Supplemental Data

Spatiotemporal Elements of Macaque V1 Receptive Fields

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Figure S1. Dependence of the Number of Filters Revealed by STC on the Number of Spikes Included in the Analysis

Shown are the number of significant excitatory and suppressive filters revealed as a function of the number of spikes collected per spatiotemporal dimension (16 frames times N bars) for 3 neurons. Dotted line: 512 dimensions; 143,000 spikes total. Dashed line: 384 dimensions, 212,000 spikes total. Solid line: 256 dimensions, 230,000 spikes total.

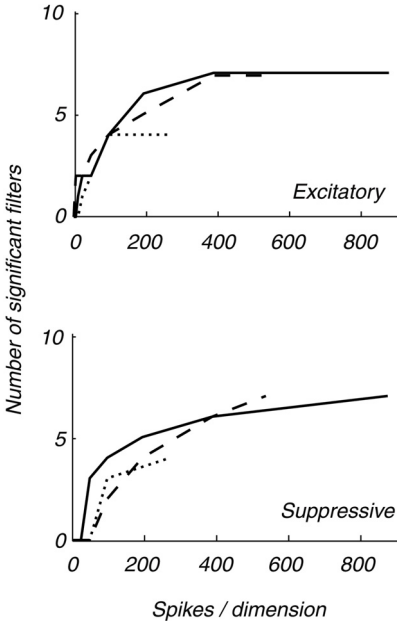

Figure S2. Eye Movement Analysis

(A) Estimation of eye position during data collection for the example simple cell shown in Figure 2 and the example complex cell shown in Figure 3 (recorded in different animals). For each cell, we estimated eye position from the data collected in 2.5 minute windows; successive eye position estimates were obtained by shifting the window forward in 10 second increments. For the simple cell (red), eye position was estimated from the STA computed for each window. A Gabor (sine multiplied by a Gaussian) was fit to the time slice at the peak offset (t = 65 msec before a spike) and the position of the center of the Gaussian was used as an estimate of eye position. The estimated eye position deviated over 0.09 degrees, approximately half the width of one bar (0.2 degrees). For the complex cell (blue), a STC analysis was computed from the windowed data and the spatial envelope was calculated by taking the L^2-norm (square root of the sum of squares) of the two strongest excitatory filters. A position parameter was extracted by fitting a Gaussian to the data at the peak offset (t = 55 msec before a spike). The eyes moved over range of 0.17 degrees, approximately 2 bar widths (bar width, 0.09 degrees). The magnitude of the estimated eye movements are within the range reported by direct tracking of the eyes under similar experimental conditions, as are the oscillations shown in both traces with a period of 3-8 minutes (Forte et al., 2002). To examine the effects of eye movements of this magnitude on the STC analysis, we simulated a standard model simple (Figure 1A) and complex (Figure 1B) cell. The filters included in the model simple and complex cell are shown. Eye movements were simulated by shifting the filters by the magnitude given by the traces in A and taking the dot product of the resulting filters and a binary bar stimulus every 10 msec. For both simulations, the size of the receptive field, number of bars used in the experiment, firing rate, and experiment duration (total number of spikes collected) were matched to the experiment. (B) Actual firing rates over the course of data collection for the simple (red) and complex cell (black). Also shown are the firing rates over the course of the two simulations (grey). (C) In simulation, the eye movements shown in A do not produce artifactual filters. For the model simple cell, only an STA was recovered. Also shown is the strongest (nonsignificant) excitatory filter revealed by STC, which had no spatiotemporal structure. For the model complex cell, only the two expected excitatory filters were revealed by STC. Also shown is the third strongest (nonsignificant) filter, which had no spatiotemporal structure. Additional simulations reveal that larger movements of the eyes can produce unexpected filters. Simple cells appear to be particularly prone to artifactual filters, due to the residual variance remaining after the STA is projected out of the spike-triggered stimulus distribution in preparation for STC (e.g. the red eye movement trace magnified four-fold produced an artifactual filter in simulation). In both simple and complex cells, large deviations of the eyes result in shifts of the receptive field away from the stimulus array and consequently decreases in firing rate during these episodes. We explored the parameter space and were unable to find conditions under which the firing rate remained constant throughout the simulated experiment (as shown in B), and yet a large number (>4) filters was revealed.

