

Supplemental Material for “Gamma-band Synchronization in the Macaque Hippocampus and Memory Formation”

Michael J. Jutras, Pascal Fries, Elizabeth A. Buffalo*

*To whom correspondence should be addressed. E-mail: Elizabeth.Buffalo@emory.edu

Recording locations.

A post-surgical MRI was performed to determine recording locations. Before the scan, a cilux plastic grid was inserted in the recording chamber, and a 23-gauge guide tube was lowered through the center hole in the grid and through the dura mater. A sterile, 24-gauge glass tube was then lowered through the guide tube and 20 mm into the brain. This tube was clearly visible in the MRI scan and allowed us to calibrate our recording depths. All recordings took place in the anterior part of the left hippocampus, in the vicinity of the CA3 subfield, the dentate gyrus, and the subiculum (Supplemental Figure 1).

Removal of powerline noise.

The powerline artifacts were removed from the LFP in the following way: We estimated the amplitude of the powerline fluctuations with a Discrete Fourier Transformation (DFT) of long data segments which contained the data epochs of interest. We then computed the DFT at 60 and 120 Hz. Because the powerline artifact is of a perfectly constant frequency and amplitude, and because the long data segments contained integer cycles of the artifact frequencies, essentially all the artifact energy is contained in those DFTs. We constructed sine waves with the amplitudes and phases as estimated by the respective DFTs, and subtracted those sine waves from the original long data segments. The epoch of interest was then cut out of the cleaned epoch. Power spectra of the cleaned

epochs demonstrated that all artifact energy was eliminated, leaving a notch of a bin width of 0.1 Hz in the monkey recordings. The actual spectral data analysis was performed using the multi-taper method on 0.25 s data epochs, with a spectral smoothing of ± 8 Hz. Thus, the original notch became invisible.

Categorization of neurons as high vs. low gamma.

Spike-field coherence (SFC) typically increased relative to baseline within the first 500 ms of stimulus onset, and SFC for each neuron-LFP pair tended to cluster in either the low gamma (30-60 Hz) or high gamma (60-100 Hz) range. Neurons were thus designated either “low gamma” or “high gamma” based on the peak value of the mean coherence between the neuron and the LFPs measured on all other electrodes in the same recording session across all encoding trials. Neurons whose peak coherence was below 60 Hz were designated “low gamma” ($n = 43$); neurons with coherence above 60 Hz were designated “high gamma” ($n = 43$). Supplemental Table 1 shows the percentages of enhanced and depressed visually responsive units that displayed SFC in the high gamma and the low gamma frequency bands.

Analysis of multi-unit activity.

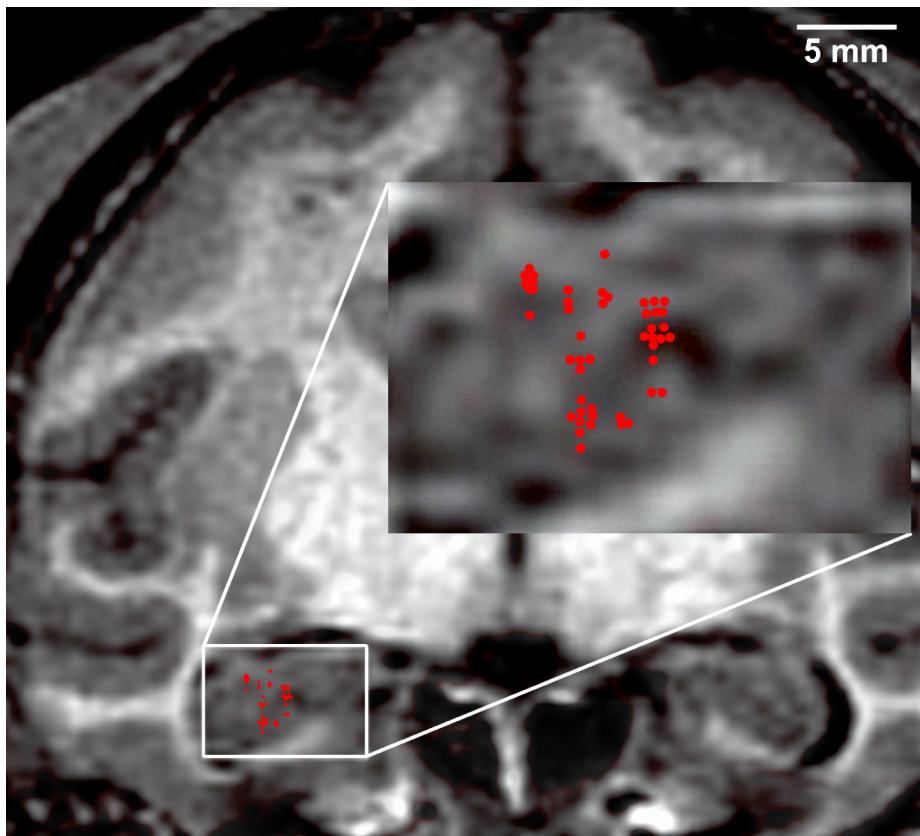
Along with single-unit activity, we also applied the non-parametric permutation test to the SFC calculated from multi-unit activity (MUA). During extracellular recording, we obtained spike waveforms simultaneously from 1-3 neurons per electrode, which gave us a total of 75 MUAs. After calculating SFC during encoding for all MUA-LFP pairs, each MUA was designated either “low gamma” or “high gamma” based on the peak value of the mean coherence between the MUA and the LFPs measured on all other electrodes in the same recording session across all encoding trials. MUAs whose peak coherence was

