

Neuronal population coding of parametric working memory

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Scatter plots and V shape fits for all frequencies

In this section we show the firing rate of the cells as a function of their a_I values for all stimulus frequencies. Both firing rates and a_I values were computed either in the stimulus (100-200 msec after stimulus onset, Fig S1) or at the end of the delay period (last 100 msec of the delay period, Fig S2). Only neurons with a_I values significantly different than zero are shown. Overlaid on the scatter plots are linear fits to the positive and negative branches, with confidence intervals displayed for the extreme points.

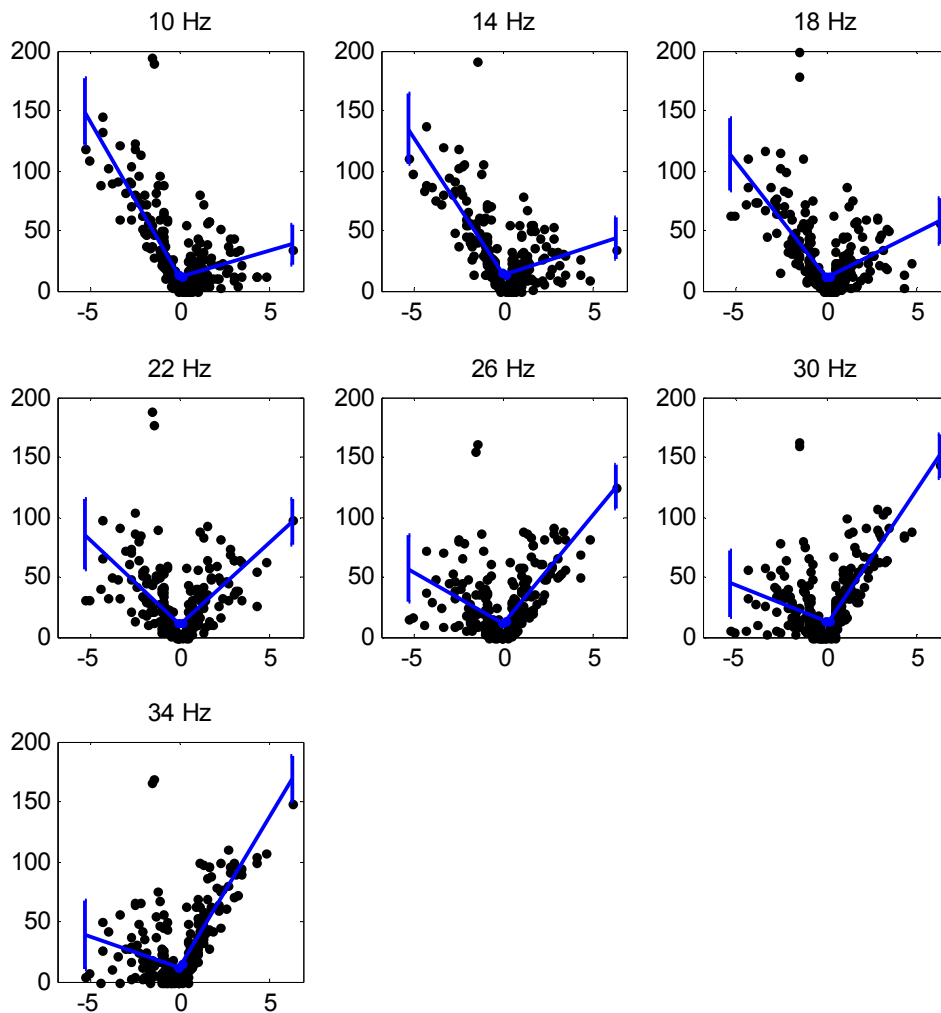


Fig S1: Firing rate as a function of a_I values for the stimulus period. 233 neurons with a_I values significantly different than zero are shown. Solid lines show the linear fit to the positive and negative branch, and error bars denote confidence intervals for the extreme points.

