Supplementary Materials

Effects of visual stimulation on LFPs, spikes, and LFP-spike relations in PRR

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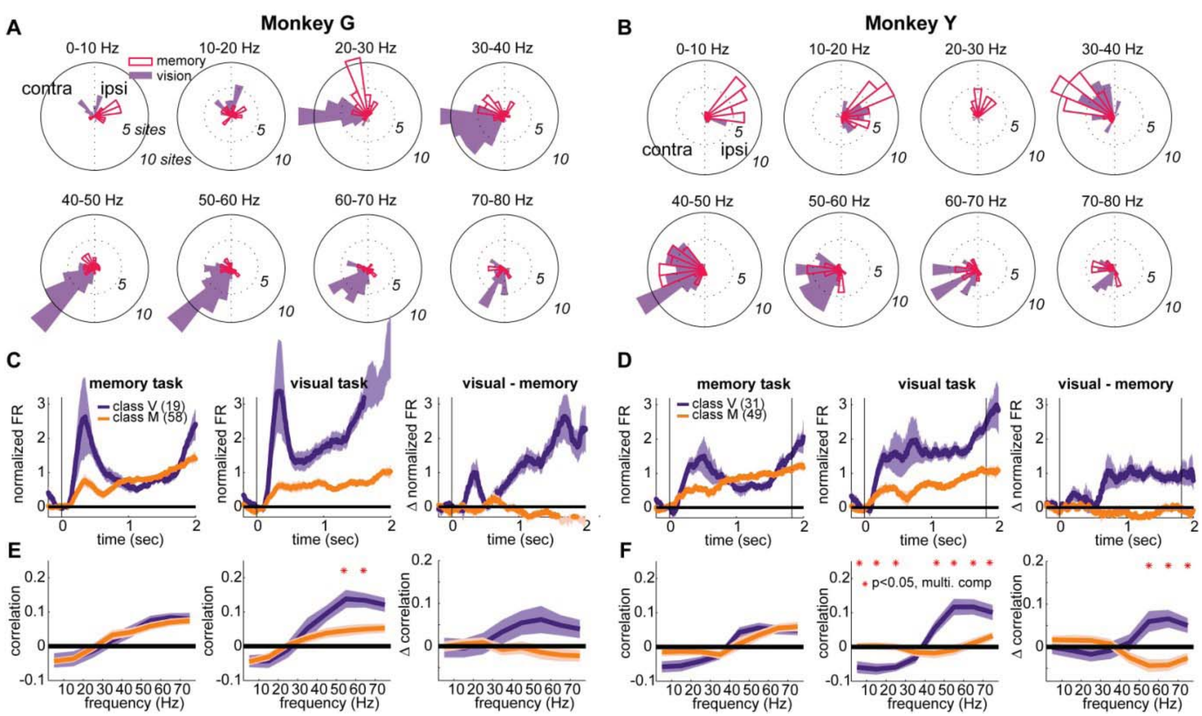
Comparisons between the two monkeys

