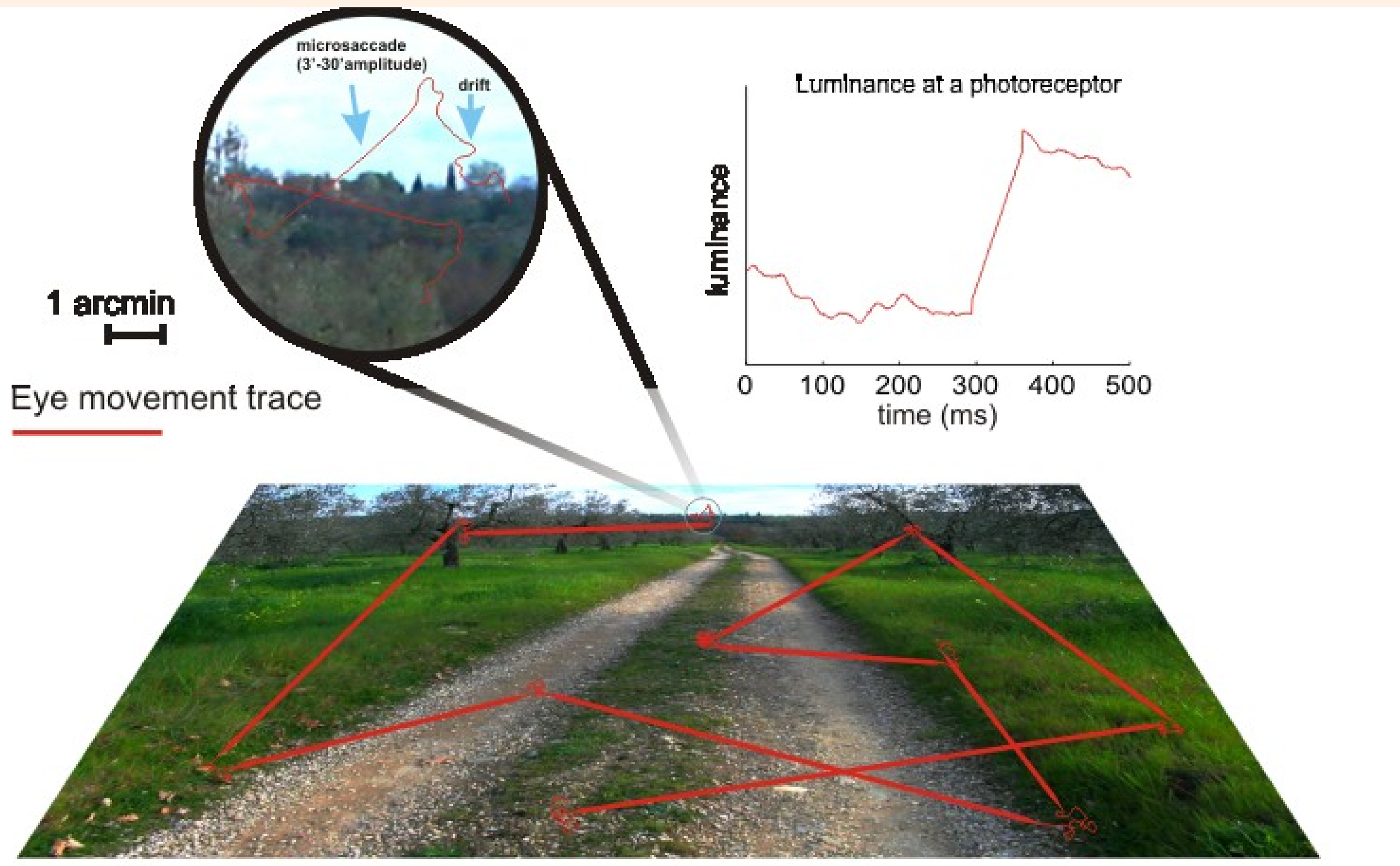
Frequency content of the retinal stimulus during active fixation

Jonathan Lansey[1], Martina Poletti[2] and Michele Rucci[2-4]

1Department of Cognitive and Neural Systems, Boston University, 2-4 Department of Psychology, Department of Biomedical Engineering, Program in Neuroscience, Boston University

-Introduction

A presumption of several theories of early visual processing is that the actual stimulus on the retina is a static visual scene. However, the signals entering the eyes depend not only on the external scene, but also on the observer's behavior.



