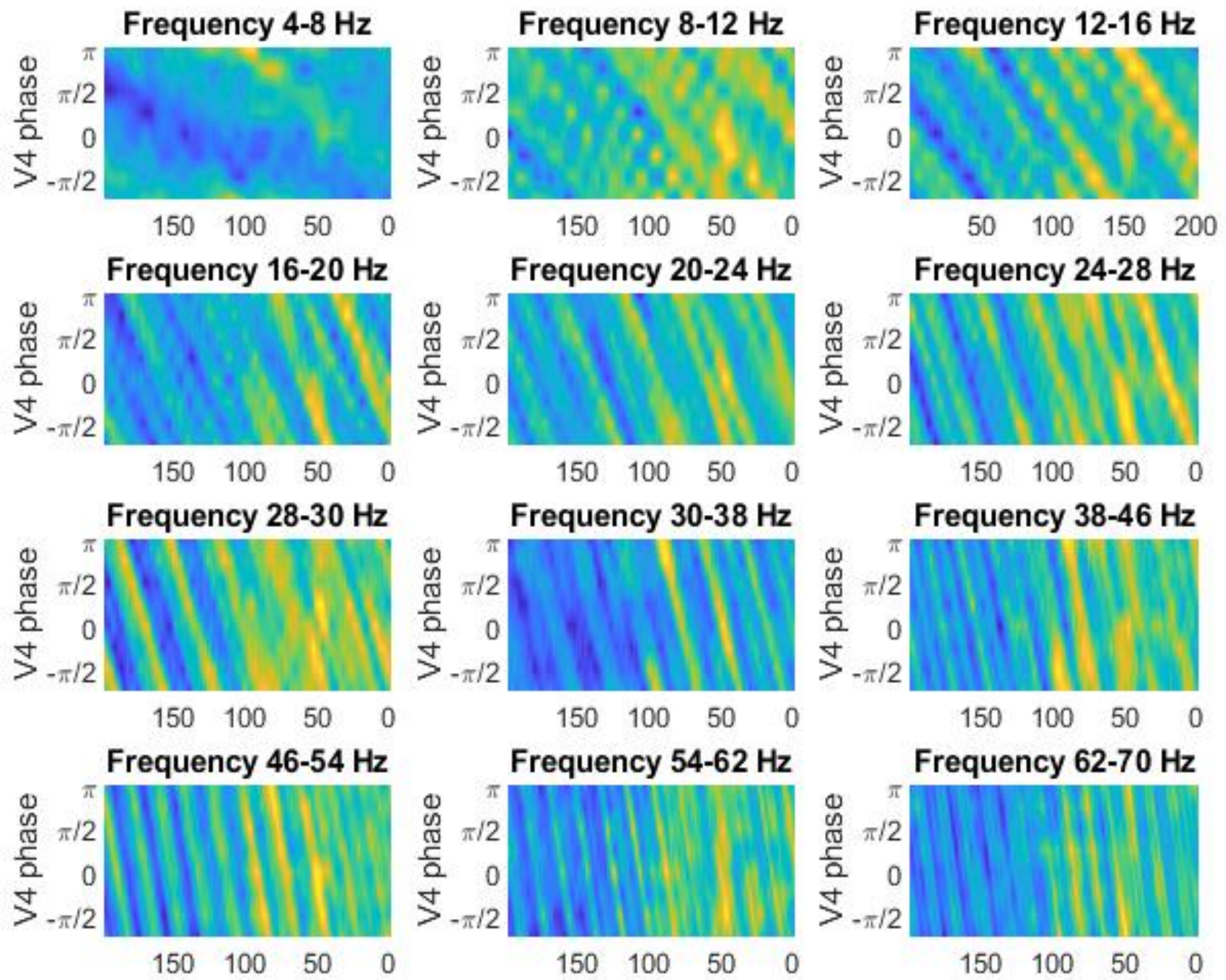

Figure 1. Spike-triggered averages for a neuron, categorized by the phase within which the spike for each frequency range.

Results

The first breakdown of data was to record spike-triggered averages (STAs) across the frequency and phase distributions. Pre-spike activity showed significantly higher relative stimulus input ~80-100 ms prior to spikes, most prominently visible in the 46-54 Hz frequency range. The cresting of the oscillation waves in each frequency range was visible through the phase bins, consistent across all recordings and frequency ranges analyzed. This data is shown in the bottom left plots.

Continuing from this data, we created a generalized linear model (GLM) using the pre-spike activity alone, weighted by the overall recording STA to predict a spike. Across the 200 ms before a spike, the starting point of the window of analysis and the length of the window were varied.

