

Supplemental Material for “Spike-train communities: finding groups of similar spike-trains”

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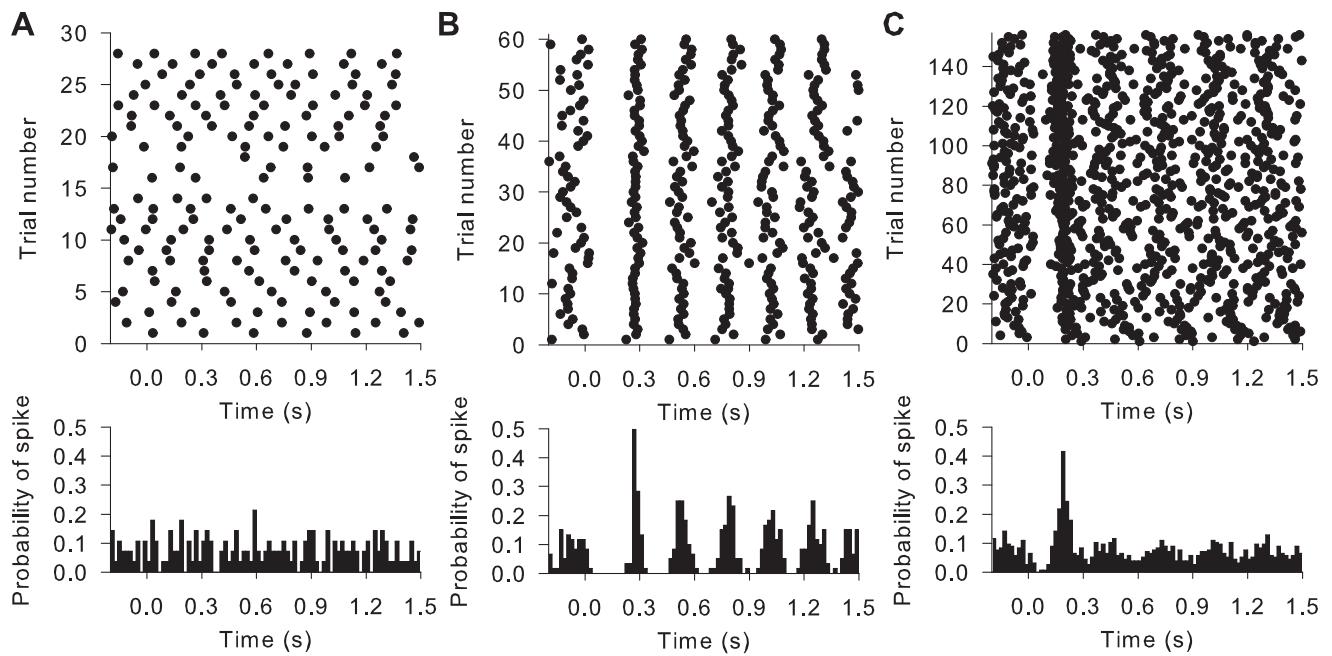


Figure S1: Single SNC unit responses across stimulation conditions. Raster plots and peri-stimulus time histograms (PSTHs) are aligned here from -0.2 to 1.5 s around the stimulus application (at time 0 s) to make clear immediate post-stimulus effect on spike trains. Top row shows raster plots of all spikes on each trial. Bottom row shows PSTHs for each raster plot, giving the probability that a stimulus elicited a spike in that 20 ms bin. **A** Applications of the control stimulus (hindpaw brush) had no detectable effect on the SNC neuron: its spike train showed the typical pacemaker firing throughout. **B** Application of footshock caused a clear, robust pause in the ongoing firing, followed by a precisely timed spike at around 280 ms. The neuron then resumed regular, pacemaker-like firing, phase-locked across trials. **C** After application of bicuculline in superior colliculus, the same stimulus elicited a pause in firing, and a higher consequent probability of a spike at around 190 ms. Compared to the baseline condition, the pause was less clear, shorter, and the subsequent firing was not clearly reset each time. Nonetheless, the clustering algorithm clearly revealed that the neuron resumed pacemaker-like firing on each trial, but with the restart not strictly time-locked to the stimulus application (and, hence, obscured in the PSTH): this is illustrated in Figure S2.