below 60 Hz were designated “low gamma” ($n = 34$); MUAs with coherence above 60 Hz were designated “high gamma” ($n = 41$). The non-parametric analysis revealed significant clusters of gamma-band coherence modulated by recognition memory performance for both high-gamma and low-gamma MUAs (Supplemental Figure 2).

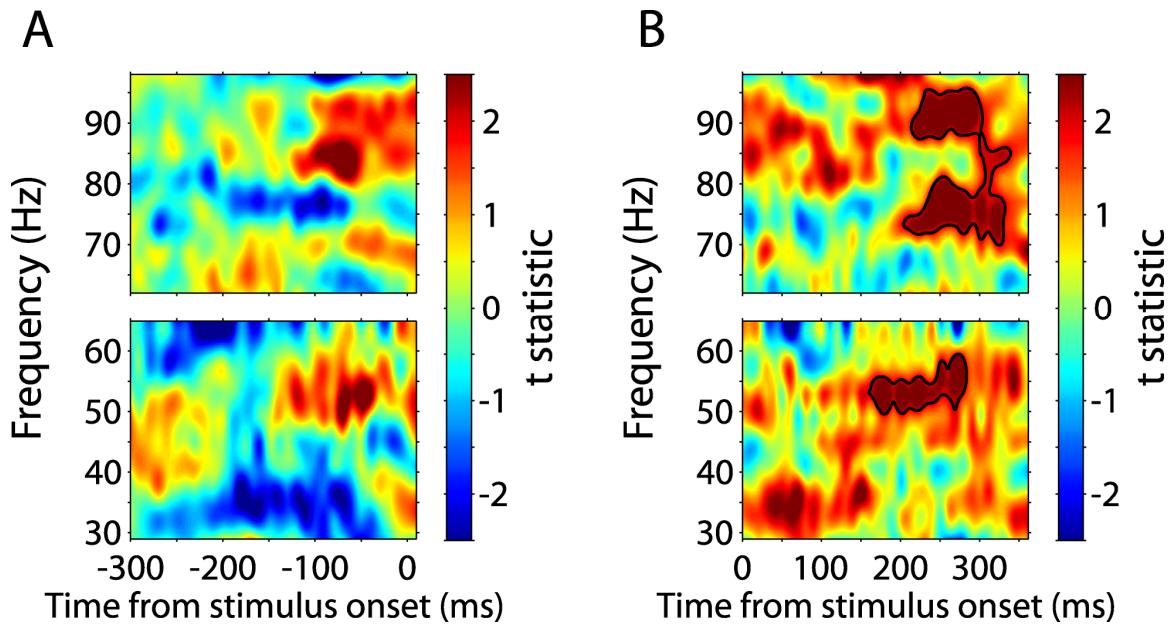
Supplementary Table 1.

	Low gamma SFC (30-60 Hz)	High gamma SFC (60-100 Hz)	Total
Firing enhanced by stimuli	20 (46.5%)	14 (32.6%)	34 (39.5%)
Firing depressed by stimuli	23 (53.5 %)	29 (67.4%)	52 (60.5%)
Total	43 (50.0%)	43 (50.0%)	86