Using a threshold set by the mean of the GLM predictive matrix multiplied by the actual binary spike train, specificity and accuracy over 70% were achieved with select window parameters with only STA data as input. The downside to the model has been a low sensitivity and an extremely low precision. The specificity and accuracy plots for the GLM are below.

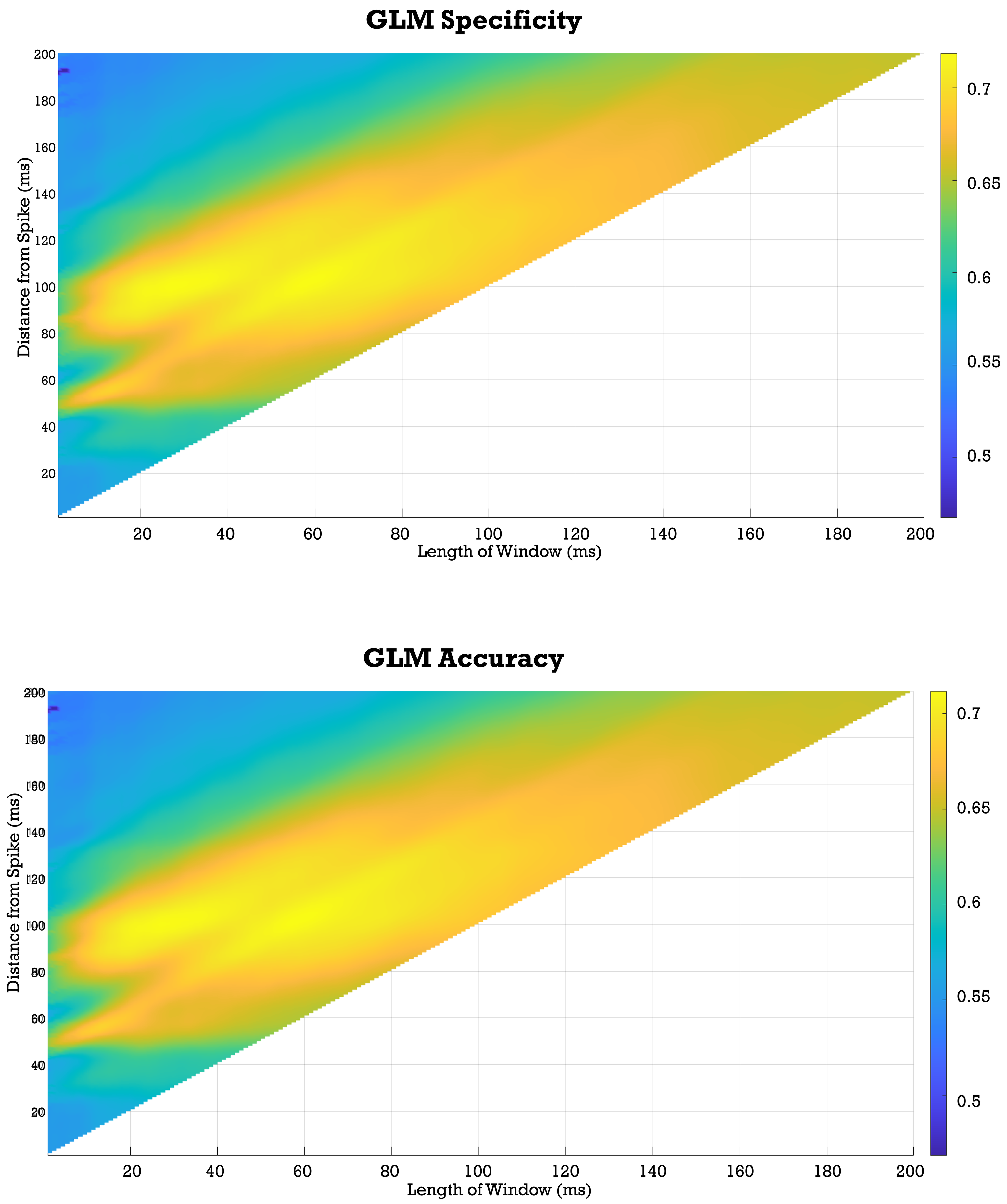

Figure 2. Recorded specificity and accuracy for a GLM using spike-triggered average data.

Future Direction

Initial modeling has shown that while the pre-spike stimulus is an important parameter to predicting spiking activity, it is not sufficient alone. While focusing on STA response 80-100 ms prior to a data point has proven to be effective at predicting activity, the model is far from ideal. The specificity and accuracy reach maximums in the low 70s%, but sensitivity in the same region is below 60%, and precision is below 10%.

