Population Coding of Motion in the Retina

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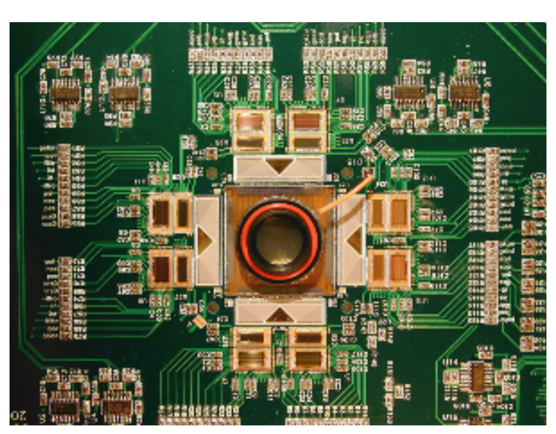
Introduction

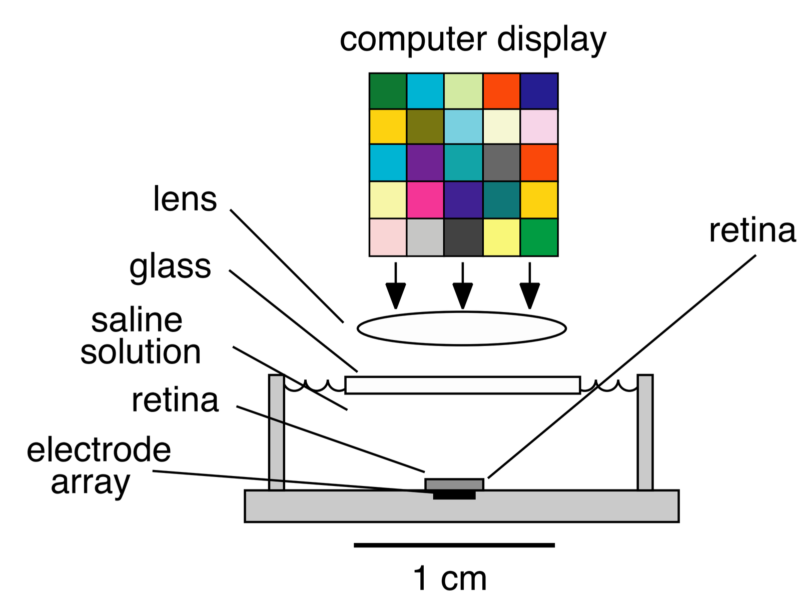
Motion is an biologically important visual signal, and is encoded by population activity in retinal ganglion cells, the output neurons of the retina. Roughly 20 types of ganglion cells send distinct visual signals along parallel pathways to the brain. Previous studies have suggested that ON and OFF parasol cells may encode visual motion more faithfully than other cell types, namely ON and OFF midget cells. However, the evidence is circumstantial, does not take into account signal and noise properties, and is based on single-cell measurements even though the neural code for motion in the primate retina is a population code. By recording nearly complete populations of ON parasol, OFF parasol, ON midget, and OFF midget cells, we can analyze how populations of the different cell types may be representing motion.

Methodology

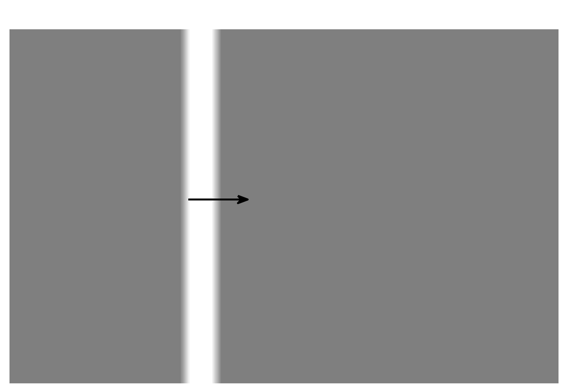
An array of 512 electrodes was used to record from the retinal ganglion cells of isolated macaque monkey retina while the retina was illuminated with a moving bar at various speeds. Eyes were obtained from other research groups when they concluded a monkey experiment.