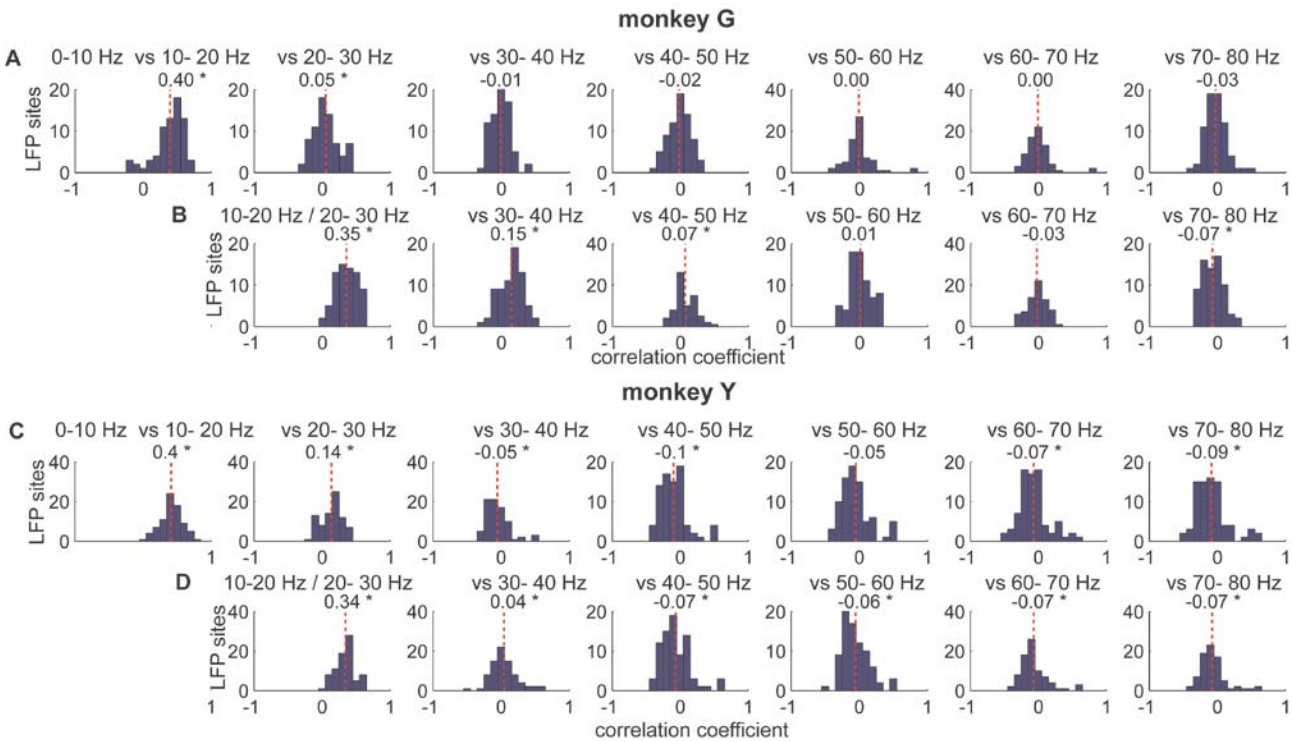
Unlike the gamma bands (>40Hz), inter-task LFP power differences in the lower frequency bands (< 40 Hz) were inconsistent between the two monkeys. For monkey G, the lower frequency power was higher in the visually-guided reach than the memory-guided reach. For monkey Y, it was the opposite. Moreover, the spatial tuning to the reach goal in the memory-guided reach was weaker for monkey G than Y, whereas the tuning in the visually-guided reach was stronger for monkey G than Y. The overall impact of the visual stimulation was larger on monkey G than Y. These inter-subject differences may stem from various factors as follows. The recording sites of monkey G were more posterior by ~ 4 mm on average than those of monkey Y. The reaction time to the 'go' cue was slower by ~130 ms in monkey G than Y. In addition, the reaction time was faster in the visually-guided than memory-guided reach for monkey G. The opposite was true for monkey Y, implying that the two monkeys may have used different strategies in the two tasks. Despite these inter-subject differences, the gamma band LFPs, the anti-correlation between the low and high frequency band LFPs, and the LFP-spike relations were highly consistent between the monkeys (Fig. 3 & Suppl. Fig. 1-2).



Supplemental Figure 1. Comparison between the two monkeys. Plots on the left column are from monkey G, and those on the right column are from monkey Y. **A-B.** Distribution of preferred directions of LFP power in 8 frequency bands. **C-D.** The normalized firing rate (mean ± S.E.M.) of the two classes in the two tasks and the inter-task difference. **E-F.** Correlation between the LFP power and firing rate.