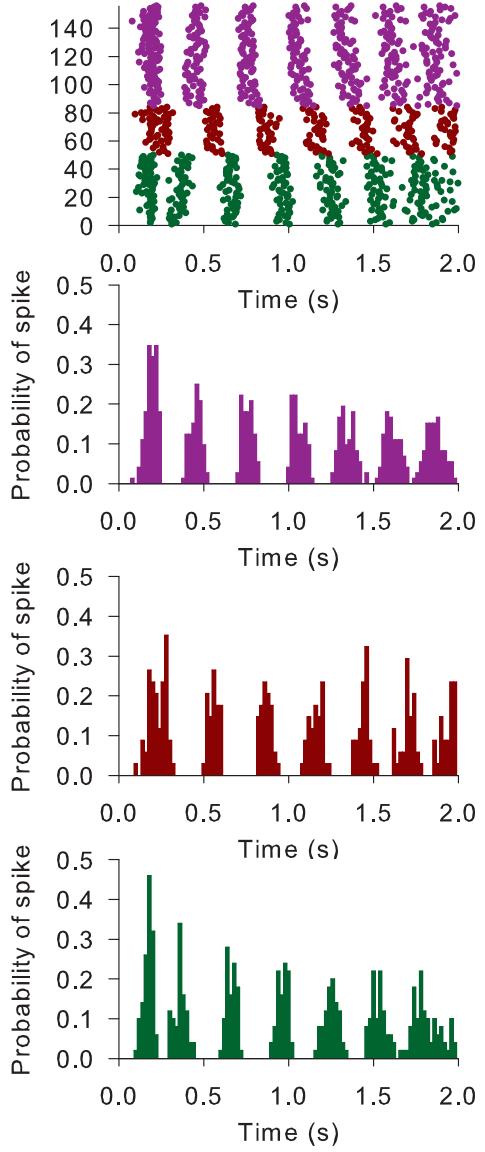


Figure S2: Separate peri-stimulus time histograms (PSTHs) for each of the three detected groups of SNC neuron responses to pain stimuli in the modulation (post-bicuculline) condition. Each PSTH is colour-coded according to the grouped raster plot (top). The discrete firing evident in the individual group PSTHs is very similar to that of the baseline condition (Figure S1B), emphasising that the SNC neuron resumed pacemaker-like firing on every trial, but resumed at different times.