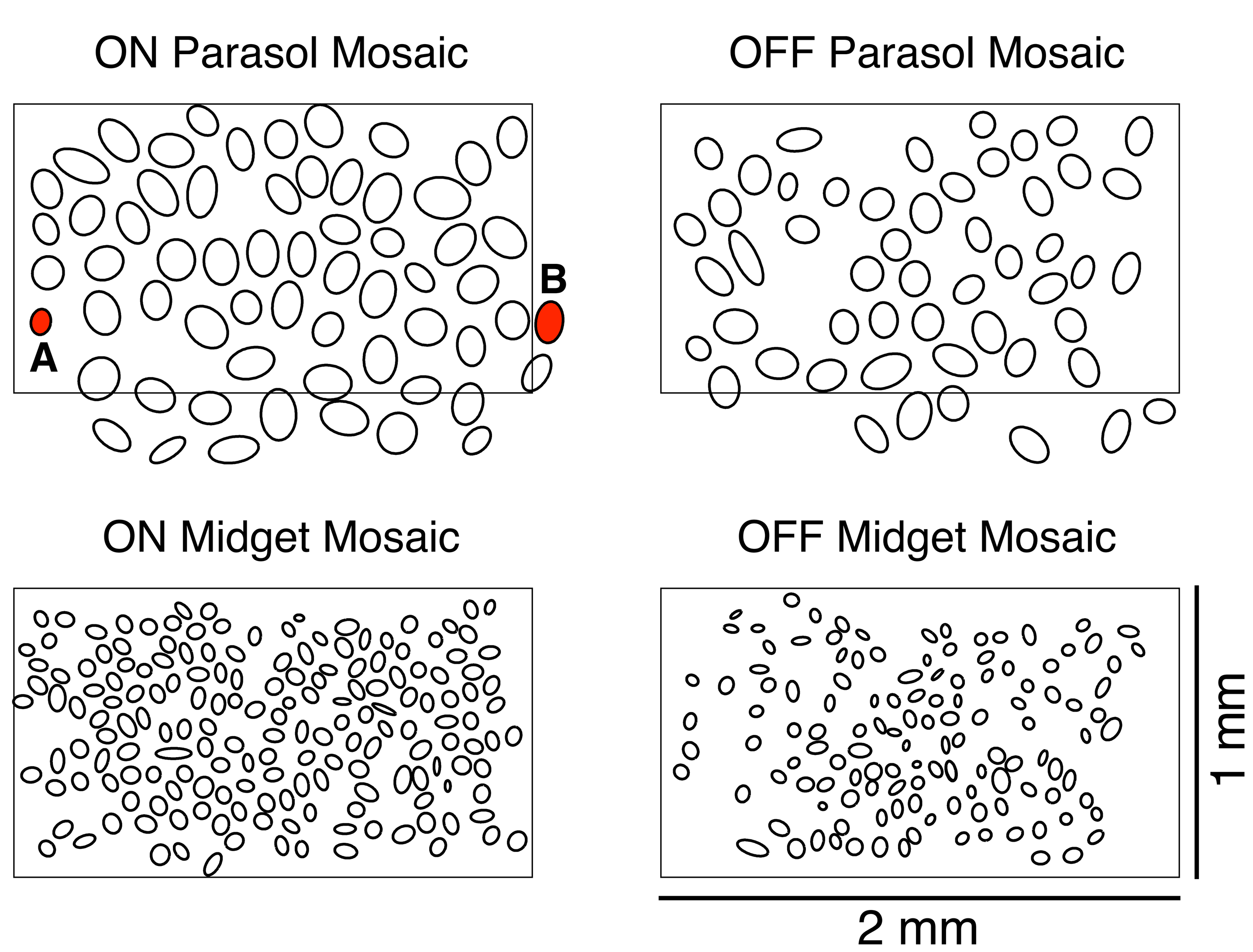
Litke et al (2004), Frechette et al (2005)