Correlations between the LFP power in the different frequency bands

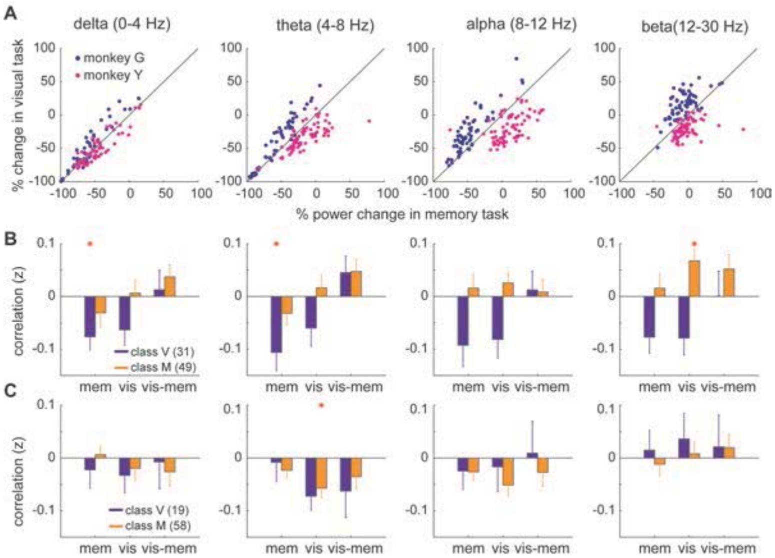
The power spectra of LFPs were subdivided into 8 frequency bands and the trial-to-trial correlations between the LFP powers in two frequency bands were computed for each LFP site and each monkey. The delay period power in the higher frequency bands (>40 Hz) tended to anti-correlate with the power in the lower frequency bands (<20 Hz) of the same site in both monkeys (Suppl. Fig. 2).



Supplemental Figure 2. Distributions of correlation coefficients between the LFP power in a low frequency band and a higher frequency band for individual monkeys. **A.** The correlation from monkey G. The lower frequency band is 0-10 Hz. The higher frequency band is noted at the top of each panel. The red dotted line indicates the mean of each distribution. Distributions with a mean that is significantly different from zero (t-test, $p<0.05$) are maked with asterisk next to the means. **B.** The lower frequency is 10-20 Hz. **C-D.** The same as **A-B** but for monkey Y.

Analysis of the conventional EEG bands

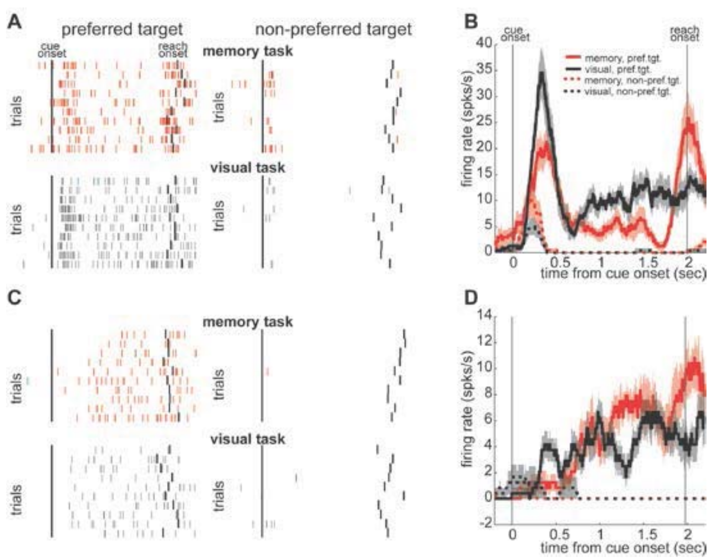
The 10 Hz steps used in our LFP analysis may have obscured differential effects among the functionally distinct EEG bands that are separable only with a finer resolution. Thus, we reanalyzed our low frequency LFPs with a finer frequency resolution (2 Hz) using a larger temporal window (1 s) and divided the low frequency bands into four EEG bands: delta (<4Hz), theta (4-8Hz), alpha (8-12 Hz) and beta (~12-30 Hz). Overall, effects in these bands were consistent with the 10 Hz step analysis (Fig. 3). The LFP power in all four EEG bands was larger in the visually-guided reach for monkey G, while it was smaller for monkey Y (Suppl. Fig. 3A). The spike-LFP correlation tended to be negative, especially for class V, in the delta, theta, and alpha bands, while it was less negative in the beta band. Finally, the correlation was not significantly different between the two tasks in any EEG bands (Suppl. Fig. 3B-C).



