Traveling waves in quasi one-dimensional neuronal minicolumns - supplemental information

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Model Summary

Table 1: Model Summary

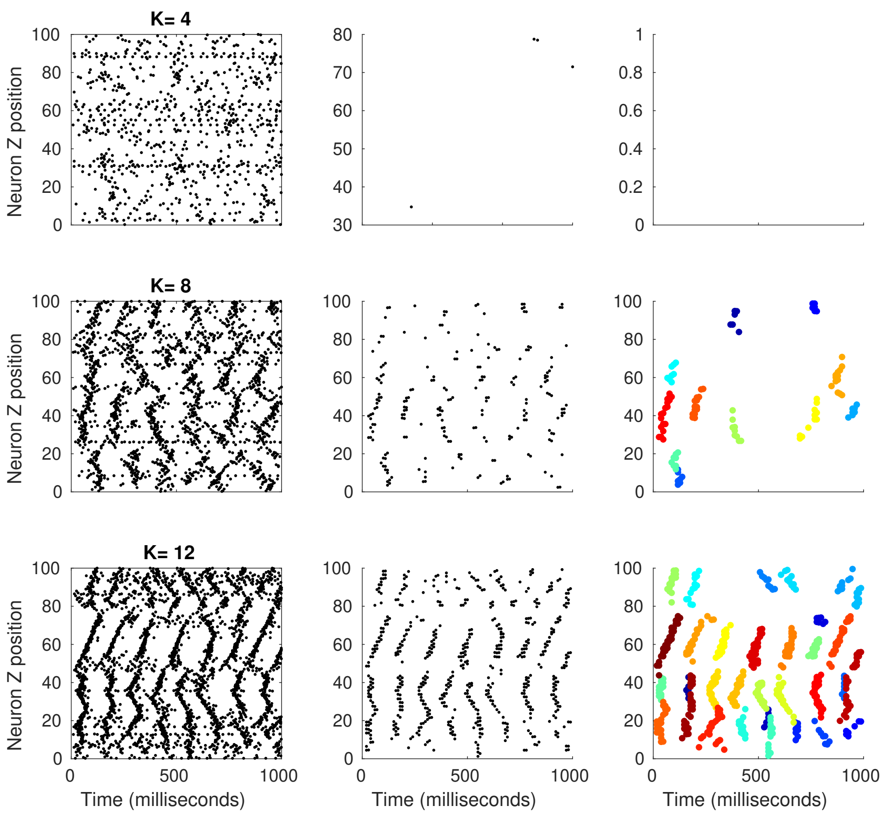
Model

Population	Excitatory, inhibitory
Topology	Small columnar ensemble, Z extents $\gg$ X,Y extents
Connectivity	Stochastic, P_c exponentially decays with distance between neurons
Neuron model	Izhikevich model with distribution of neuron parameters
Synapse response	Exponential synaptic response with randomized peak connection strength
Spike propagation	Delay proportional to distance, Fixed propagation time
Input	Random input to all neurons, Fixed stimulus to neurons at the bottom of the SCE