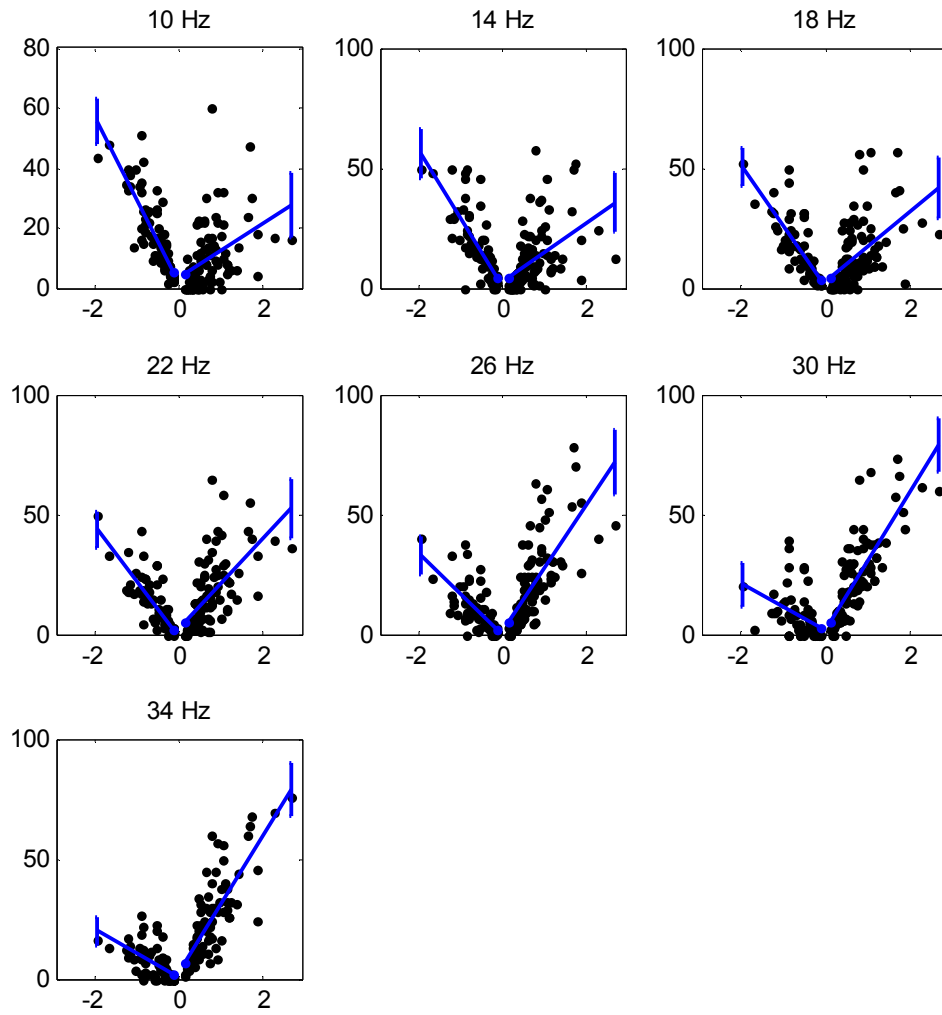