Supplemental Figure 3. A. LFP power in the memory- versus visually-guided reach in the four EEG bands. Each dot represents a single LFP site and the black lines are unity lines. **B.** Correlation between the LFP power and firing rate in the two tasks and the inter-task difference in the four bands for monkey Y. **C.** The same as **B** but for monkey G.

Two classes of neurons

Two or three neuronal units were simultaneously recorded at 17 recording sites. In 1 site, both neurons were visuomotor. In 10 sites, all neurons were motor. In 6 sites, one neuron was visuomotor and the other was motor. Supplemental Figure 5 shows a pair that was heterogeneously classified.

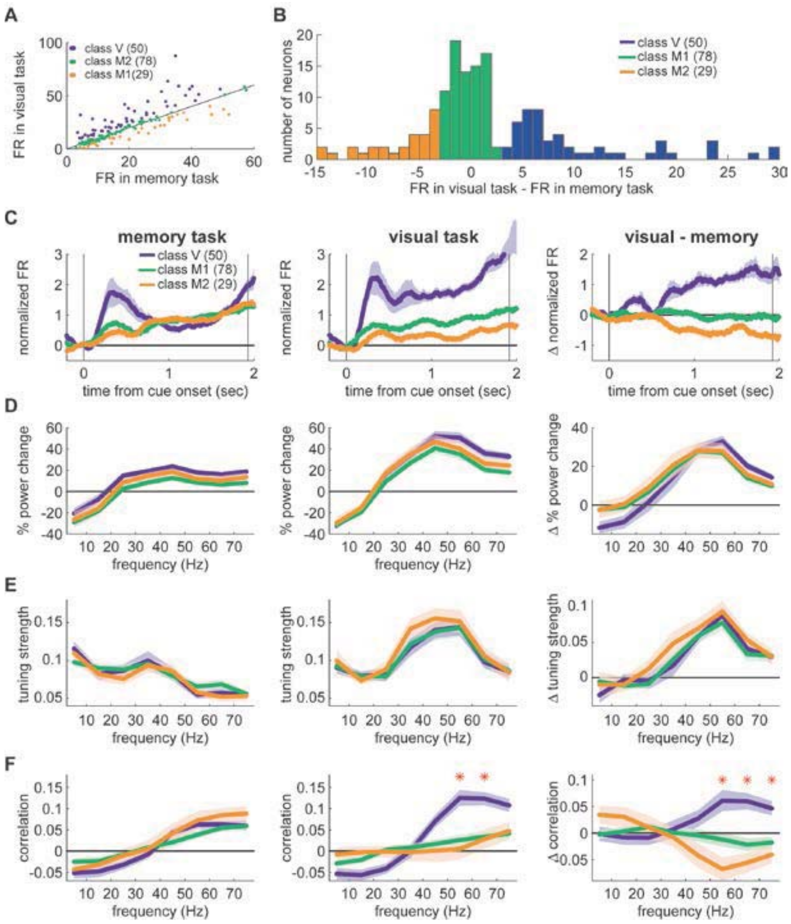


Supplemental Figure 4. A. Spike rasters of two neurons recorded from the same electrode. Ten trials for each of its preferred and non-preferred reach targets. For each trial, the black thick bars indicate cue onset, and reach onset from left to right. **B.** Spike density histogram (mean ± S.E.M.) of the neuron in **A. C-D.** The same as **A-B** but for another neuron.