Wave detection and labeling

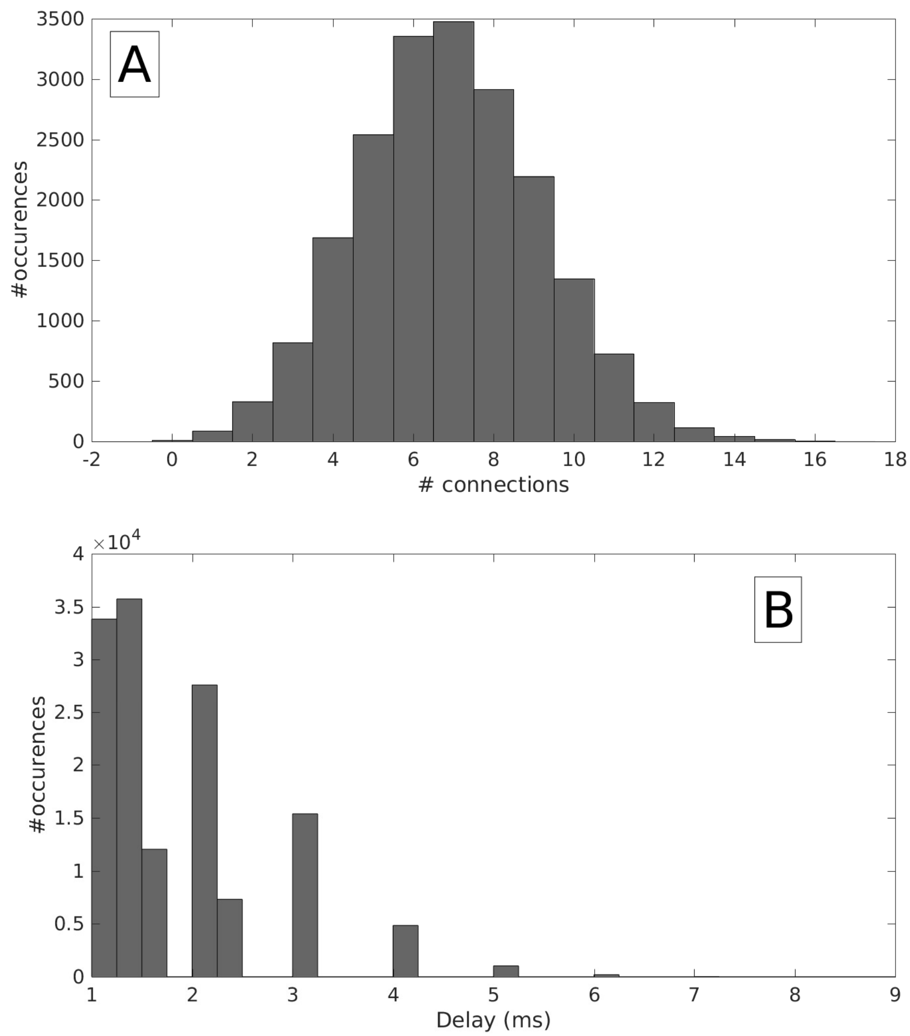
Our automated wave detection and labeling process must find and characterize waves under the varying conditions set by our simulation parameters. The wave extent, wave speed, and the number of background spikes all depend upon the simulation parameters. To validate the detection and labeling process we visually inspected the results for a variety of simulations. Sample visualizations for varying values of K are shown in Figure 1.

Figure 1: The clustering and wave labeling process. Spike raster plot (left), filtered clusters (middle) and labeled waves (right, each color is a unique wave) are shown for SCE with different values of K.



