Section: Behavioral/Systems/Cognitive

The sparseness of neuronal responses in ferret primary visual cortex

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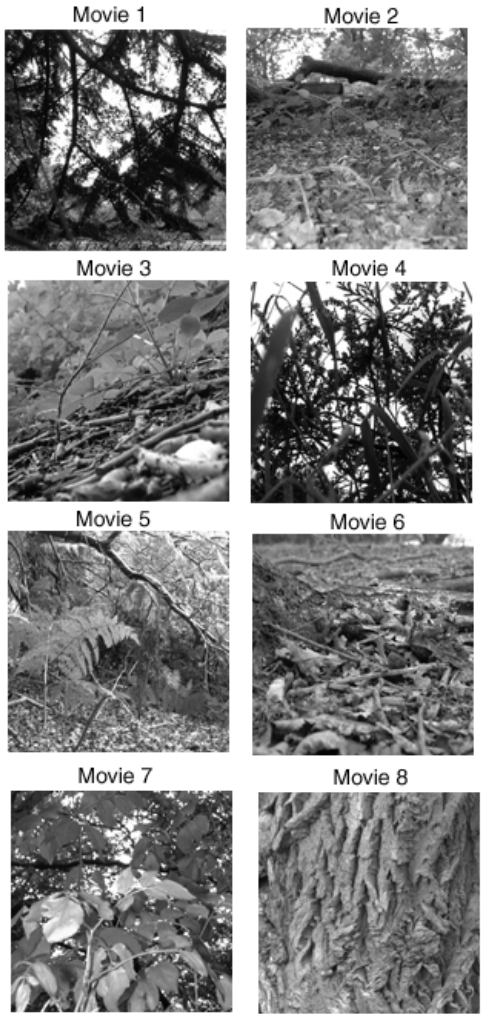
Supplementary materials

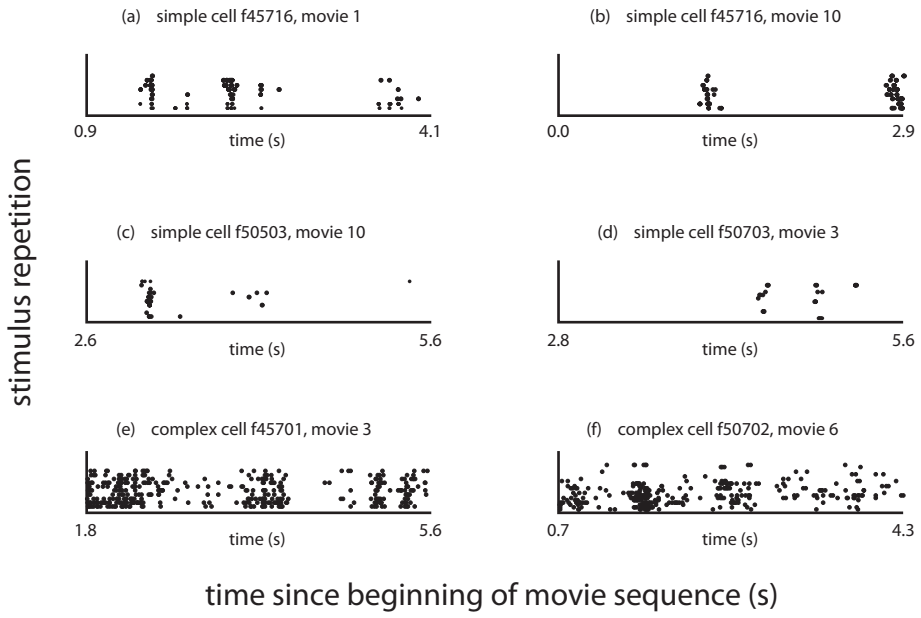
In the Discussion of the main paper, we briefly report on experiments (summarised by Smyth et al, 2002) on anaesthetized ferrets in which the natural-image presentation protocols are more naturalistic than the metronomic sequences of 100ms flashes of unrelated scenes (as used in the main paper). We have also studied the responses of ferret V1 neurons to "movies", each based on a single monochrome photograph of a natural scene (see Supplement.Fig.1 for some examples).



Supplementary Figure 1: Eight examples of monochrome photographs from which 5.6 s movie sequences were made.

