# Space-time characteristics of visual input modulations resulting from saccades

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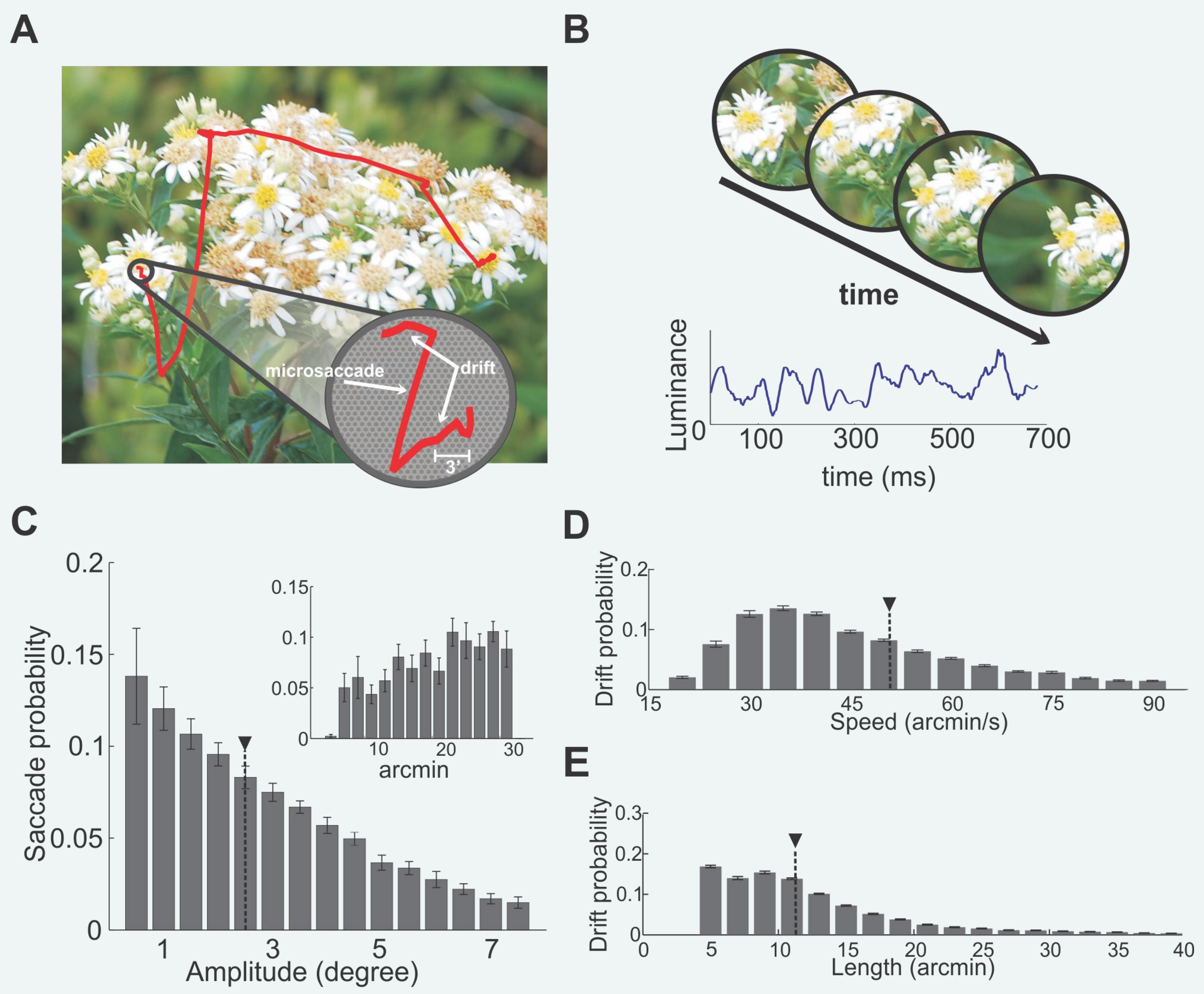
## Vision is active