Small involuntary eye movements keep the retinal image continually in motion, even during visual fixation. In this study, we examined the frequency content of the retinal stimulus during the normal instability of visual fixation.

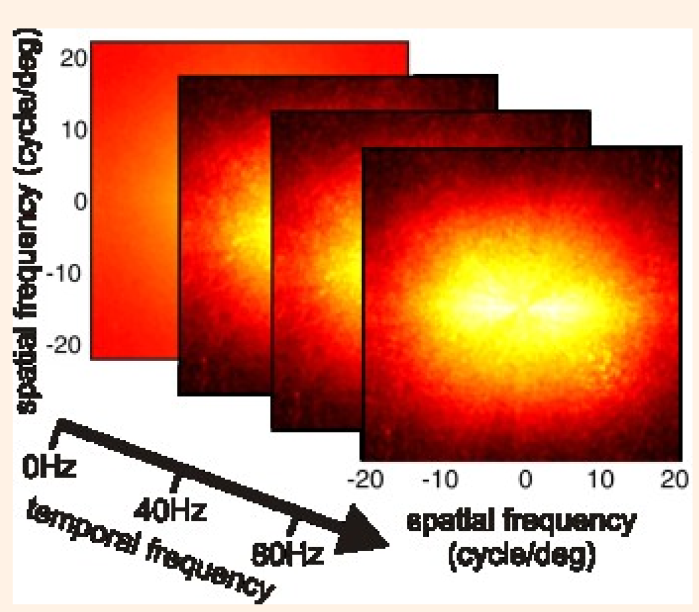
-Methods and Procedures

To examine the impact of fixational eye movements on the statistics of the visual input, we recorded the eye movements of humans (N=13) during free viewing of grayscale pictures of natural scenes.

The visual input $I(\mathbf{x},t)$ reaching the retina of the observer at different times.

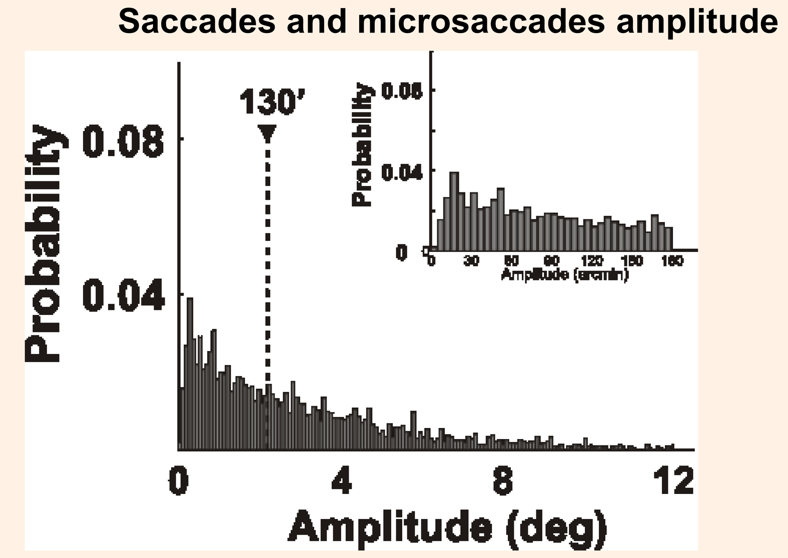
We reconstructed the spatiotemporal stimulus on the retina for each fixation.

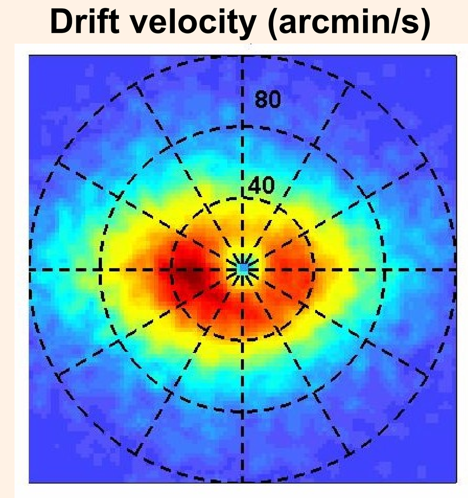
The power spectrum of such stimulus was then estimated by means of Welch's method.