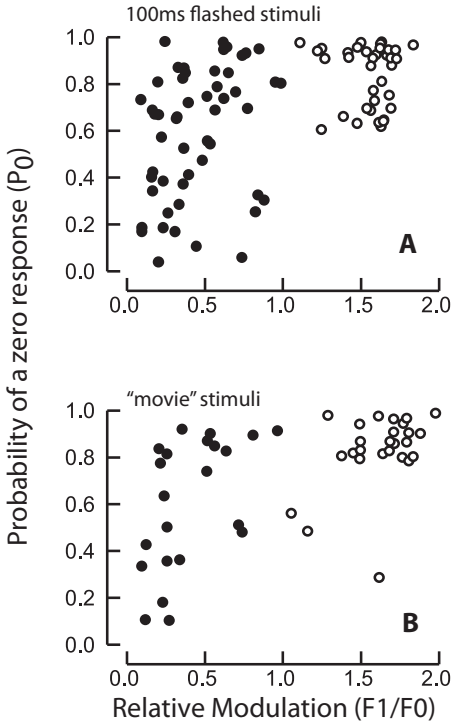
A large photograph of the scene was viewed on the display CRT through a 55 deg circular aperture, centred on the neuron's classical receptive field. Every 37.5 ms (6 display frames on the CRT with frame rate of 160Hz), the photograph was moved "behind" the aperture by 0.15-0.75 deg, the step size being chosen randomly. Thus, spatial frequencies in the photograph of 0.1-0.2 c/deg would have moved at about 1-2 Hz. These spatial and temporal frequencies are the ones most likely to be optimal for ferret V1 neurons (Baker et al, 1998). The direction of the first step in a movie was chosen randomly but, thereafter, each subsequent step was chosen from a Gaussian distribution, centered on the previous direction and with a standard deviation of 18 deg. This resulted in a steady but slightly erratic trajectory across the photograph. Overall, there were 150 stops (including the first and last 37.5 ms episodes) so that the "movie" lasted some 5.6 s. For each of the parent photographs, one trajectory was calculated so that the same movie stimulus could be presented repeatedly to any given neuron; different trajectories were associated with different parent photographs.

Each of 57 V1 neurons was stimulated with 8-12 different movie sequences, each presented 8-20 times. The presentations of the different movies were randomly interleaved. Supplement.Fig.2 shows some examples of neuronal responses to movies. Each panel shows the response of a different neuron to a different movie. The results are presented as rasters, where the x-location of each dot shows the time of an action potential with reference to the start of the movie. Each row represents a different repetition of that movie. The panels mostly show that neurons gave a few discrete bursts of activity during a movie, and the timing of these bursts was reliable across repetitions of a stimulus. These rasters look similar to those presented as Fig.5 in the main paper in so far as the panels are mostly blank, with a few columns of dots. The only real difference is that, in Fig.5, each column on the x-axis represented one image totally unrelated to its neighbours whilst, in Supplement.Fig.2, neighbouring columns represent slightly displaced views of the same image. The columns of action potentials in the movie experiment spread across several static frames of the movie because (a) the same critical spatial feature will likely have remained within the receptive field for several successive frames and (b) it will have taken time for the neuron to generate a burst of action potentials in response to any single powerfully-stimulating feature.



Supplementary Figure 2: Six examples of neuronal responses to parts of movies. The rasters show extracts from the 5.6 s duration of the movies. Each row of dots represents the response to a repetition of the identical movie sequence. The 4 simple cells (a-d) clearly show sparser responses than the 2 complex cells below.

In Fig.5 in the main paper, the small proportion of each raster plot occupied by black squares is a rough indicator of response sparseness. Our simplest measure of response sparseness was P_0, the proportion of flashed photographs that elicited no response. Figure 8A in the main paper plotted P_0 against the relative modulation (*F1/F0*) in the responses to moving gratings. That graph is reproduced here as Supplement.Fig.3A to show the range of sparseness values in response to isolated flashes of unrelated photographs and to show how sparseness was related to grating response modulation; there is one data point per neuron. We have used an analogous measure to characterize the sparseness of response during the movies. On what proportion of the 150 stops of 37.5 ms in each repetition of each movie were no action potentials generated? Supplement.Fig.3B plots *movie sparseness* against grating relative modulation.



Supplementary Figure 3: **A**, Response sparseness for neurons measured as the proportion of 100 ms flashed images which evoked no response is plotted against modulation ratio measured with moving sinusoidal gratings of optimal spatial frequency and orientation. The filled symbols are for complex cells, and the open symbols are for simple cells, defined with respect to the modulation ratio. This is Fig.8A in the main paper. **B**, The same for a different set of neurons, but with response sparseness defined in terms of their responses to movie stimuli: the proportion of 37.5 ms stops in all the repetitions of all the movies in which no action potentials were generated.

The forms of Supplement.Fig.3A and 3B are very similar, showing near-identical ranges of sparseness and the same relation with *F1/F0*. Although our presentation protocol in the main paper (100ms flashes of unrelated images separated by 100ms or more of blank screen) may not have been especially naturalistic, the results with movie sequences are almost identical. The movie sequences represent a more naturalistic situation where an animal views a *single* scene for some seconds at a time, allowing its eyes to drift and flick across it in an erratic sequence.

Baker, G.E., Thompson, I.D., Krug, K., Smyth, D. & Tolhurst, D.J. (1998). Spatial frequency tuning and geniculocortical projections in the visual cortex (areas 17 and 18) of the pigmented ferret. *European Journal of Neuroscience*, **10**, 2657-2668.

Smyth D., Small J. E., Tolhurst D. J. & Thompson I. D. (2002). Contextual modulation in visual cortical responses to natural movies. *FENS Abstracts*, **1**, 083.17.