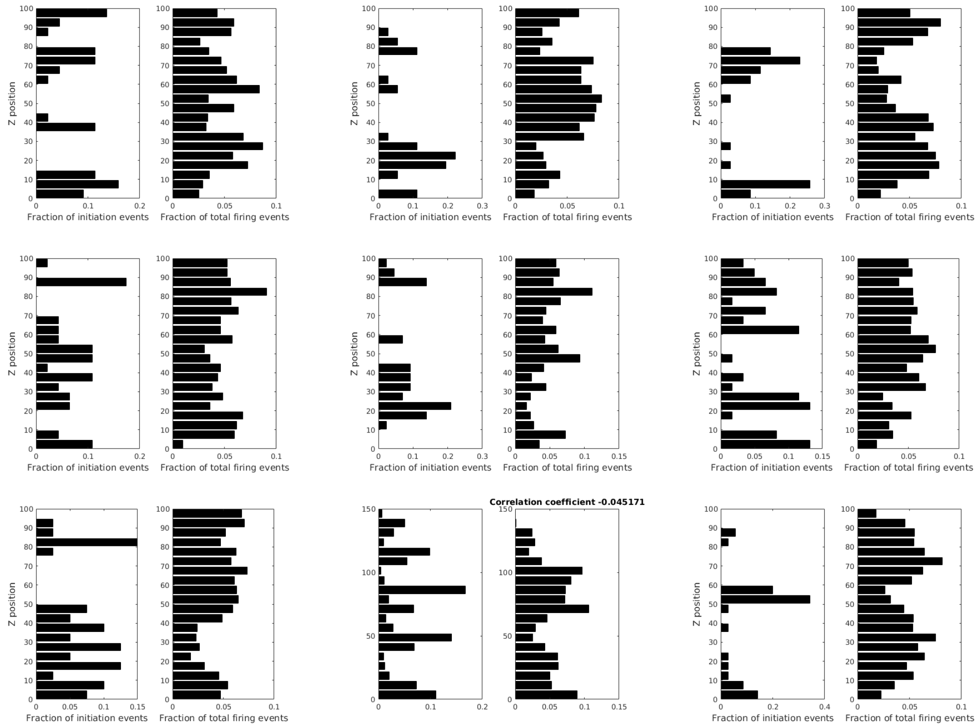
Additional SCE statistics

Figure 2: Distribution of (A) number of post-synaptic connections per neuron and (B) delay time. Data was taken over 100 realizations of a 2x2x50 SCE, $\lambda = 2.5$, $\kappa = 1$.



Example FIE and FFE plots

Figure 3: FIE and FFE for nine example columns.



Effect of long connections

The distance-dependent connectivity allows for a small probability of connections between neurons that are very far apart. To understand if these few long-range connections were significant, we recreate Figure 4 of the main text but prune all connections with length $> 5\ (2\lambda)$. We find that removing long-range connections does not significantly alter the formation and propagation of traveling waves (Figure 4).

