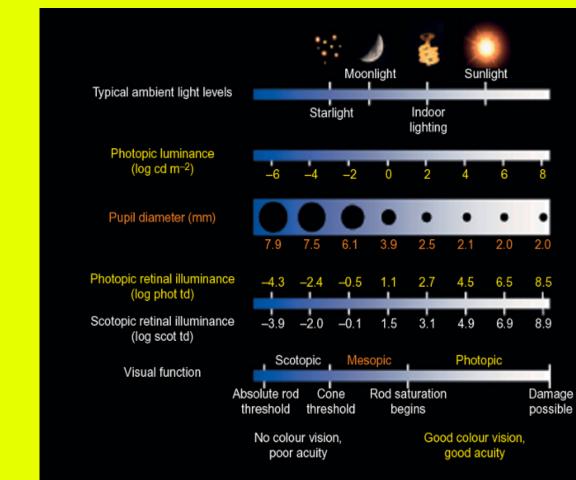
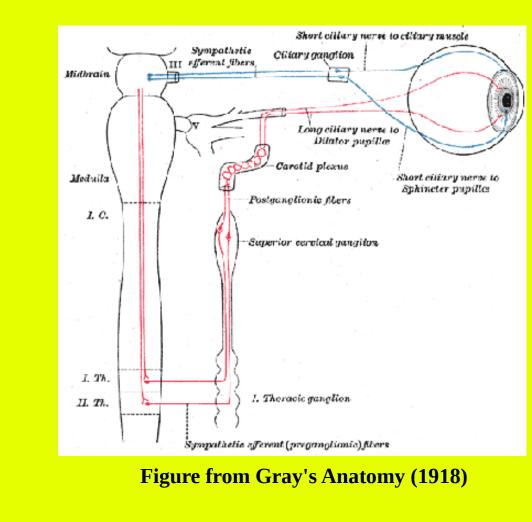
## BACKGROUND

## The pupil system

The pupil: more than just light adaptation



Dilation: sympathetic nervous system (fight or flight)



Constriction: parasympathetic nervous system (rest and digest)

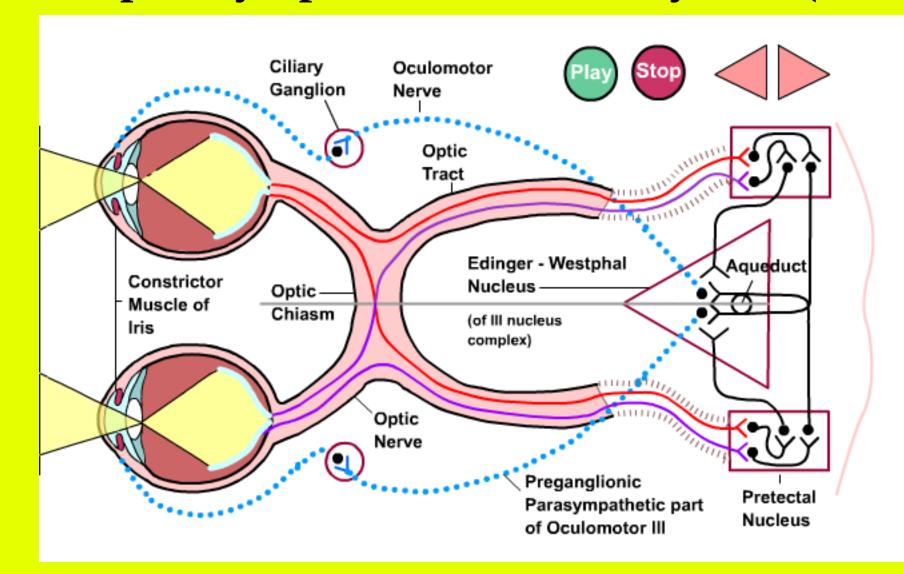
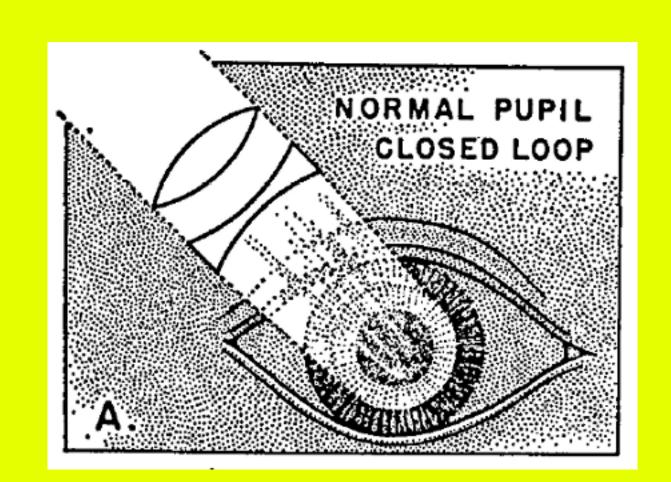
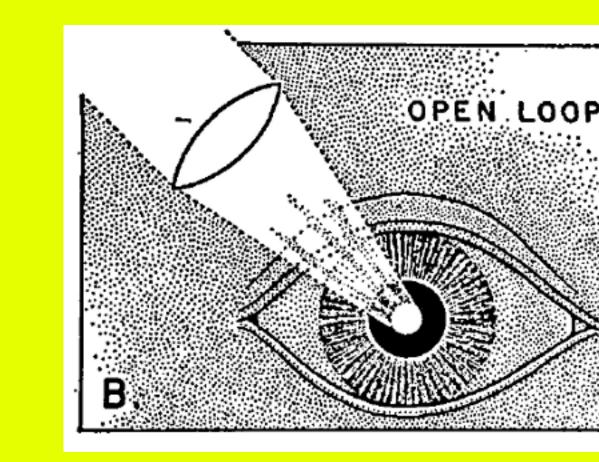
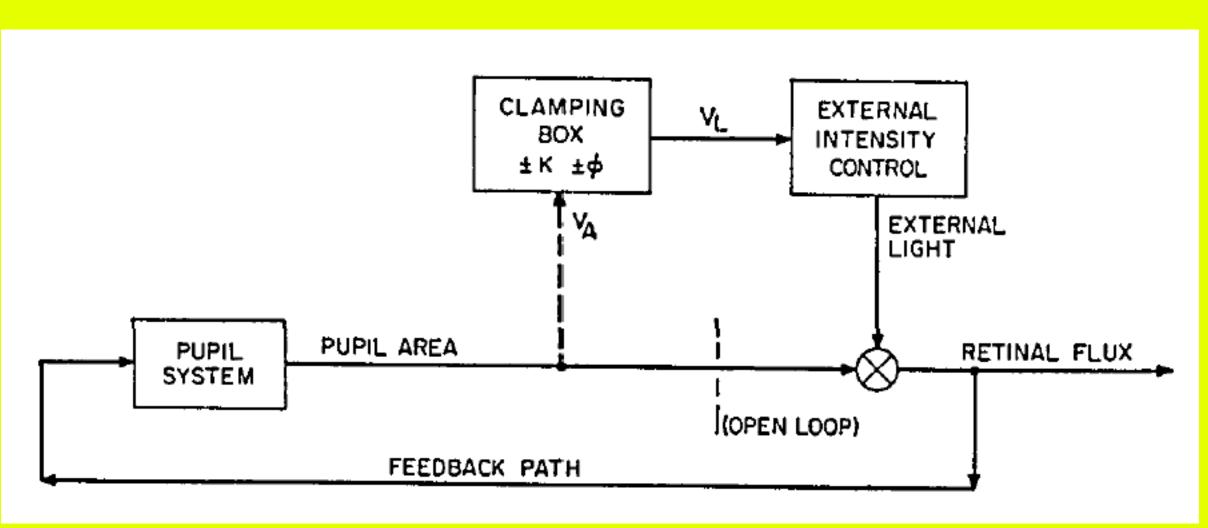