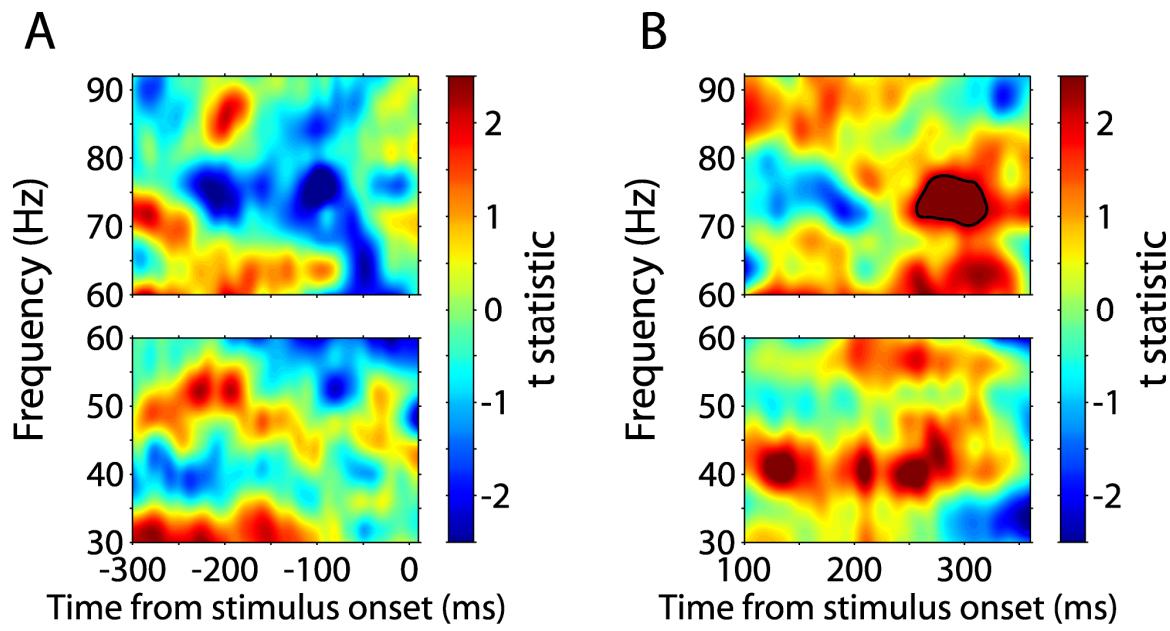
Percentages in bold indicate percentage of total number of cells (86). Other percentages indicate percentage of total cells in corresponding column.



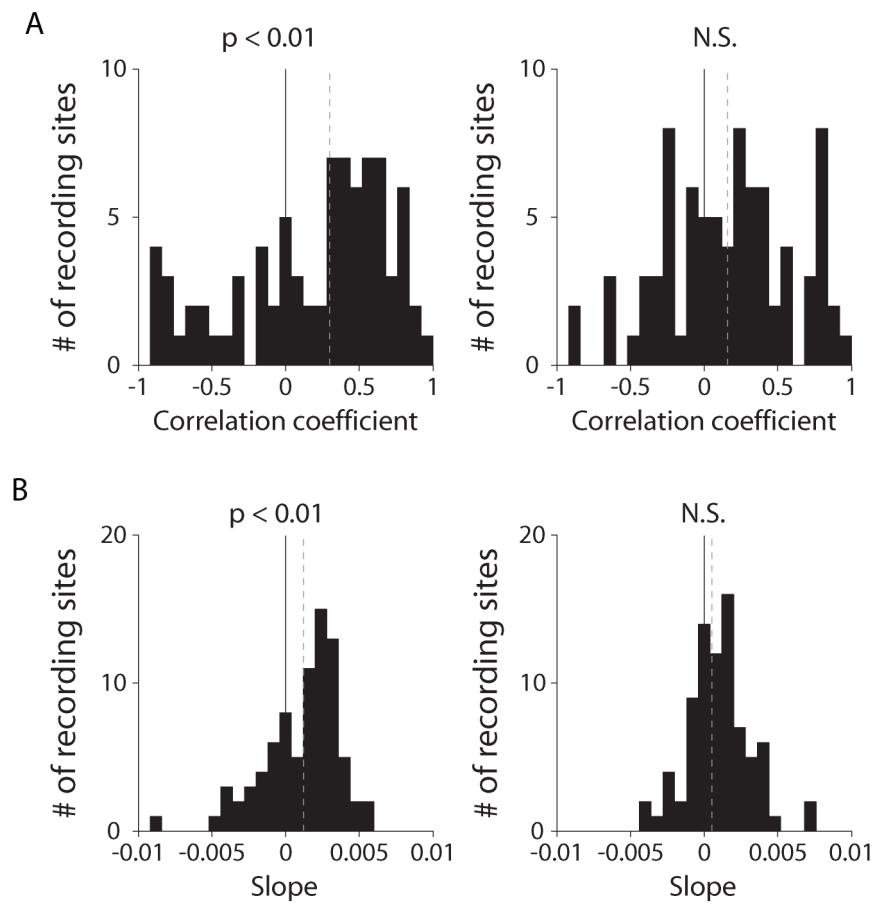
Supplementary Figure 1. Approximate recording sites for visually-responsive units in both monkeys, superimposed on a coronal MRI image from one of the monkeys. This image was taken at the level of the anterior hippocampus (13 mm anterior to interaural plane). Because recordings took place in multiple anterior-posterior planes, recording locations depicted may not align perfectly with regions of high cell density on the representative MRI image.