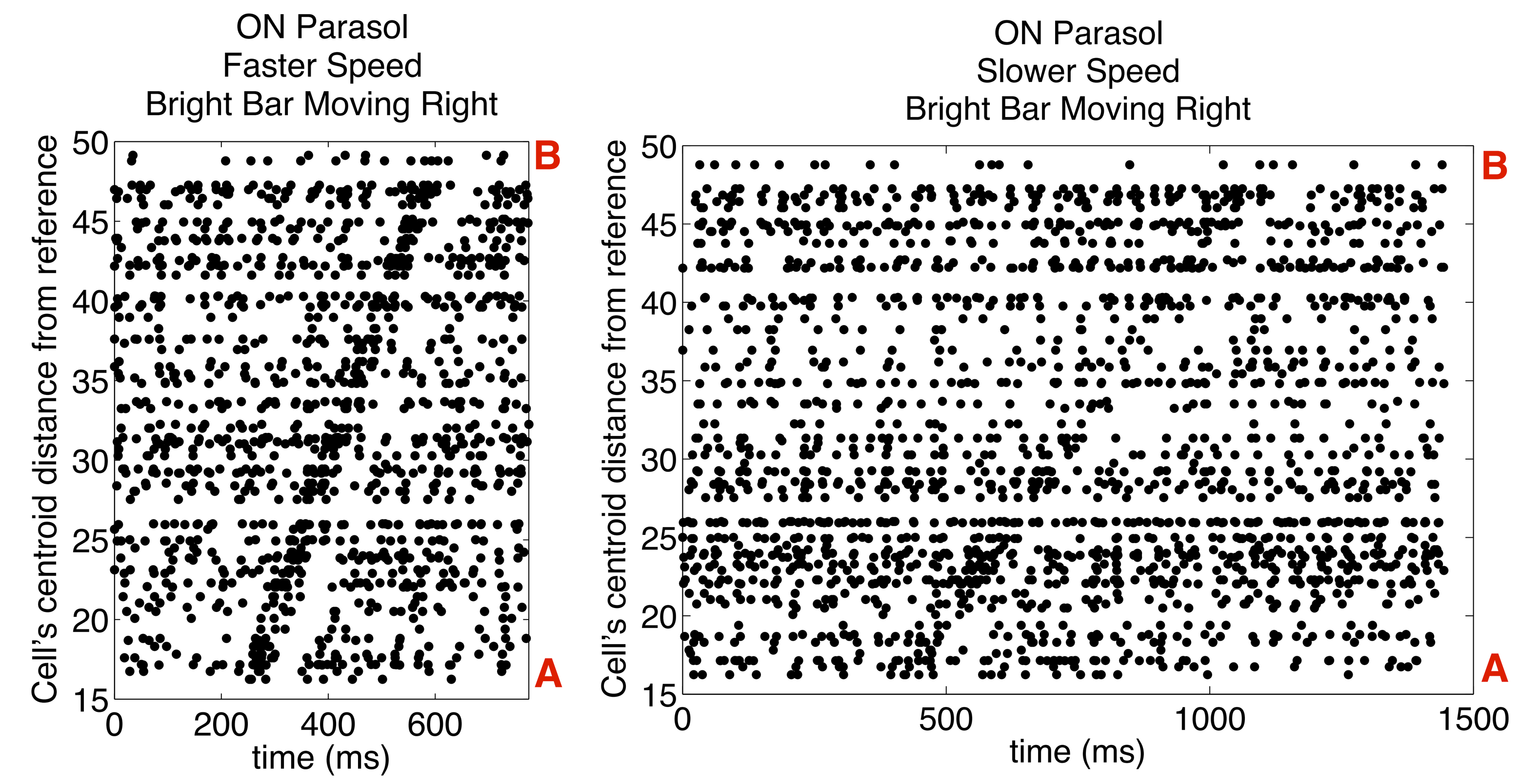
Stimulus



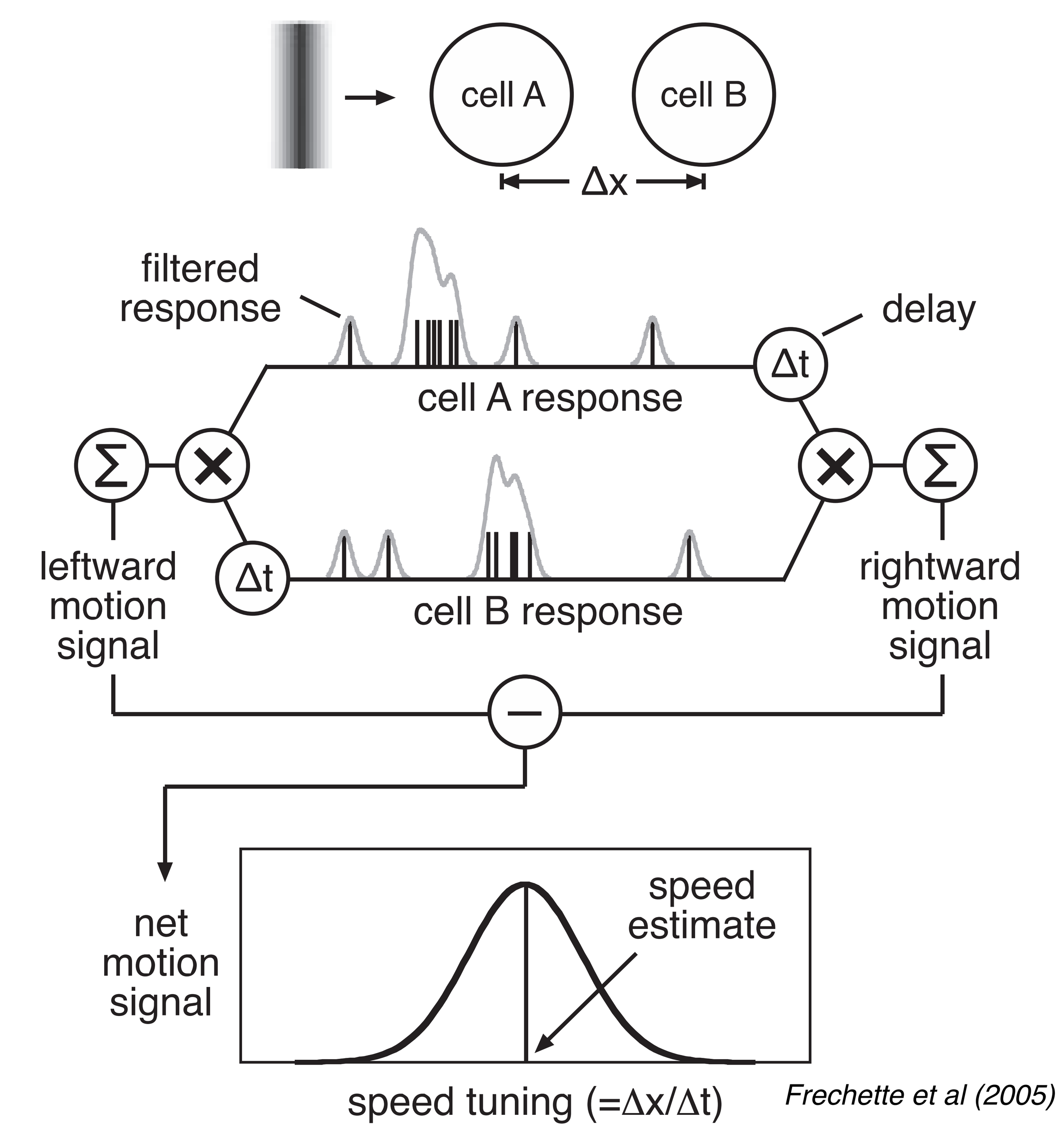
The light response properties of each cell were determined by its averaged response to spatiotemporal white noise. The mosaics show the 1.5 SD boundaries of elliptical Gaussian fits of the spike triggered average.



