Spike latencies in retinal ganglion cells encode spatial image details

Tim Gollisch and Markus Meister

MCB Department and Center for Brain Science, Harvard University

Vision is a highly dynamic process, structured by frequent eye movements that bring a new image onto the retina and initiate a short episode of visual processing. Analysis of the spatial scene can be extremely rapid and precise: For example, human subjects can detect and classify objects in brief image presentations of ~100 ms [1]. What neural codes underlie such rapid image processing has been a longstanding question.

We investigated the structure of visual information emerging from the eye, by recording spike trains from many ganglion cells in the isolated salamander retina. A square-wave grating stimulus was flashed briefly onto the retina, and the considered image analysis task consisted in identifying the grating's spatial phase. Most ganglion cells responded with a burst of spikes to all presentations, regardless of phase and sign of the grating. We recorded the time of the first spike in the burst (latency) and the total number of spikes (spike count). The response latency varied systematically with grating phase, with a range up to 40 ms. The precision of this latency for identical stimuli was 3-5 ms. These stimulus-dependent latency variations generally contained much more information about the stimulus than did the spike count.

Since the brain circuits that receive retinal spike trains may not know the time of stimulus onset other than through retinal activity itself, we further investigated what information is carried by the relative latency of two neurons. For some cell pairs, the relative latency was more informative than any single-neuron latency. Furthermore, these latency differences were largely invariant with stimulus contrast, since each cell's response latency tended to decrease with increasing contrast. In addition, we found stimulus-independent fluctuations in latency, with strong covariation across neurons; this resulted in low fluctuations of the latency difference. Altogether, this suggests that a population latency code would be a powerful mechanism for transmitting spatial detail of a briefly exposed scene. It is robust to retinal noise; it encodes stimulus shape independent of the overall contrast level; and it provides the information in the shortest possible time, namely with the first spike.

Finally, we explored how these response patterns might be produced within the retinal network, and analyzed several models consistent with known anatomy. Two features of spatio-temporal integration were found to contribute: the combination of inputs from both ON and OFF pathways, and the strong rectification of those signals before spatial integration at the ganglion cell.

1. Thorpe S, Fize D, Marlot C (1996) Speed of processing in the human visual system. Nature 381: 520-522.