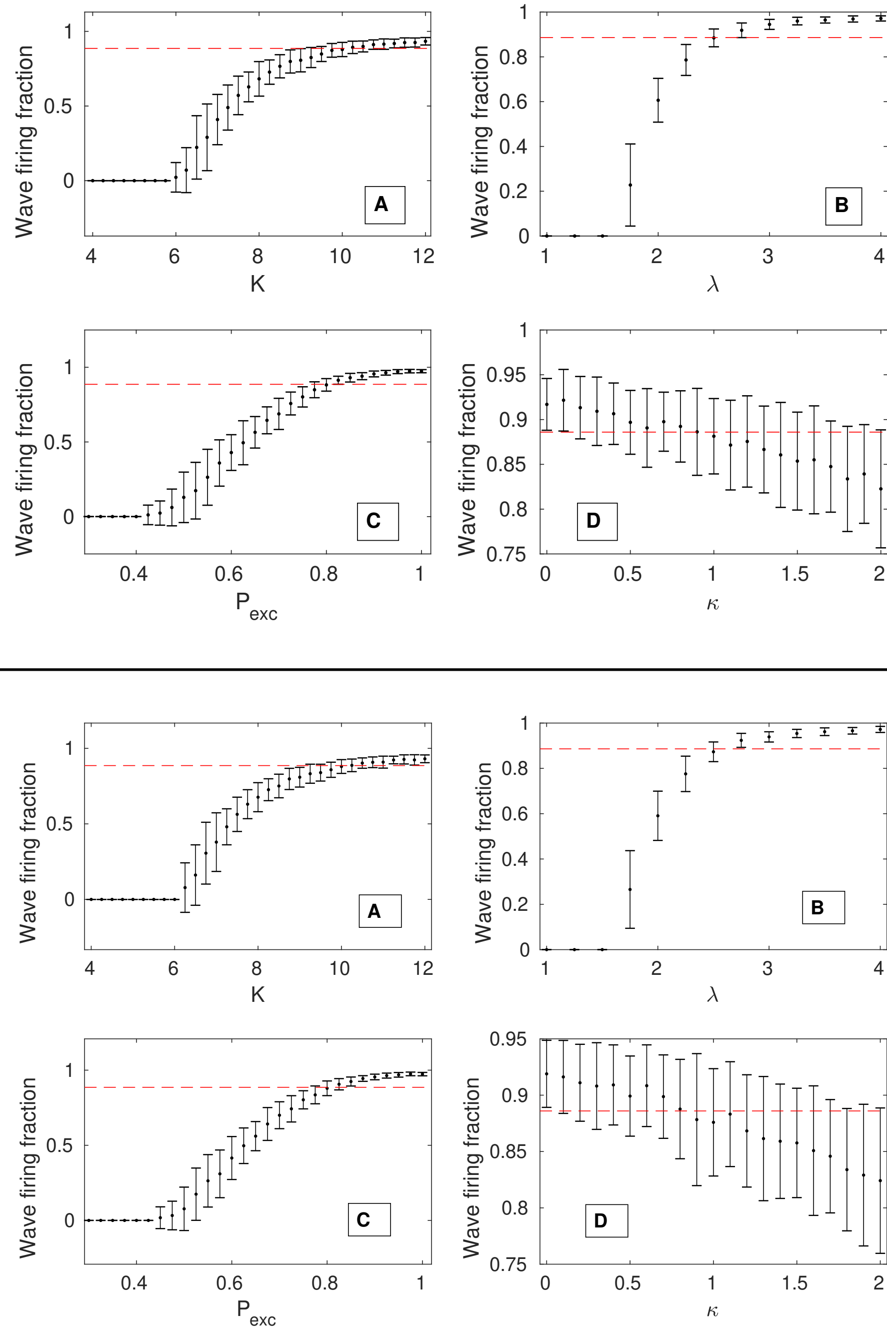
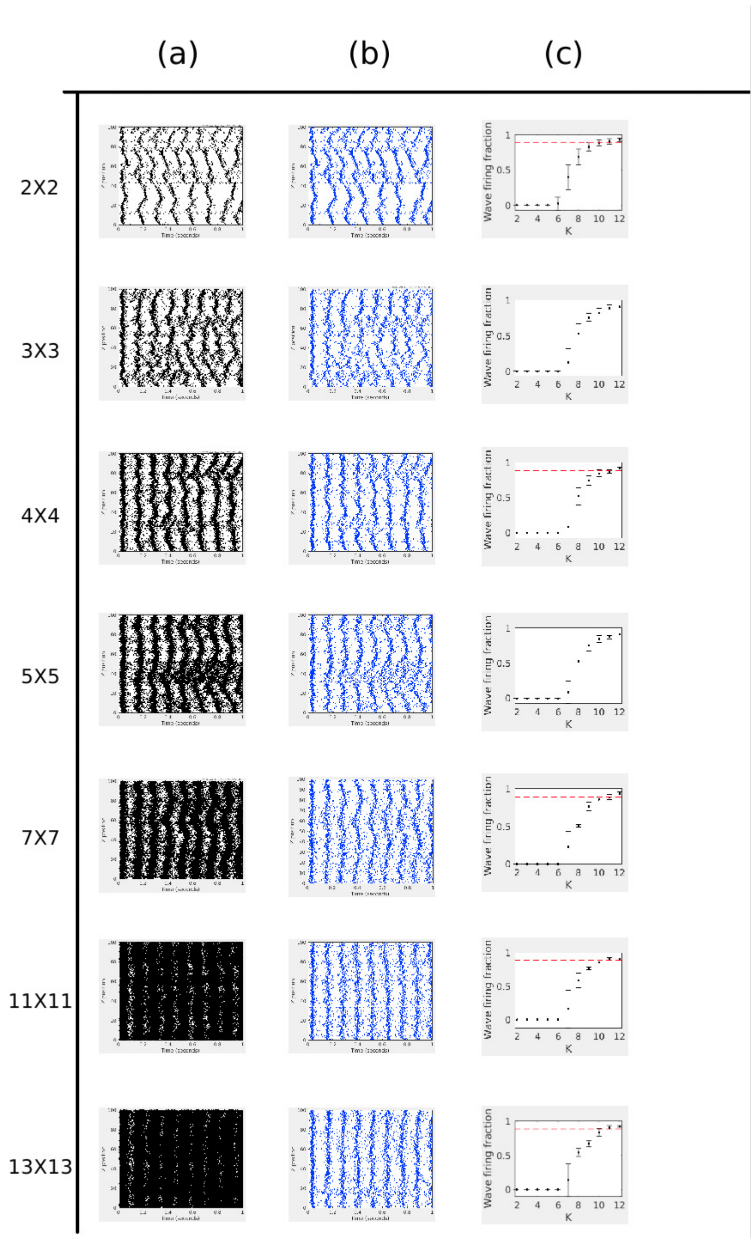