Three classes of neurons

In our main analysis, we divided the PRR neuronal population into two groups, neurons with a stronger response in the visually-guided reach versus the others, based on the apparent two modes in the distribution of the inter-task difference in the delay period firing rate. However, one can test a more symmetric classification criterion involving three groups, neurons with a stronger response in the visually-guided reach (class V), neurons with a stronger response in the memory-guided reach (class M1), and neurons with similar responses in the two tasks (class M2). As shown in Supplemental Figure

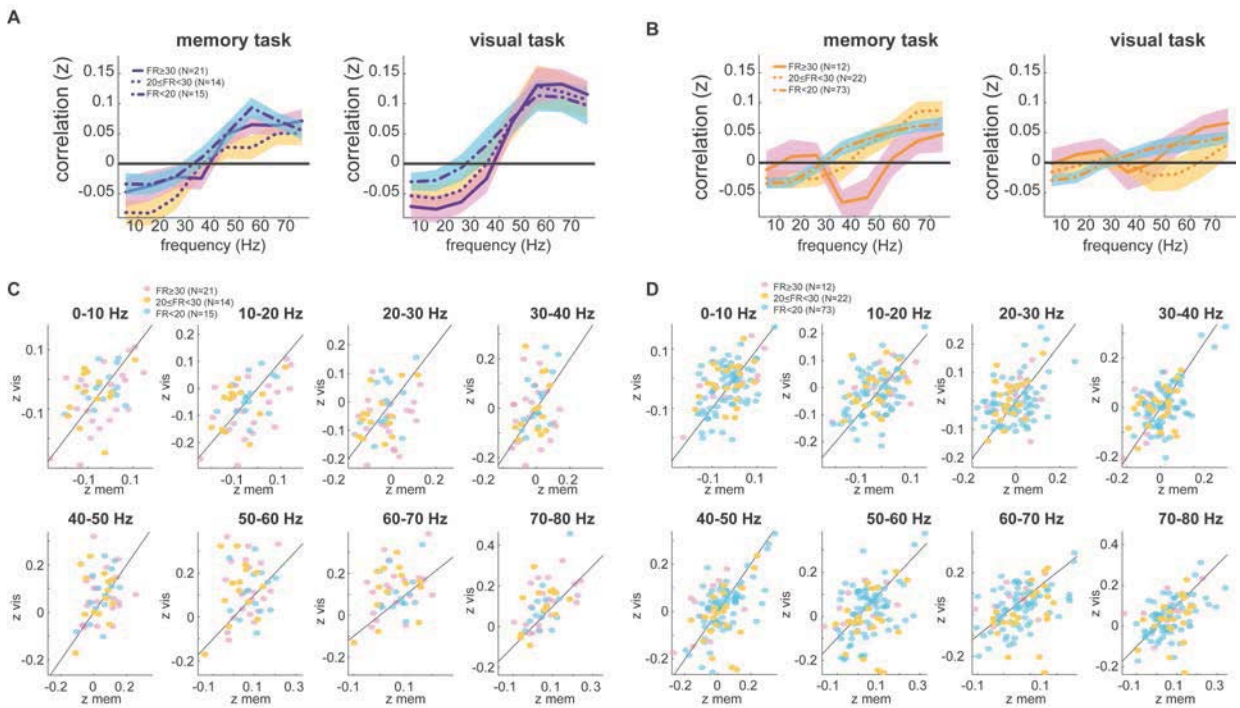
5, the LFP-spike correlations were indistinguishable among the three classes during the delay period in the memory-guided reach, but became separable in the visually-guided reach as the gamma band correlation became larger for class V, became smaller for class M1, and remained the same for class M2. Thus, the average correlation difference between the two tasks was predictable by the average firing rate difference between the two tasks. However, this does not mean that the firing rate level per se determines the correlation as shown in the next section.