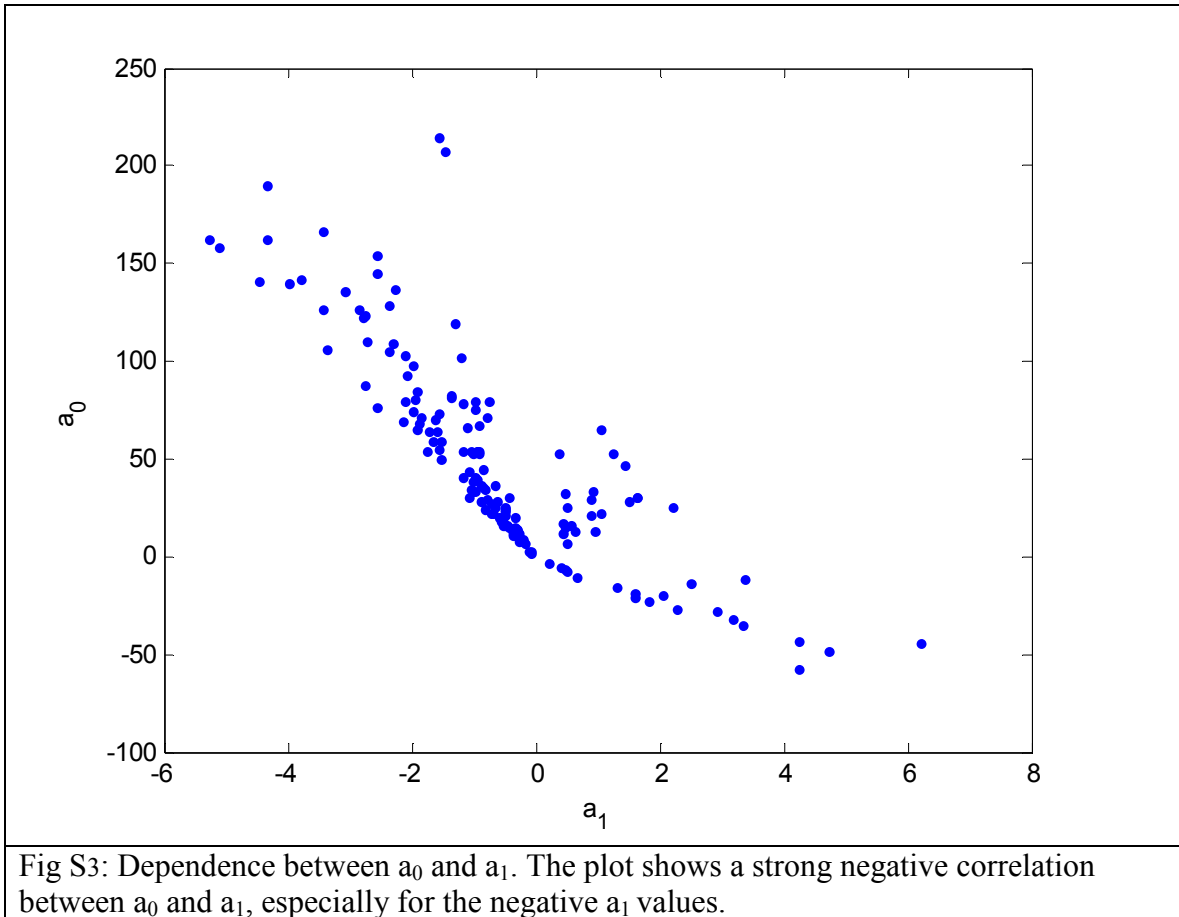