Data



Algorithm for Readout of Motion Signal

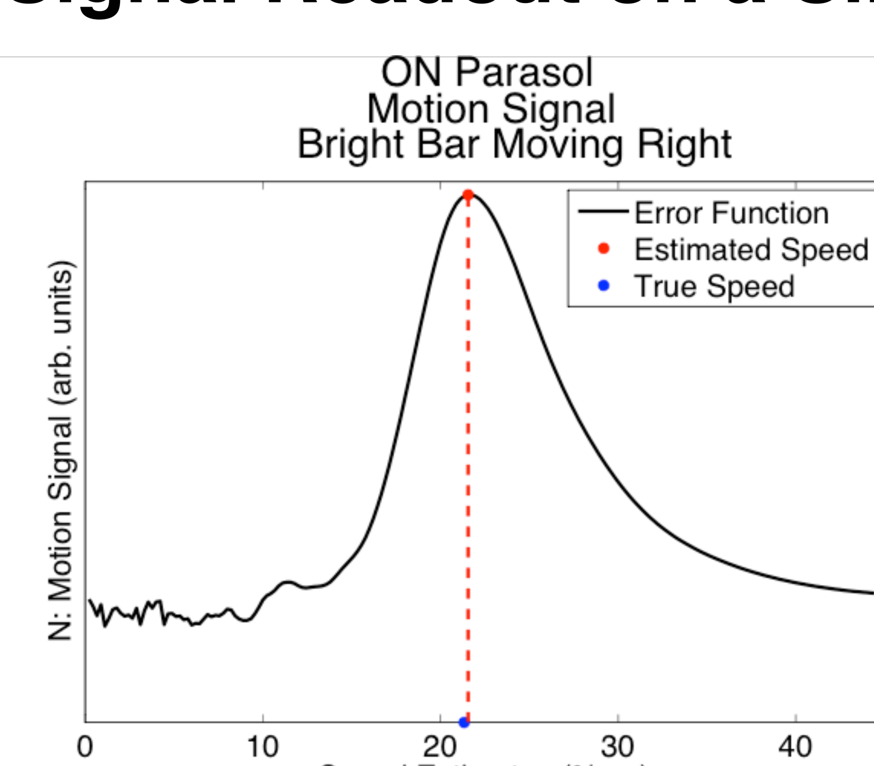


Frechette et al (2005)

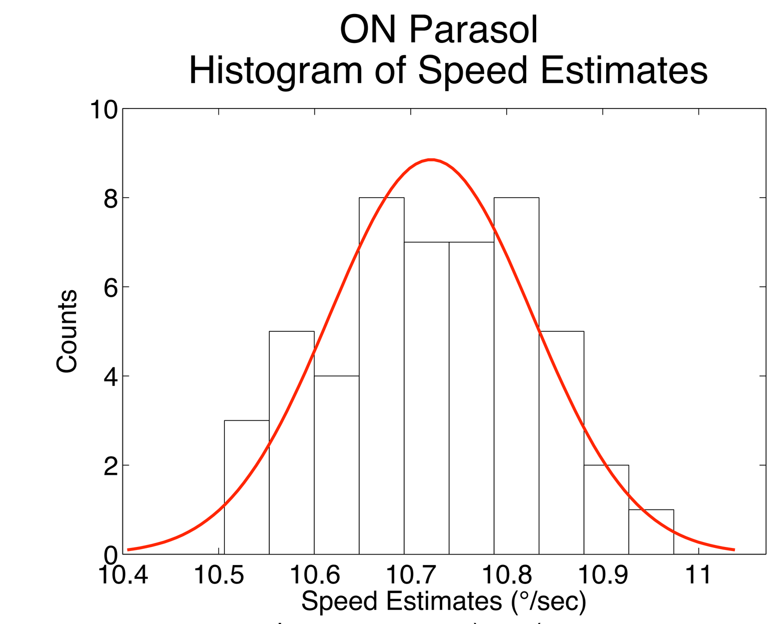
$$N = \sum_t \left[\sum_i r_i(t - \Delta t_i) \right]^2 - \sum_t \left[\sum_i r_i(t + \Delta t_i) \right]^2$$