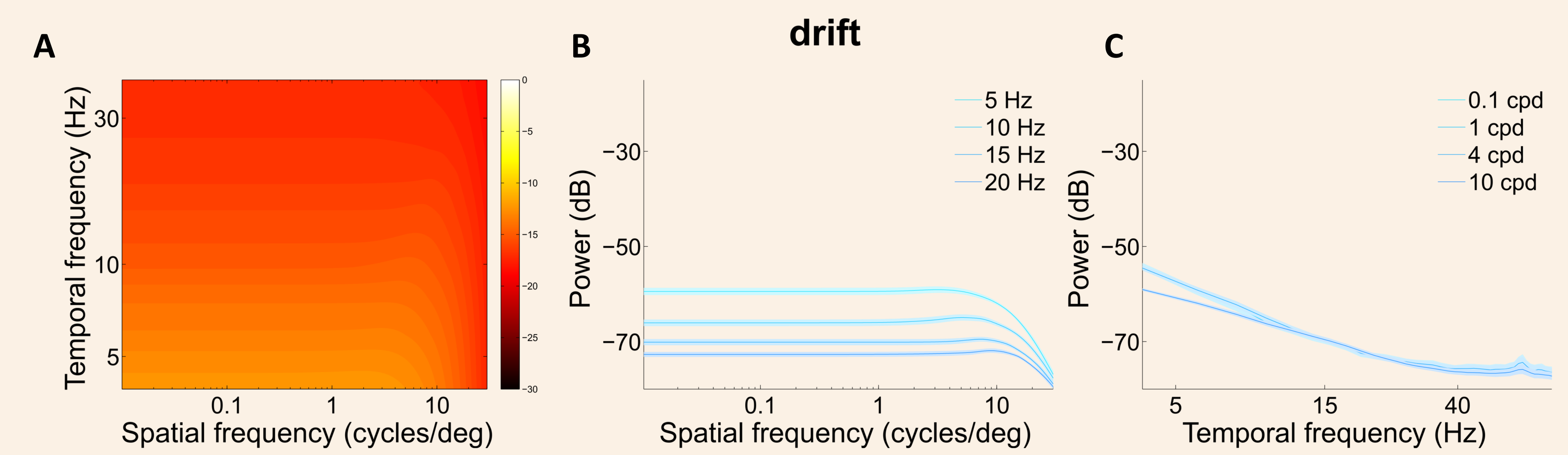
Under natural viewing conditions, saccades occur 2-3 times per second and move the gaze between different objects in the scene. Microscopic eye movements are also present during the intersaccadic periods of visual fixation.




(A) An example of recorded eye movement superimposed on the observed image. The enlarged region shows the eye movements occurring during a period of fixation in relation to the size of photoreceptors. (B) The resulting spatio-temporal stimulus impinging on a region of the retina (top) and on a single photoreceptor (bottom) (C–E) Average distributions of saccade amplitudes (C), ocular drift speeds (D), and lengths (E) over N= 14 observers. The insert in (C) shows the range of microsaccades. Data in (E) represent the arc lengths of the trajectories followed by the eye during the intersaccadic periods. Black triangles indicate means. Error bars represent one SD.

## Fixational eye movements whiten visual stimuli

In a previous study [1,2], we have shown that, during viewing of natural scenes, fixational eye movements remove predictable correlations in natural scenes by equalizing the spatial power of the retinal image within the frequency range of ganglion cells' peak sensitivity. This transformation was previously attributed to center-surround receptive field organization.