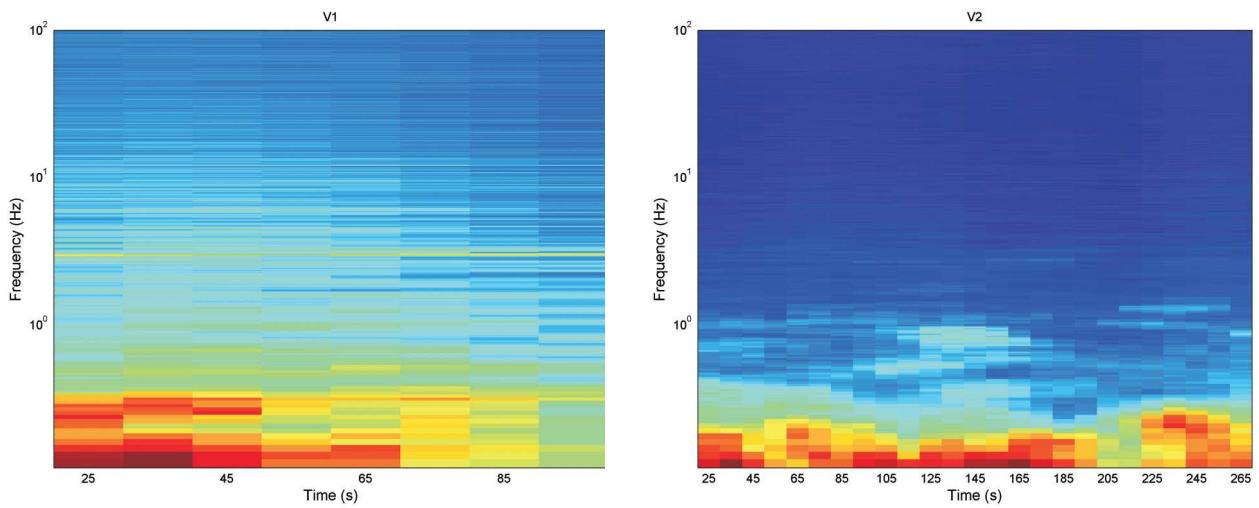


Figure S3: Power spectra of V1 and V2 neural activity show the dominance of slow oscillatory activity under isoflurane anaesthetic. We computed the multi-taper spectrum (Jarvis and Mitra, 2001) of each spike-train in each 50s sliding time window (using MATLAB routines from the Chronux toolbox: www.chronux.org). For each time-window we then averaged the spectra over all spike-trains, and plot here per-window as colour-coded spectrograms (increasing red intensity equates to increased power). Both V1 (**A**) and V2 (**B**) average spectrograms show the clear dominance of low (< 1 Hz) frequencies, consistent with slow oscillations in cortex induced by isoflurane (Ferron et al., 2009).