We have already run analysis on the data to observe the number of spikes occurring in each pairing of V4 and FEF phases across frequency ranges, in addition to the STA traces. There were found to be two patterns worth analyzing. The first is found in the range of FEF phase from $\frac{\pi}{4}$ to $\frac{3\pi}{4}$ corresponding to V4 phase $\frac{\pi}{2}$ to π in the low frequency 4-12 Hz range. The second is found in frequencies above 30 Hz, where the V4 phase completely defined the activity of the neuron, with the FEF phase inconsequential to neural activation. When the V4 high frequency oscillation was between $\frac{-\pi}{2}$ and $\frac{\pi}{2}$, neural activity increased, regardless of FEF phase. These plots are shown below.

The next stage is to integrate phase into our GLM. We have identified phase-phase alignments of potential note with regards to spiking activity, so the obvious next phase would be to attempt to improve upon the accuracy of the model by integrating phase.

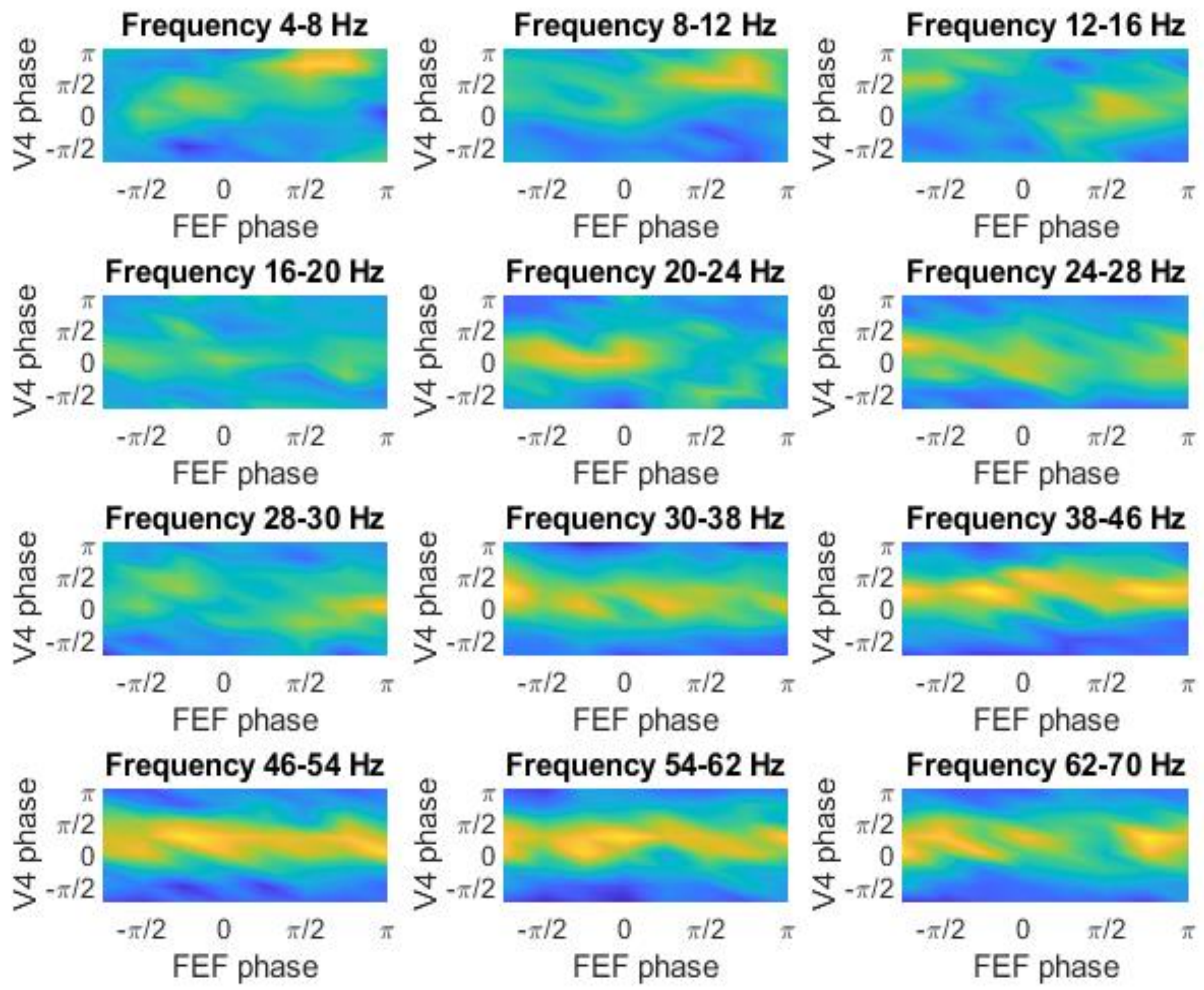

Figure 3. Spikes recorded in each V4 phase –FEF phase pair.

References

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