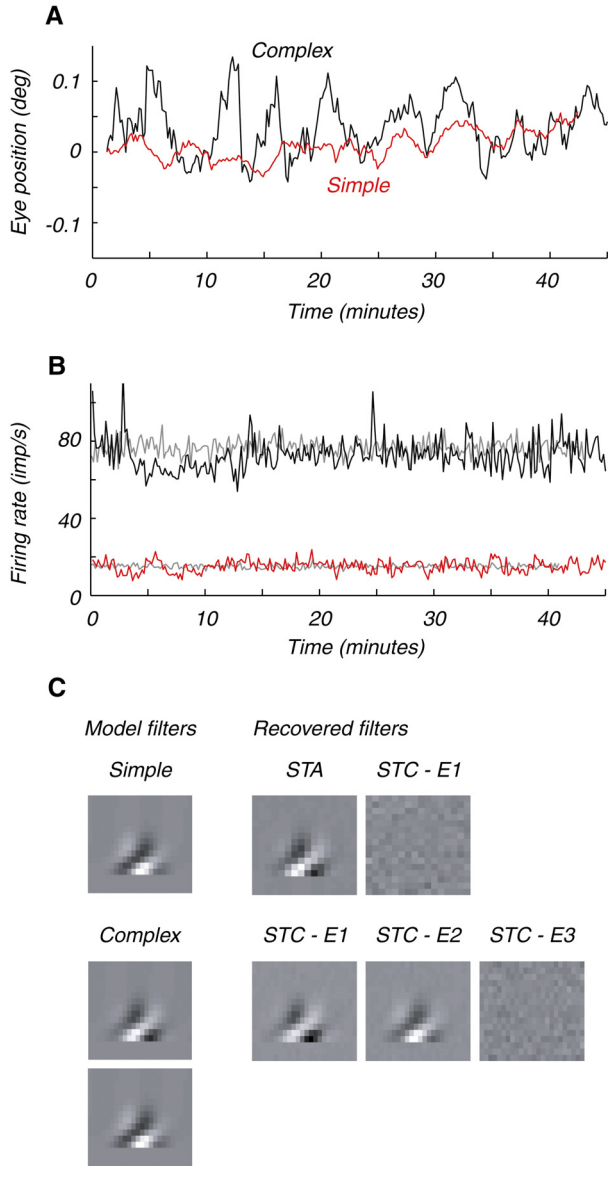
A
Complex
Simple
Eye position (deg)
0.1
0
-0.1
0
10
20
30
40
Time (minutes)
B
Firing rate (imp/s)
80
40
0
0
10
20
30
40
Time (minutes)
C
Model filters
Recovered filters
Simple
STA
STC - E1
Complex
STC - E1
STC - E2
STC - E3

Figure S3. Comparison of Results Using Gaussian versus Binary White Noise
In these experiments, all parameters of the stimulus were matched (stimulus size, number and position of the bars, bar orientation, total number of frames presented and approximate number of spikes collected) with the exception of the intensity distributions of the bars. (A) The STA and STC filters revealed for one cell under the two stimulus conditions for cell classified simple by its response to a drifting grating (relative modulation 1.39). Under both conditions, STC revealed excitatory and suppressive filters beyond the STA. Furthermore, each filter pair has nearly indistinguishable structure. The weakest excitatory filter revealed under Gaussian noise conditions would presumably be recovered under binary stimulation as well if we had continued data collection. (B) Number of excitatory and suppressive filters revealed for six cells under the two stimulus conditions; similar numbers were revealed in each case. To assess the similarity of each pair of Gaussian and binary filters, we compared the similarity index (dot product) between the Gaussian and binary members of each pair to a distribution of similarity indices between the Gaussian filter and 1000 randomly scrambled versions of the binary filter. In each case, we found that the pair of filters were more similar than expected by chance (p ranged from <0.01 to <0.001).