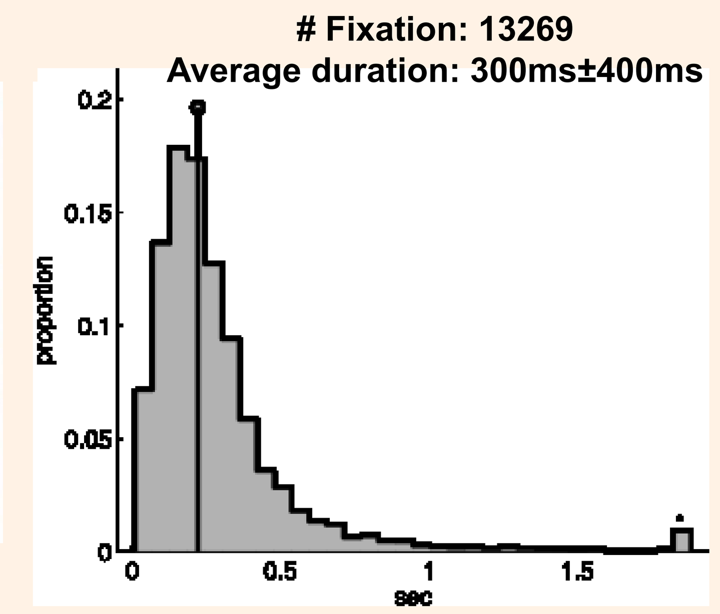


The power spectrum $P_I(\mathbf{u},\omega)$ of this retinal input at different temporal frequencies.