Fig S2: Firing rate as a function of a_1 values for the end of the delay period. 158 neurons with a_1 values significantly different than zero are shown. Solid lines show the linear fit to the positive and negative branch, and error bars denote confidence intervals for the extreme points.

Dependence of a_0 on a_1

The activity profiles mentioned in the previous section and in the main text have the form of a V-shape. This implies a dependence between a_0 and a_1 values, which we explicitly plot in Fig. S3:



Readout of branch slopes

The V shape activity profile, and specifically the slopes of its branches was introduced in the main text as a compact representation of the population state. We utilized this representation to analyze the data in a convenient manner. Importantly, the branch slopes are also highly accessible to readout by downstream neurons. In order to see this, we write the least square approximation to slope of the positive branch:

$\hat{\alpha}_+ = \frac{\langle ra_1 \rangle - \langle r \rangle \langle a_1 \rangle}{\langle a_1^2 \rangle - \langle a_1 \rangle^2},$	(1)
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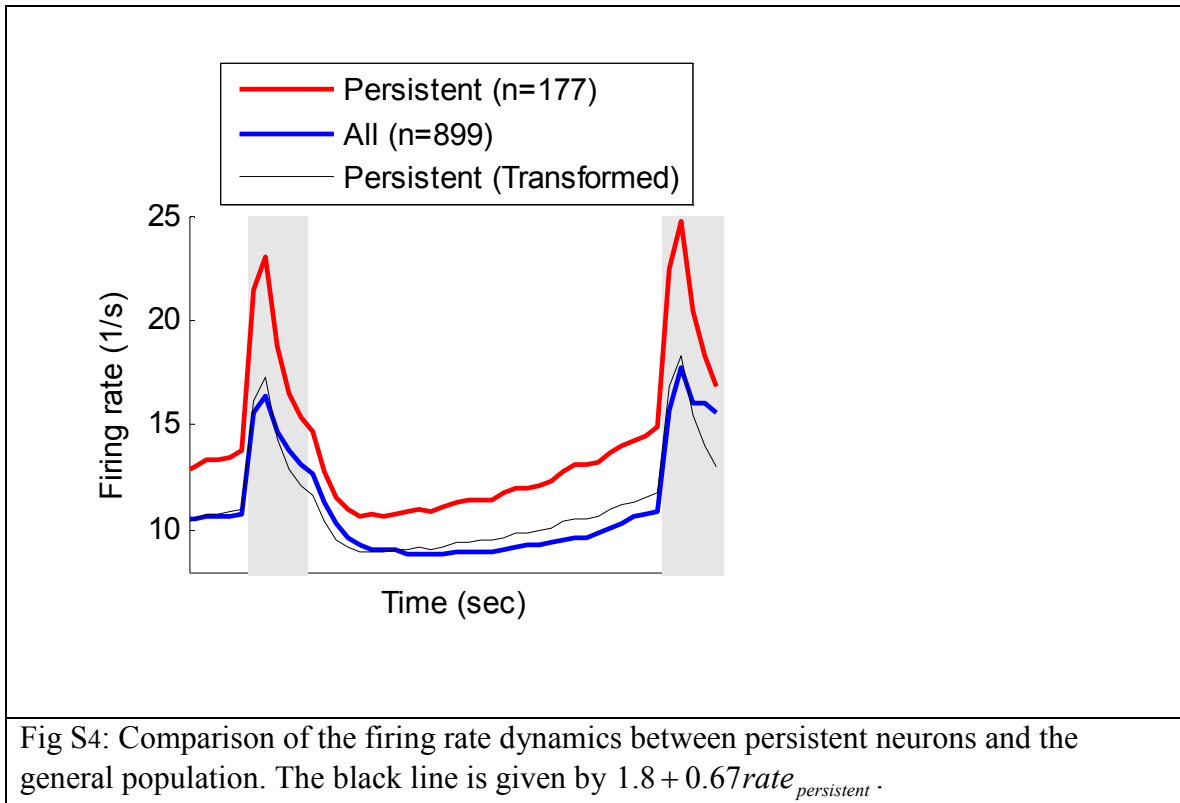
Where r is the firing rate and the brackets denote averaging across all neurons. Equation 1 is actually a linear readout of the firing rates, where each neuron's activity is weighted by its a_1 value, and a global inhibition is applied. Specifically, the weight for a specific neuron is

$w = \frac{a_1 - \langle a_1 \rangle}{\langle a_1^2 \rangle - \langle a_1 \rangle^2}.$	(2)
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A similar calculation holds for the negative branch's slope.

Firing rates of persistent neurons

In this section, we show the mean firing rate of the persistent neurons (177, 20% of the population). Neurons were defined as persistent if they had at least one 100ms bin in each of the three seconds of the delay significantly tuned to the stimulus. Fig. S4 shows the firing rate of these neurons compared with that of the general population. Since these neurons have higher firing rates than the average, we used a linear transformation to compare the two dynamics.