Figure 4: The original results for wave dependence upon model parameters (top) do not substantially change with connections of length > 5 removed (bottom).

SCE with a larger cross-section

In section 3.2 we showed that as SCE grow in the X or Y dimension the wave speed increases due to the increased connectivity, but when the average number of connections per neuron were held constant the wave speed was constant. We further examine these thicker, but still quasi one-dimensional SCE by examining the firing activity of purely one-dimensional sub-columns within the larger SCE (with topology 2x2x100 extracted from the central core of the thicker SCE, away from the surfaces, except of course for the 2x2 and 3x3 SCEs). With the average number of connections held constant, the sub-columns within the larger SCE show similar firing fraction with K regardless of the overall topology (Figure 5). We remark that as the X and Y extents increase, the behavior seems to change from traveling waves to more synchronized firing activity. This behavior as a function of width suggests that the system dynamics transition from supporting traveling waves to a system that exhibits global synchrony.

Figure 5: Spike raster plots for complete SCE (A) and one-dimensional sub-columns (B) for different topologies show similar firing patterns in the sub-columns regardless of topology. The wave firing fraction (C) measured within the sub-columns show the same dependence on K regardless of the topology.



Purely one-dimensional model

We establish purely one-dimensional systems in our model for comparison to previous work with purely one-dimensional systems. We start with the SCE described in Section 3.1 for measuring wave speed: a 2x2x50 (XxYxZ) SCE with model parameters at the reference point Σ_v. While previous work with this SCE measured the speed of the waves, here we determine the existence of traveling waves based on whether the neurons in the top layer of the SCE fire. **The baseline quasi one-dimensional SCE creates 74 traveling waves in 100 trials**, where each trial is a random draw on all randomized parameters in the model and stimulus. An example raster plot is shown in Figure 6A.

We create a purely one-dimensional version of this SCE with X=1 and Y=1 and all other model parameters at Σ_v. **No traveling waves are observed in this SCE in 100 trials**. An example raster plot is shown in Figure 6B. We then modify this purely one-dimensional SCE by increasing λ from 2.5 to 4 and increasing K from 24 to 30. These parameters represent the highest connectivity and connection strength tested in our quasi one-dimensional SCE. **We still do not observe any traveling waves in 100 trials** of this SCE with enhanced connectivity and connection strength. An example raster plot is shown in Figure 6C.

Finally we look to remove the random elements of our model to make it more comparable to previous work. We set $C = 1.0$ to create a more uniform and isotropic connectivity between the neurons. We set $P_{exc} = 1$ so that all neurons are excitatory with no inhibitory neurons at random locations. We remove all random factors from the Izhikevich model parameters a, b, c and d (Table 1). All neurons therefore have identical dynamics. **With this more uniform model we observe 98 traveling waves in 100 trials**, reproducing previous results that have found traveling waves in purely one-dimensional networks. An example raster plot is shown in Figure 6D. Although we have removed most variation from this SCE, the two trials with no waves are not unexpected as the stimulus is still randomized and the connectivity is still probabilistic (see Equation 1).

Figure 6: Example raster plots of the SCE used for comparison to previous work in purely one-dimensional systems. A) The 2x2x50 SCE with model parameters at Σ_v supports traveling waves along the entire SCE. B) The 1x1x50 version of the same SCE does not exhibit traveling waves. C) Even with K increased from 24 to 30 and λ increased from 2.5 to 4, the 1x1x50 SCE still does not support traveling waves. D) Once the random parameters are removed, the 1x1 SCE does support traveling waves.