-Results

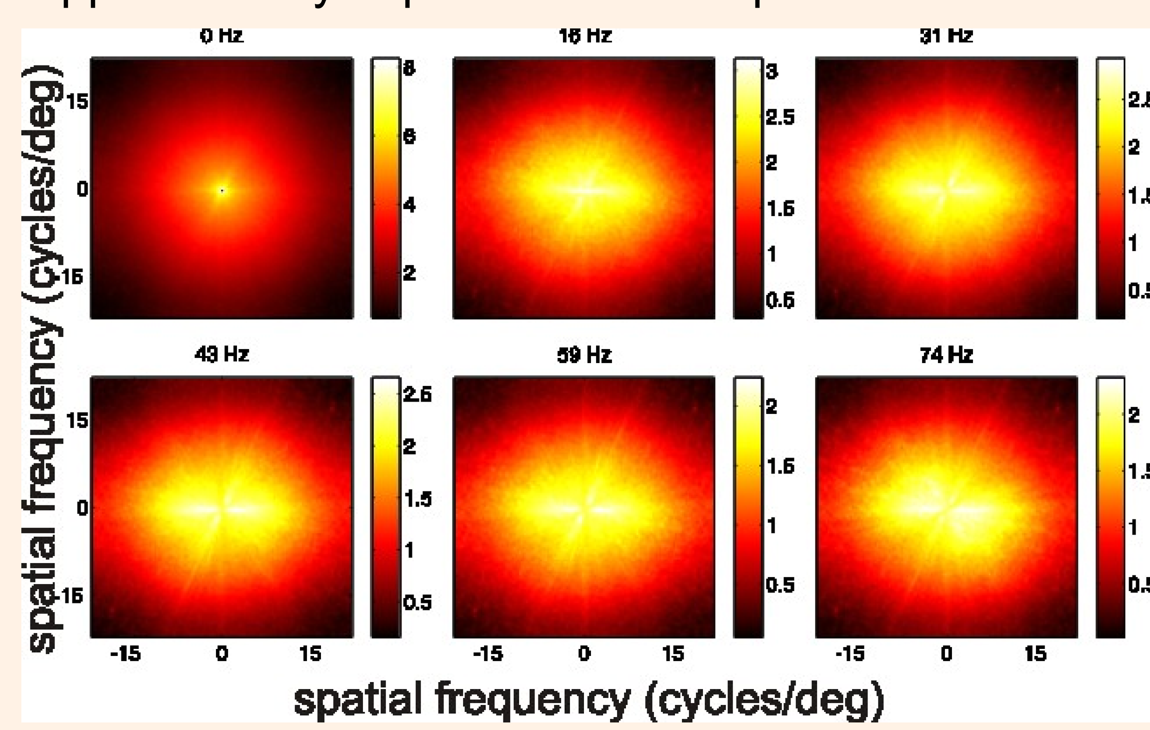


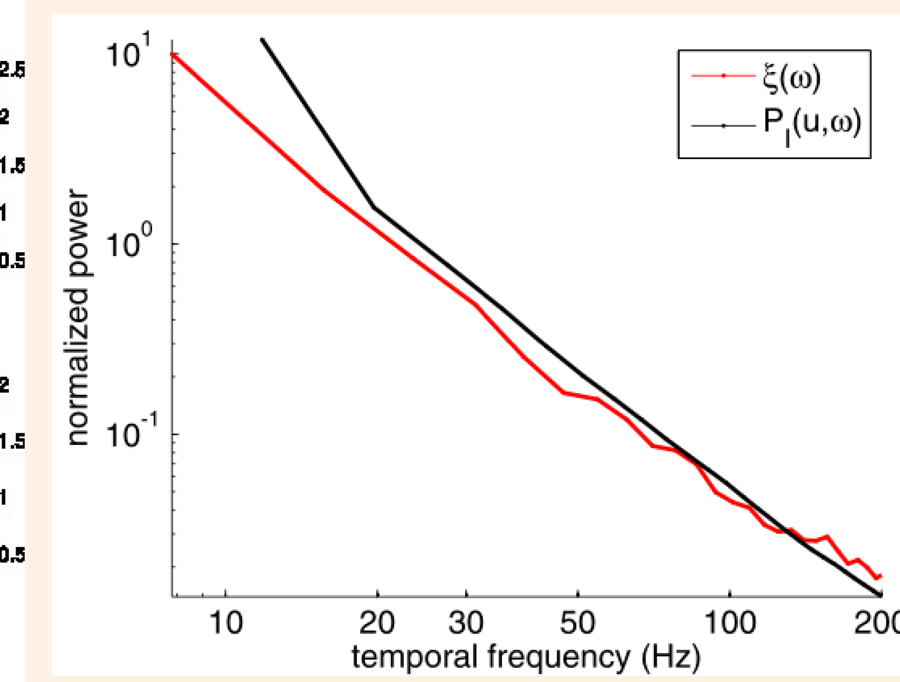




Frequency content of the retinal input

Outside of the zero temporal frequency plane, the resulting distribution of spectral density was approximately separable into the product of distinct temporal and spatial components:

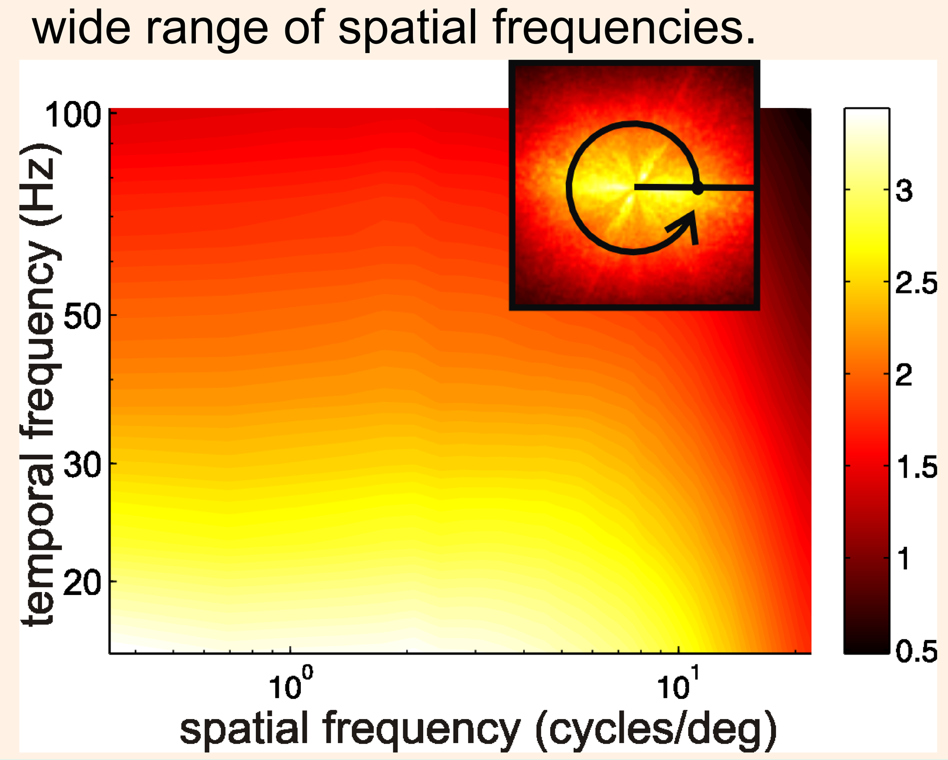




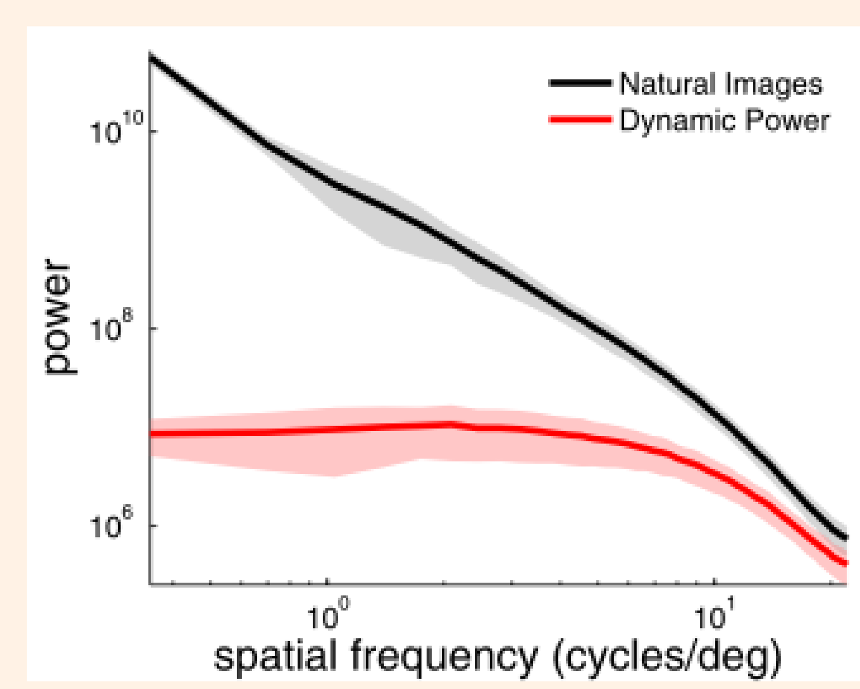
- The spatial distribution of power was similarly organized on every nonzero temporal frequency plane
- The total amount of power at any given temporal frequency was proportional to the power spectrum of eye movements.

Temporal modulations caused by fixational eye movements equalize the distribution of spatial power

At every nonzero temporal frequency the amount of power present at different spatial frequency was approximately constant. That is, the retinal stimulus is decorrelated across a wide range of spatial frequencies.