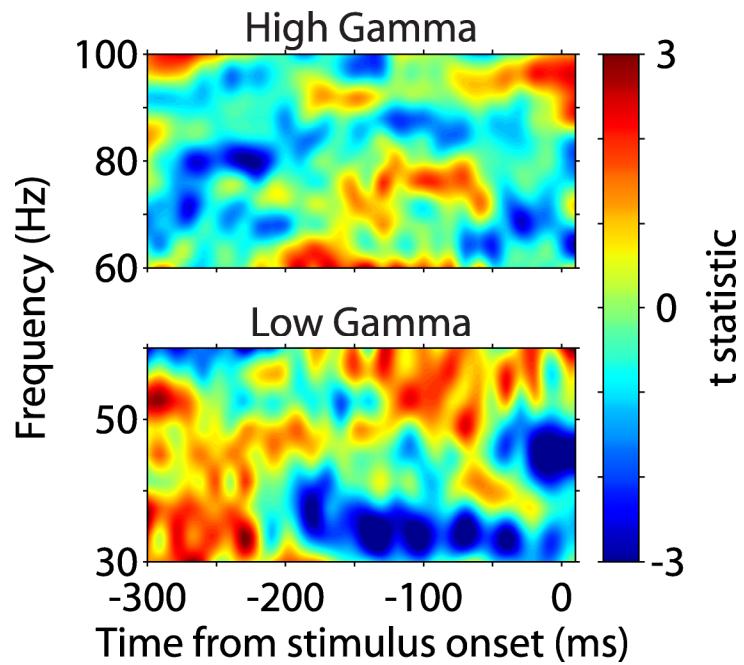
Supplementary Figure 2. (A) Modulation of multi-unit spike-field coherence between well recognized and poorly recognized stimuli, for high gamma (top) and low gamma (bottom), during pre-fixation period. There were no areas of significant coherence modulation. (B) Same as (A), but for post-fixation period. Areas of significant coherence modulation are outlined in black (non-parametric randomization test, corrected for multiple comparisons across time and frequency).



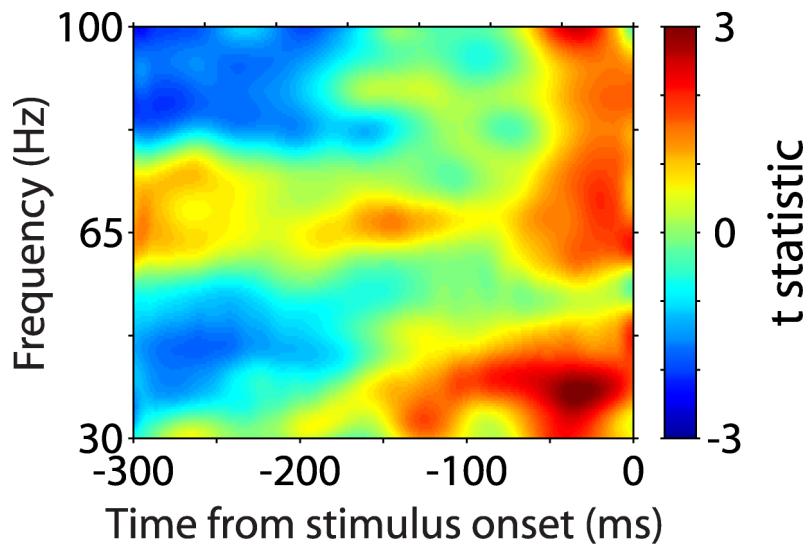
Supplementary Figure 3. (A) Modulation of single-unit spike-spike coherence between well recognized and poorly recognized stimuli, for high gamma (top) and low gamma (bottom) neuron pairs, during pre-fixation period. There were no areas of significant coherence modulation. (B) Same as (A), but for post-fixation period. The area of significant coherence modulation is outlined in black (non-parametric randomization test, corrected for multiple comparisons across time and frequency).



Supplementary Figure 4. (A) Histograms depicting correlation coefficients between gamma-band spike-field coherence and behavior across neuron-LFP pairs, after averaging coherence values obtained for each single unit, when binned according to percent change in looking time (left) or looking time during encoding (right). Black line indicates zero; dashed gray line indicates median. (A) Same as (B), but for slopes. Dashed gray line indicates median.



Supplementary Figure 5. Modulation of single-unit spike-field coherence between well recognized and poorly recognized stimuli, for high gamma (top) and low gamma (bottom) neuron pairs, during pre-fixation period. There were no areas of significant coherence modulation. The post-fixation modulation is shown in Figure 3F.



Supplementary Figure 6. Modulation of gamma-band power in the LFP between well recognized and poorly recognized stimuli, during pre-fixation period. There were no areas of significant coherence modulation. The post-fixation modulation is shown in Figure 5B.