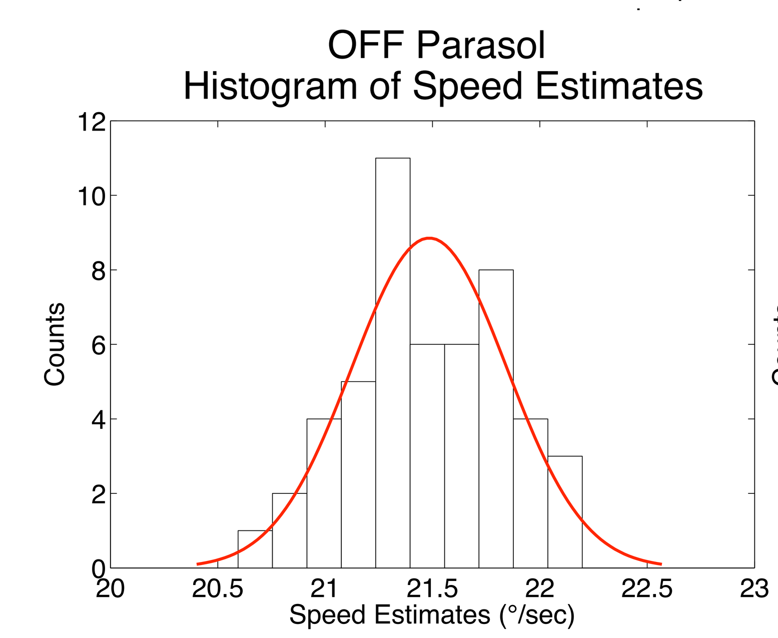
$r_i(t)$ is response of ith cell which is delayed by $\Delta t_i = \dfrac{x_i}{s}$ where x_i is the position in the receptive field and s is the speed estimate.