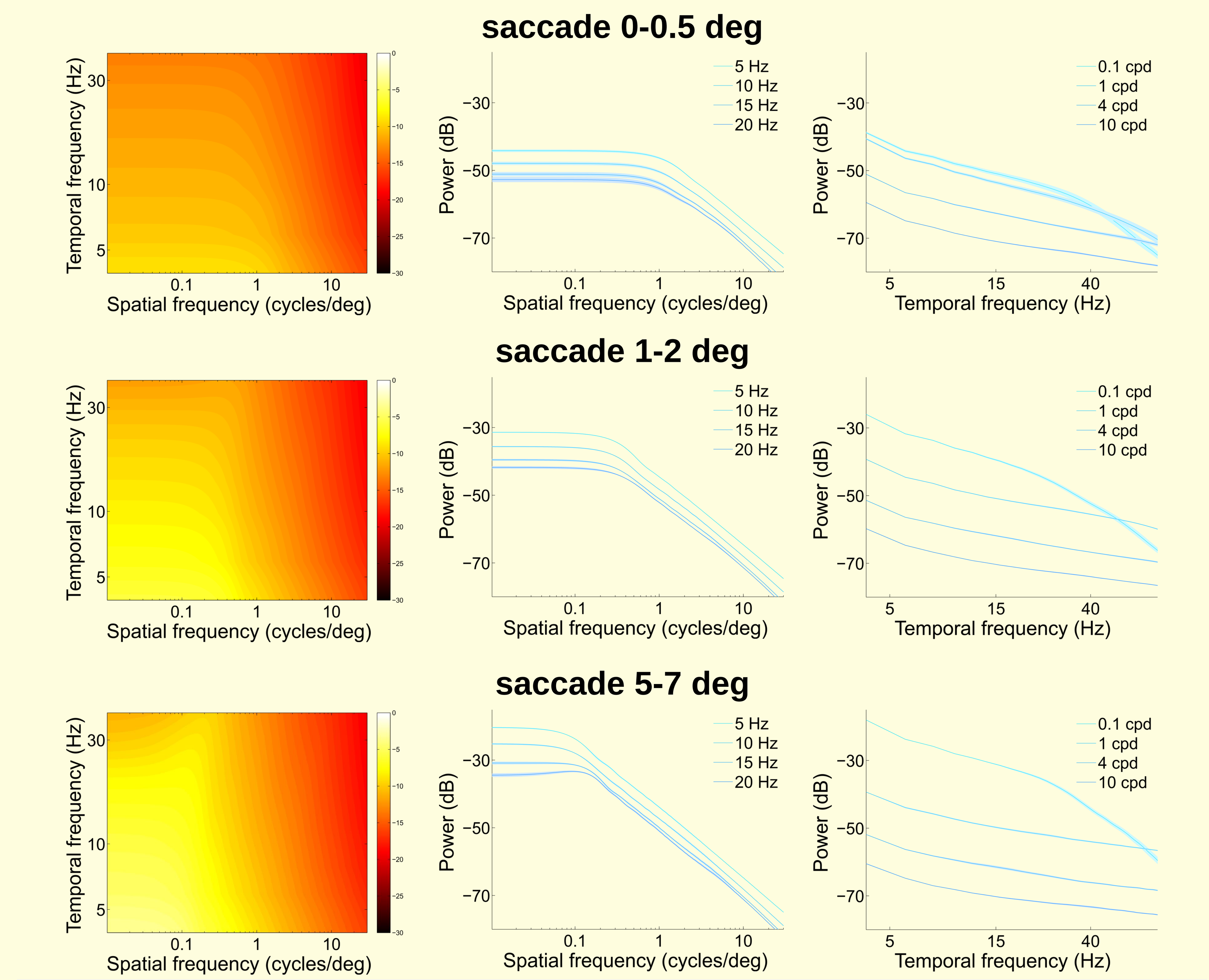



(A) Spatiotemporal frequency content of the retinal stimulus during intersaccadic fixation. (B and C) Sections at several temporal and spatial frequencies. Shaded areas represent one SE (14 observers).

**In this study,** we focus on the temporal modulations resulting from saccades, which strongly affect neural responses at fixation onset.

## Spectral consequences of saccades

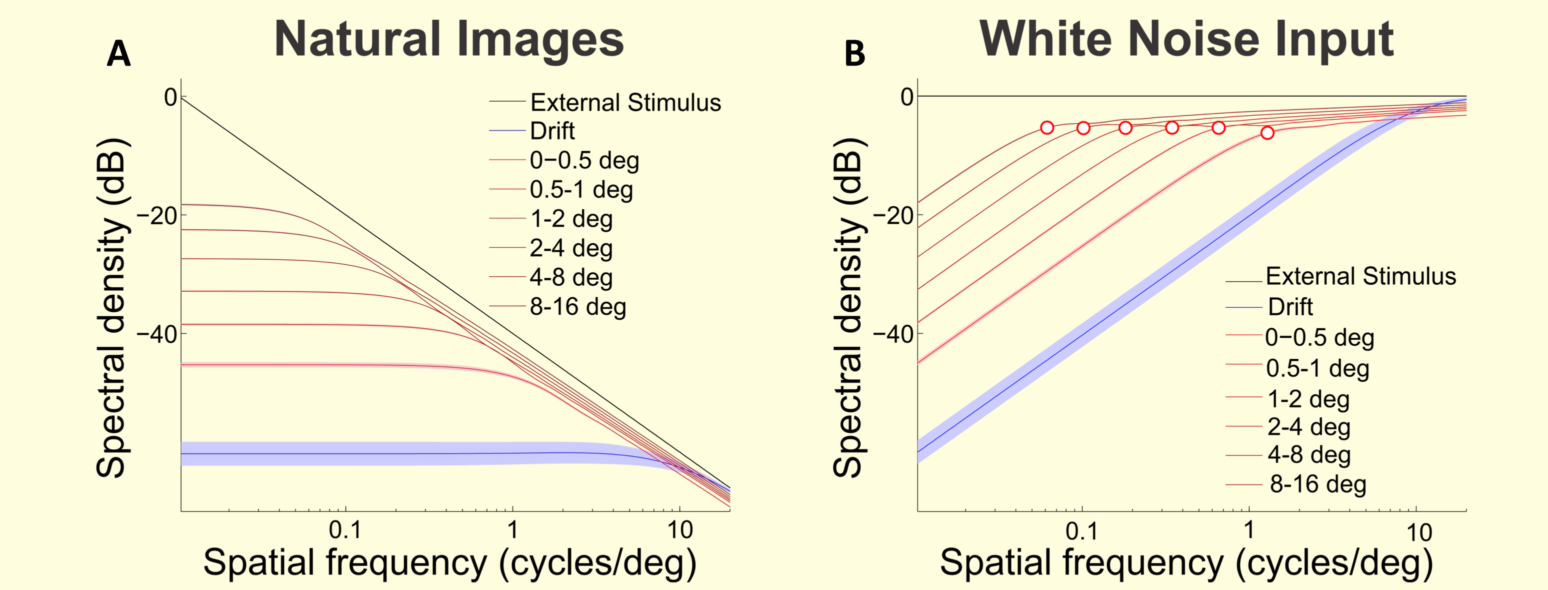
To determine the average spectral characteristics of the visual input that neurons experience immediately after saccades, we recorded the eye movements of 14 observers during free-viewing of natural images. For each saccade, we reconstructed a movie of the spatio-temporal stimulus on the retina (the visual input resulting from scanning the image following the eye trace) and quantified the characteristics of this input signal via spectral analysis.