Firing rates for trials which could be solved without memory.

Although the task is designed to rely on the memory of the first stimulus, examining the stimulus protocol (Figure 1B) shows that for some stimulus combinations (e.g. 10 vs. 18 Hz) a decision can be made upon receiving the first stimulus. If this were the strategy used by the monkey, the activity of neurons in the delay period for this group of trials could correspond to motor planning and not to stimulus memory. We believe that the monkey is actually memorizing the stimulus in all trials for two reasons: First, previous studies which compared the current protocol to another one in which all trials required both stimulus frequencies showed no qualitative difference in the neural activity of PFC neurons (Romo et al., 1999). Second, the firing rate dynamics when analyzed separately from the group of trials in which memory is not a priori necessary is indistinguishable from that of the entire set of trials (cf Fig. 1C and Fig. S5). We therefore consider the delay activity analyzed here as corresponding to stimulus memory.

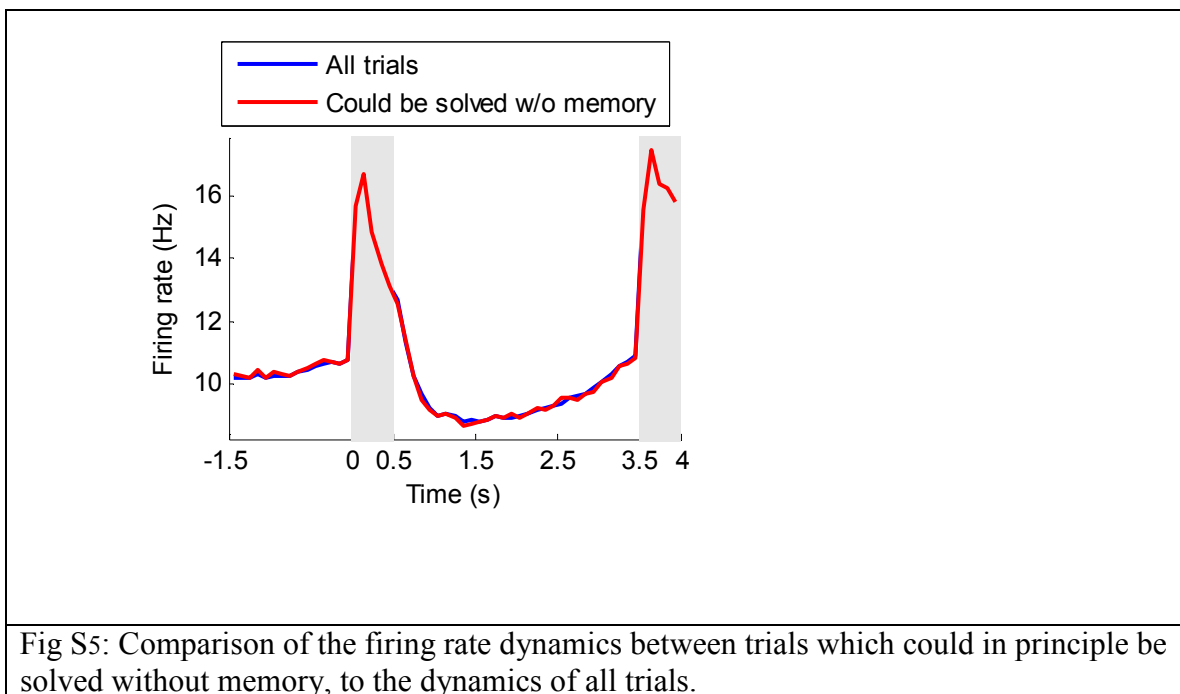


Fig S5: Comparison of the firing rate dynamics between trials which could in principle be solved without memory, to the dynamics of all trials.