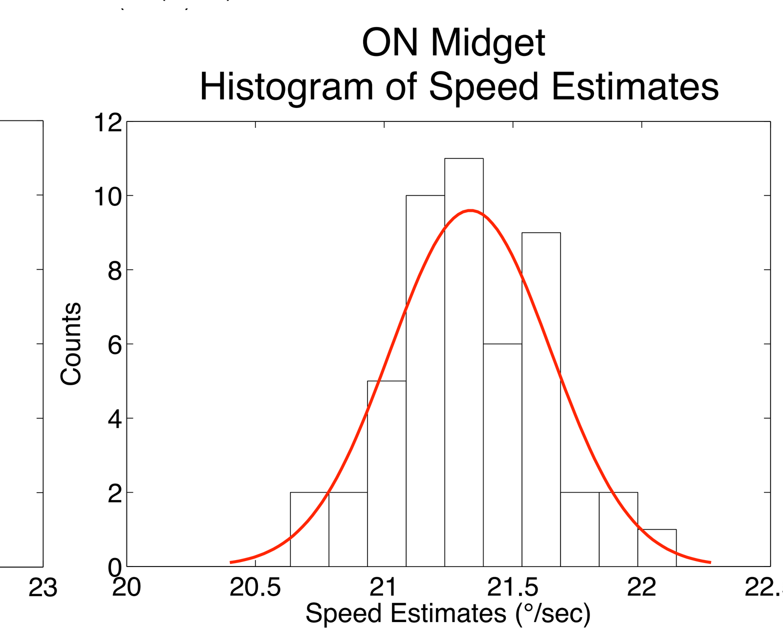
Motion Signal Readout on a Single Trial

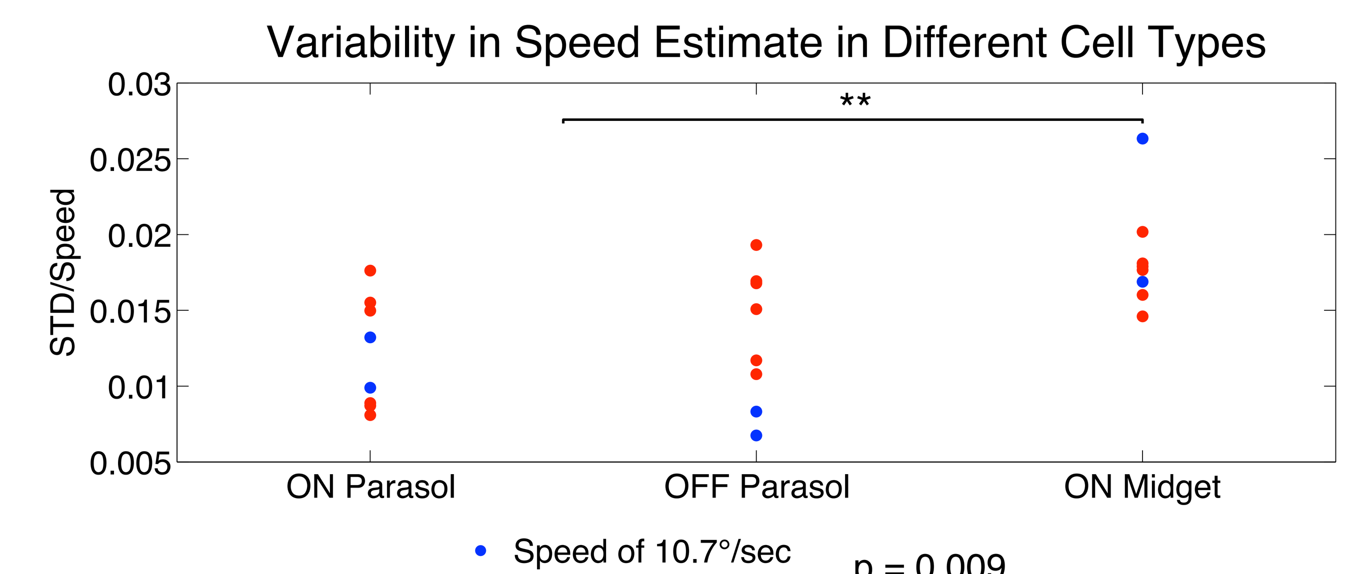


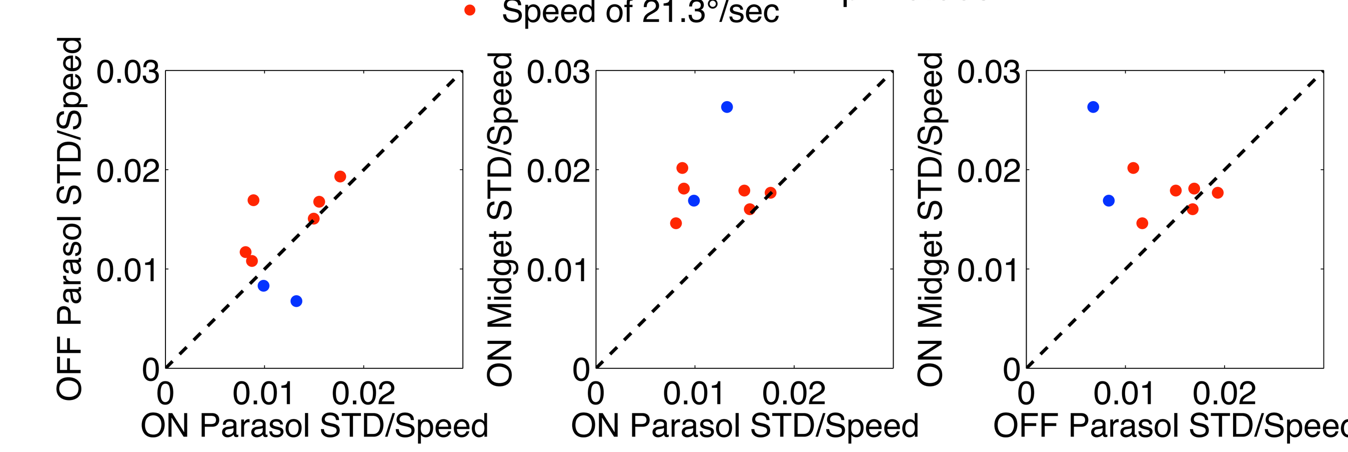
Precision of Motion Readout











Conclusion

At the bar speeds for which the data has been analyzed (10.7 and 21.3°/sec), the ON midget cells compute motion wtih slightly less precision than ON parasol cells and OFF parasol cells. Thus, a high-fidelity, motion signal is present in the high-resolution midget cells and likely affects how the visual system processes motion.

Future

- Consider other computational models for extracting motion information
- Explore how a (realistic) time varying signal could be represented by the retinal population code.
- Investigate how cortical neurons could readout this information from retinal signals.

References

1. Frechette, E. S. et al. Fidelity of the ensemble code for visual motion in primate retina. J. Neurophysiol. 94, 119–135 (2005).
2. Litke, A.M. et al. What does the eye tell the brain? Development of a system for the large-scale recording of retinal output activity. Nuclear Science, IEEE Transactions on, 51, 1434-1440 (2004).