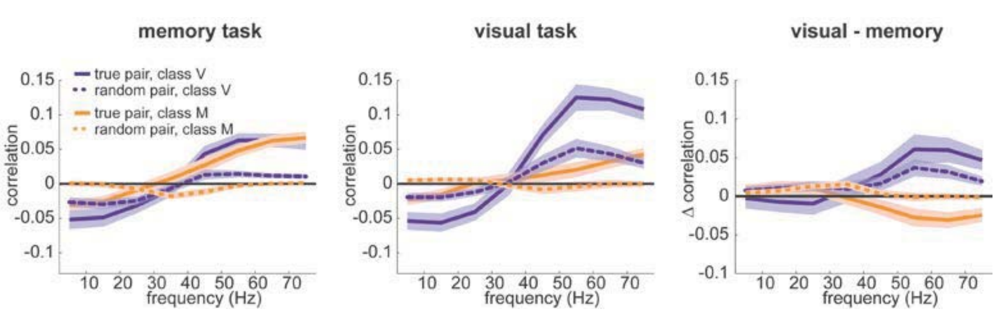
Supplemental Figure 5. A. Firing rate in the memory-guided reach versus in the visually-guided reach. Each dot represents a single neuron, and the black line is unity line. **B.** The distribution of the difference in the delay period firing rate between the two tasks. **C.** The normalized firing rate histograms for the two tasks and the inter-task difference. **D.** The delay period LFP power. **E**. Tuning strength of the delay period power. **F.** The spike-LFP correlation during the delay period. In all plots, the line and band represent mean ± S.E.M.

Control of sensitivity to firing rate for the correlation between LFP power and firing rate

In general, the observed correlation of two signals may be an underestimate of the true underlying correlation when noise is added to the two signals and thus the estimate can increase as the signal strength increases by effectively increasing the signal to noise ratio. Therefore, we examined whether the difference in the spike-LFP correlation in the visually-guided reach between the two neuronal classes could be attributed to the difference in their firing rates per se, in two ways. First, we subdivided the neurons in each class into three subpopulations based on their delay period firing rates for a preferred reach goal in the visually-guided reach: firing rate <20 Hz, 20-30 Hz, and >30 Hz. We found that correlations of LFP power and the firing rate were not significantly different between the three groups in any task or any class (Suppl. Fig. 6). Therefore, the difference between class V and M in the visually-guided reach cannot be attributed solely to the difference in their firing rates. Second, we computed the spike-LFP correlation for randomly paired recording sites to examine how much of the difference in the correlation can be attributed to the overall difference in the firing rate between the two classes. Supplemental Figure 7 shows that the correlation of the random pairs is indeed higher for class V than M in the visually-guided reach because the correlation for the class V is significantly different from zero (t-test, $p<0.05$ in all frequency bands except the 20-30 and 30-40 Hz bands). However, the correlation of the class V for the random pairs was still significantly weaker than that observed for the actual true pairs (two-sample t-test, $p<0.05$ in all bands except the 30-40 Hz band). Therefore, we concluded the different spike-LFP correlations reflected difference in the actual correlation between the firing rate and the LFP gamma power within individual sites, and not mere differences in the mean firing rates.