Each row shows the spectrum of the retinal stimulus with saccades in different amplitude ranges. Spatial and temporal sections are shown in the center and right columns, respectively. Shaded areas represent one SE (14 observers).

## Two distinct regimes

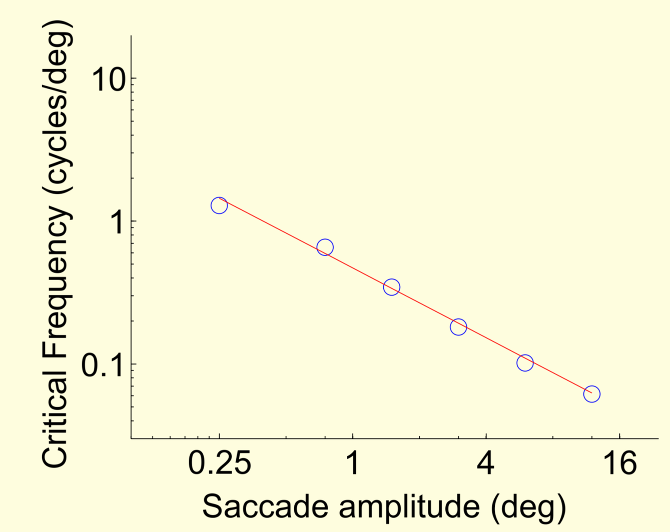
Below a critical spatial frequency, saccades whiten natural visual stimuli. That is, like ocular drift, the amount of temporal power resulting from saccades increases with the spatial frequency of the stimulus. Above this critical frequency, saccades equally transform all spatial frequencies.




Comparison of the effect of saccades with different amplitudes during viewing of natural scenes (A) and white noise (B). The power spectrum obtained during ocular drift is also shown. The curves show the sum of the temporal power above 3.9 Hz, resulting from eye movements.

Saccades also contribute less temporal power than drift at high spatial frequencies. That is transient neurons sensitive to spatial frequencies above 10 cpd are more likely to be better activated by ocular drift than by saccades.

The whitening critical frequency decreases with increasing saccade amplitude.




Critical frequencies as a function of saccade amplitude.

## Conclusion

- The frequency content of the spatiotemporal stimulus on the retina varies during the course of fixation. Saccades and ocular drift yield very different temporal modulations.
- For any given saccade amplitude, there is a critical spatial frequency below which the saccade spatially whitens natural images. Above this critical frequency all spatial frequencies contribute approximately equally to temporal modulations.
- Ocular drift is more effective than saccades in generating temporal power at high spatial frequencies.
- These results suggest that eye movements contribute to selecting useful information not only in space, by relocating the fovea, but also in time, by bringing different spatial frequency ranges close to the peak temporal sensitivity of retinal neurons.

## References

[1] M. Rucci, R. Iovin, M. Poletti, and F. Santini (2007), Miniature Eye Movements Enhance Fine Spatial Detail, *Nature*. 447(7146), 851-854.

[2] X. Kuang, M. Poletti, J.D. Victor and M. Rucci (2012), Temporal encoding of spatial information during active visual fixation, *Current Biology*, 22(6), 510-514.

## Acknowledgments

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