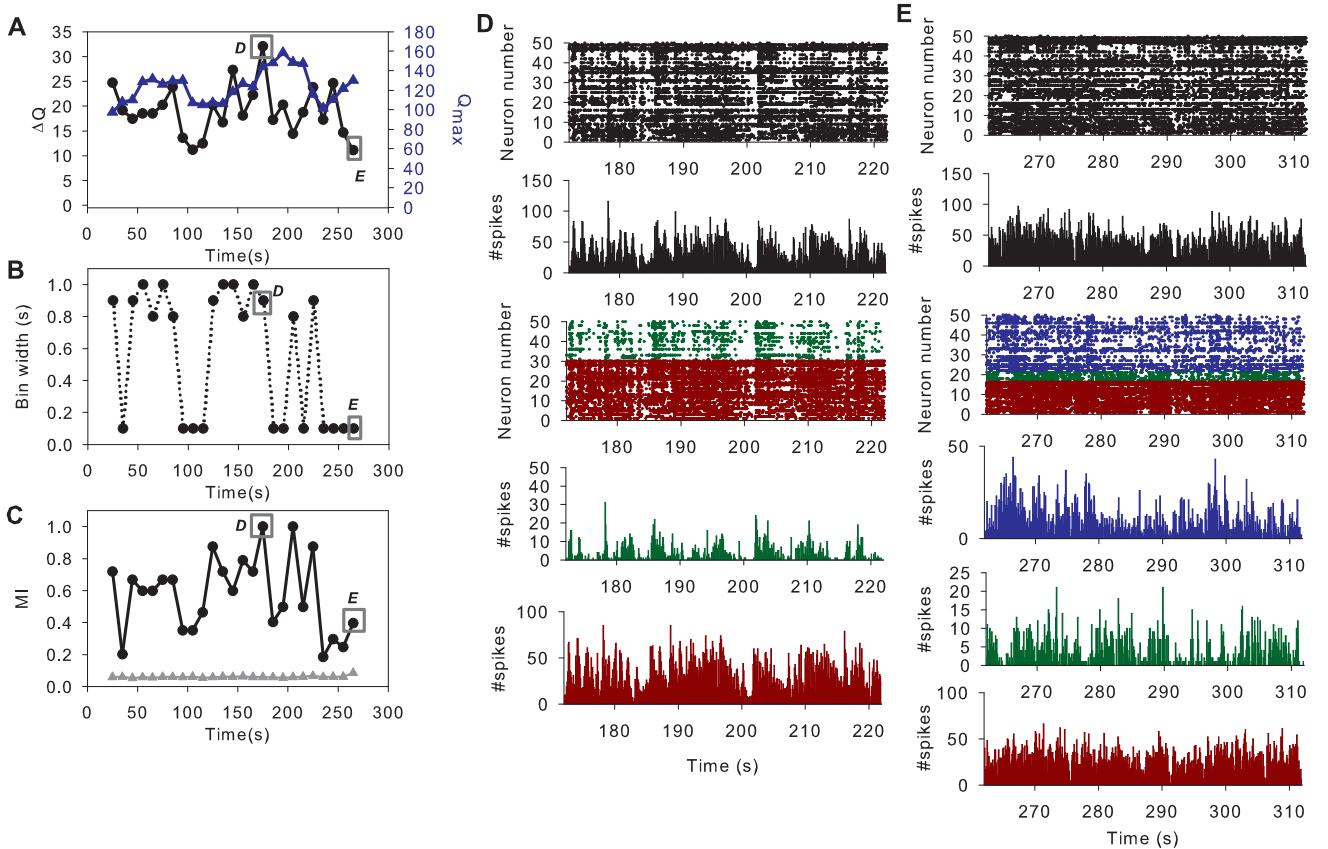


Figure S4: Preliminary clustering analyses using binned spike-trains revealed evolving spontaneous neural activity in cat area V2 under anaesthesia. Compared to the analyses using binless representations (see main text), the results here show simpler groupings that were more stable over time. We ran the algorithm on all 50 spike-trains using a 50 second sliding window, applying the window every 10 seconds within the 299 seconds of retained recording. **A** Plotting maximum ΔQ shows that the correlation structure of the population activity fluctuated considerably over the recording. The algorithm returned two groups for each time window except the last, which had three groups. Similarly, the maximum modularity scores Q_{\max} also indicate an evolving group structure – but we see here that there is considerable discrepancy between the evolution of spike-train groupings detected when (ΔQ) and when not (Q_{\max}) controlling for spurious “by chance” spike-train groups. Grey boxes here and in panels B and C indicate the time windows plotted in detail in panels D and E. **B** ΔQ in each window was consistently found for binsizes around either 0.1 or 0.9 seconds. **C** The group membership changed over the recording, but retained a consistent core. Here we plot the mutual information between each window’s grouping and the grouping found in the window with maximum ΔQ (the sixteenth window, centered on 175s). This exact grouping of spike trains was repeated only once (window 19, centred on 205s), but a large set of the spike trains (26/50) was always assigned to the same group in each window. Further, the mutual information always considerably exceeded the upper bound given by randomly assigning the spike trains to groups of the same size (grey line and symbols, plotting the mean plus 2 s.d. of 1000 samples from randomly generated $I(A, B)$ s for each window, where A is the group structure in window 16, and B was a random assignment of the spike-trains into the same size of groups found for that window). **D** The breakdown of group activity from the window with the maximum ΔQ shows structure on the 0.9s time-scale. From top to bottom, we plot for the 50s window: the raster plot of the spike trains; the corresponding spike-time histogram (using 0.1s bins); the raster plot sorted by group membership; and the corresponding spike-time histograms of the two groups. From these, it is clear that there was a smaller group of sparser firing neurons in the recorded population, whose activity showed synchronised oscillations. Note how this group’s activity is indiscernible from the whole population raster or spike-time histogram. **E** The equivalent breakdown of group activity from the window with minimum ΔQ (window 25) shows that this reflects the loss of strong slow oscillations in the whole population. The three detected groups had the most evident structure on the 0.1s time-scale, as reflected in the irregularly occurring bins with large peaks in the first (blue) and second (green) groups.