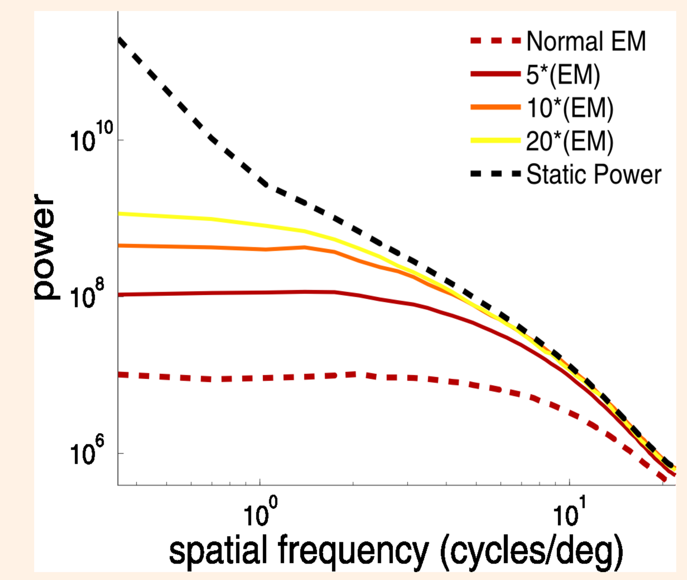


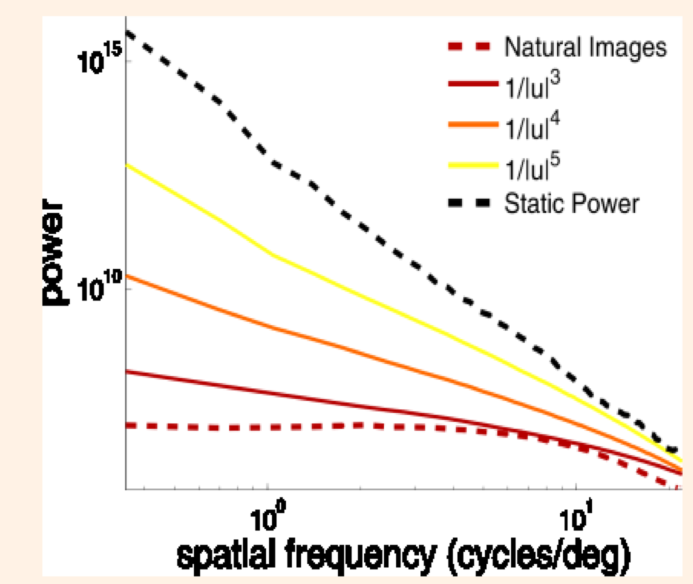
The power was averaged radially across spatial frequency as shown in the inset.



Comparison between the spectral distribution of spatial power in natural images and in the input fluctuations resulting from fixational instability.

This equalization of spatial power only occurred during viewing of images with scale-invariant power spectrum, such as natural images and was lost when the trajectories of eye movements were artificially enlarged.





-Theoretical explanation

$$P_I(\mathbf{u},\omega) \approx |\mathbf{u}|^2 P_L(\mathbf{u}) P_\xi(\omega), \quad \omega \neq 0, \quad \xi << 1$$

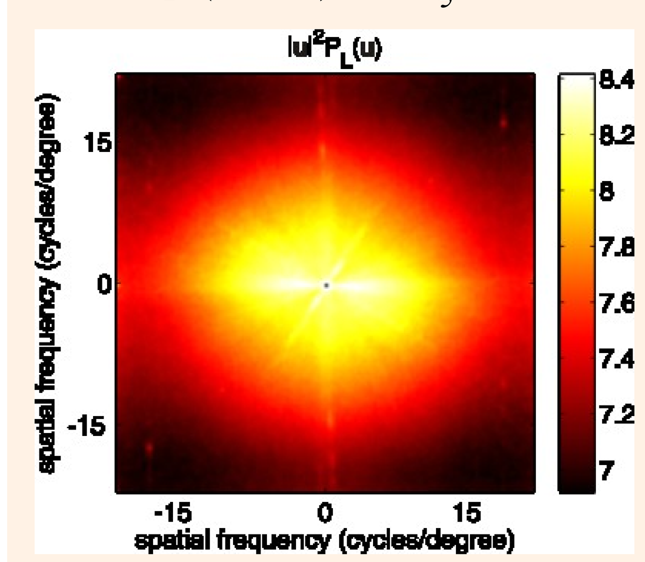
With the $1/\mathbf{u}^2$ spectrum of natural images, we obtain:

$$P_I(\mathbf{u},\omega) \approx P_\xi(\omega)$$

$P_L(\mathbf{u})$ = power spectrum of the image

$P_\xi(\omega)$ = power spectrum of eye movements

$P_L(\mathbf{u},\omega)$ = the power spectrum of the retinal input.



This approximation replicates the spatial distribution of power at nonzero temporal frequencies.

-Conclusions

- Fixational eye movements alter the visual input by introducing spatially uncorrelated temporal fluctuations in the input to the retina.

- Equalization of spatial power implies that neurons sensitive to different frequency bands will, on average, be equally stimulated during viewing of natural images.

- Spatial decorrelation and spectral whitening, are often held as a fundamental principle to explain the shape of neuronal receptive fields in the early stages of the visual system. These theories should look at the real input on the retina during eye movements. The effective input signal in driving transient neurons is **already** spatially whitened during the normal instability of visual fixation.

Acknowledgments

Supported by NIH R01 EY18363, NSF BCS-0719849, and NSF IOS-0843304