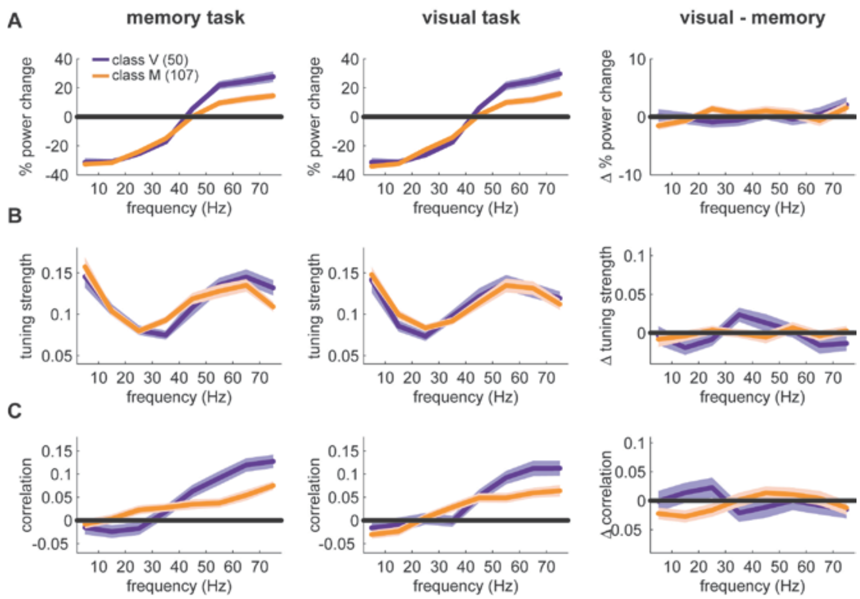
Supplemental Figure 6. A. The spike-LFP correlations (mean ± S.E.M.) for three different firing rate groups within class V. **B.** The correlation in the memory versus visual task for the 8 frequency bands. The legend indicates the color code and the number of neurons in each of the three groups. Each dot represents a single LFP site and the black lines are the unity line. **C-D.** The same as **A-B** but for class M.



Supplemental Figure 7. The spike-LFP correlation (mean ± S.E.M.) when spikes and LFPs were recorded from the same electrode (true pairs) or different electrodes (random pairs).

Correlation between the LFP power and firing rate during the cue period

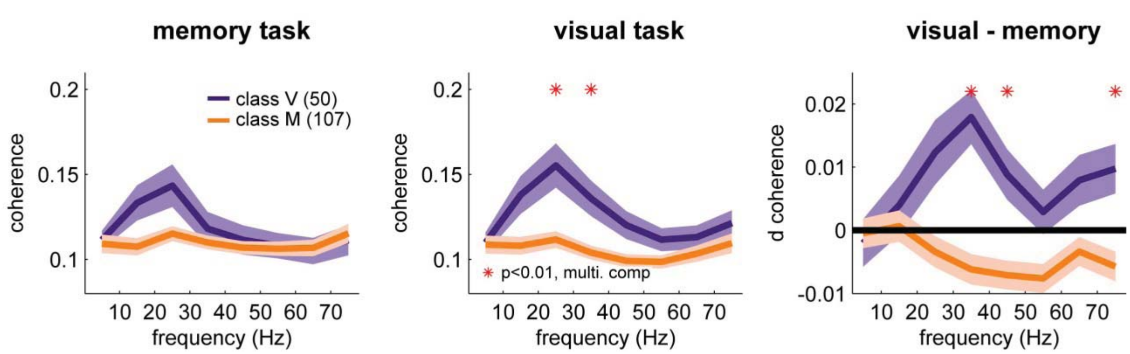
If the visual input induced different gamma-spike correlations between the two classes of neurons, we predict a similar inter-class difference in the correlation during cue period in both tasks because the visual input was available during this time period. We indeed observed the higher correlation in the gamma bands for class V than class M in both tasks, confirming our prediction (Suppl. Fig. 8).



Supplemental Figure 8. A. The cue period LFP power in the memory and visual tasks and the inter-task difference . **B.** Tuning strength of the cue period LFPs. **C.** The spike-LFP correlation during the cue period. In all plots, the line and band represent mean ± S.E.M.

Coherence

The power spectra of LFPs and spikes within a 0.2 s window and their coherence were computed every 50 ms using multi-taper methods (Pesaran et al., 2002). The variance of coherence across recording sites was high, probably due to the small number of trials (Suppl. Fig. 9). However, similar to the correlation coefficient between the LFP power and spike firing rate, the sustained visual stimulus increased coherence in the high gamma bands for class V but decreased for class M.



Supplemental Figure 9. Coherence (mean ± S.E.M.) during the delay period in the memory-guided and visually-guided reach task, and inter-task difference for the two subpopulations respectively.