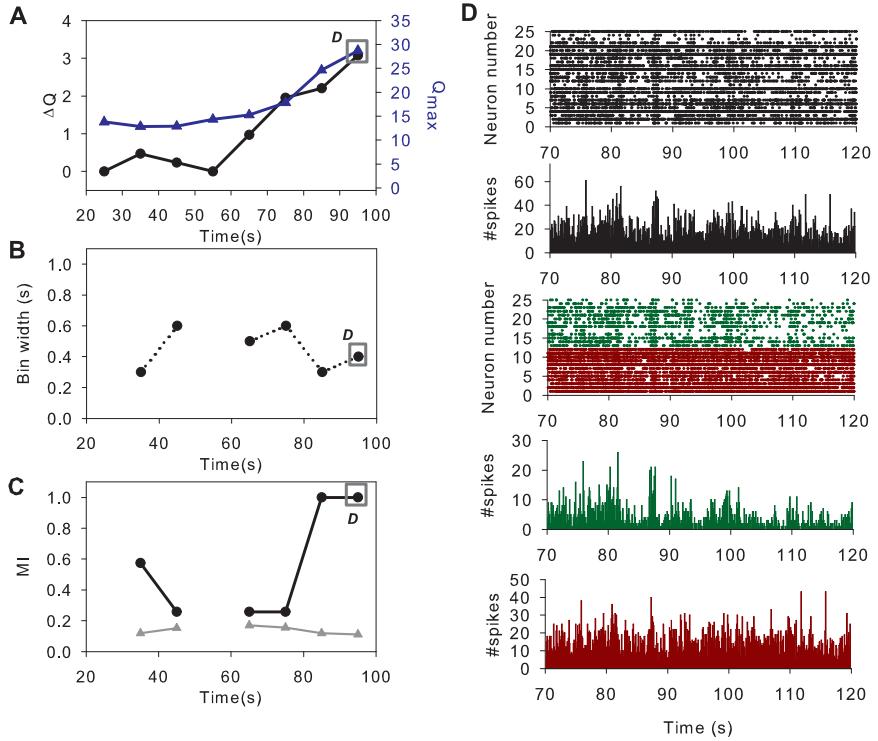


Figure S5: Preliminary binned spike-train based analyses of spontaneous activity in V1 of isoflurane-anaesthetised cat. We ran our clustering algorithm on all 25 spike-trains within a 50 second sliding window, applying the window every 10 seconds within the 120 seconds of recording. Using the binned spike-trains revealed qualitatively the same organisation of groups as the Gaussian-convolved spike-trains (main text Fig. 8), once controlled for by-chance groupings. **A**. We found that detectable structure was split into two discrete periods; two of the time-windows had no $\Delta Q > 0$ for any of the 11 binsizes tested. The clearest structure only emerged towards the end of the recording period. **B** All windows with $\Delta Q > 0$ had ΔQ for a binsize of between 0.3 and 0.6 s, and hence the detected structure was always at different time-scales than those in V2. **C** The last two windows had the same grouping, which was the most distinct from the random assignment of spike-trains to the groups (grey lines and symbols, as in Fig. S4C). **D** The distinction between V1 and V2 dynamics is illustrated by the detailed plots of activity in the last window (centred on 95 seconds): two groups of approximately the same size were found, both showing periods of synchronised activity, but no clear repeating oscillation. Both groups had synchronous activity peaks at around 87 seconds, but otherwise were largely independent.

References

- Ferron, J-F., Kroeger, D., Chever, O., Amzica, F. (2009). Cortical inhibition during burst suppression induced with isoflurane anesthesia. *J Neurosci* 29: 9850–9860.
- Jarvis, M. R. Mitra, P. P. (2001). Sampling properties of the spectrum and coherency of sequences of action potentials. *Neural Comput* 13: 717–749.