Figure captured from animated online demo at tedmontogomery.com

## Stark's experiment (1962)

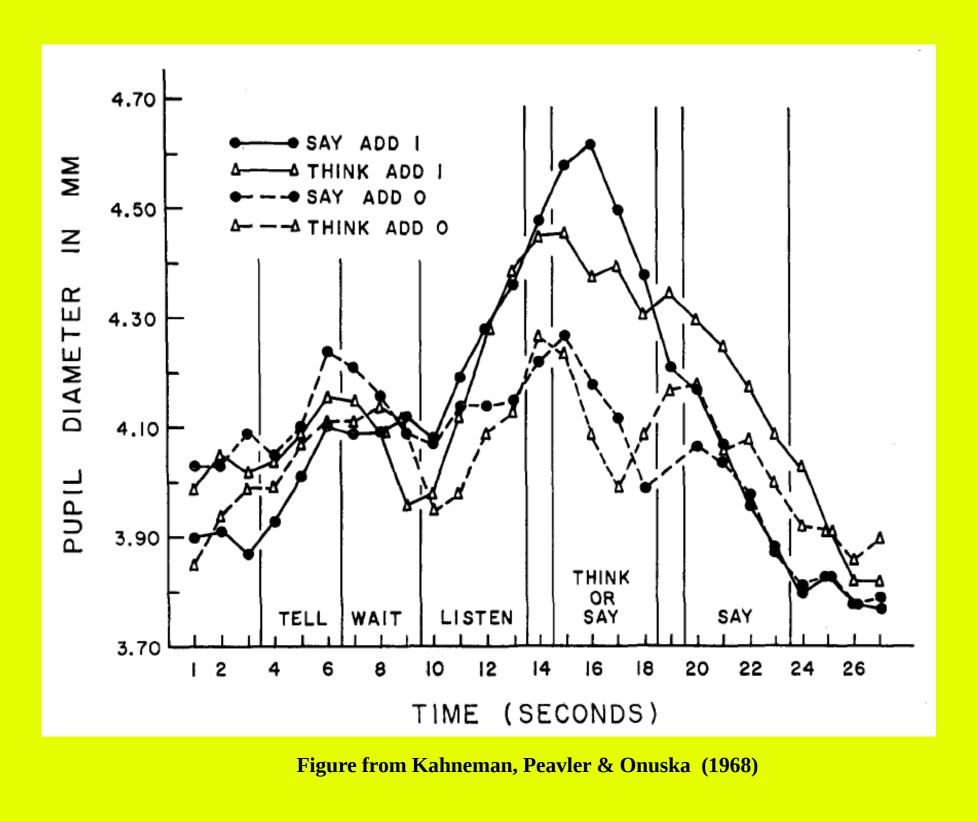






Figures from Stark (1962)

## The pupil and cognition

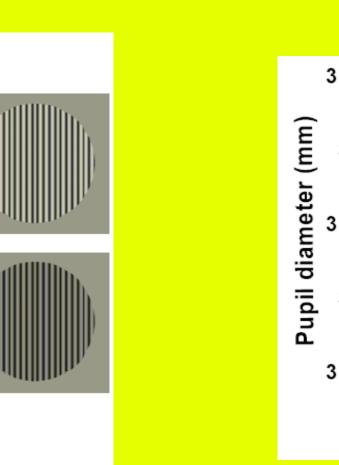


## Pupil pattern responses

**Pupil grating response** 

0 1 2 3 4 5

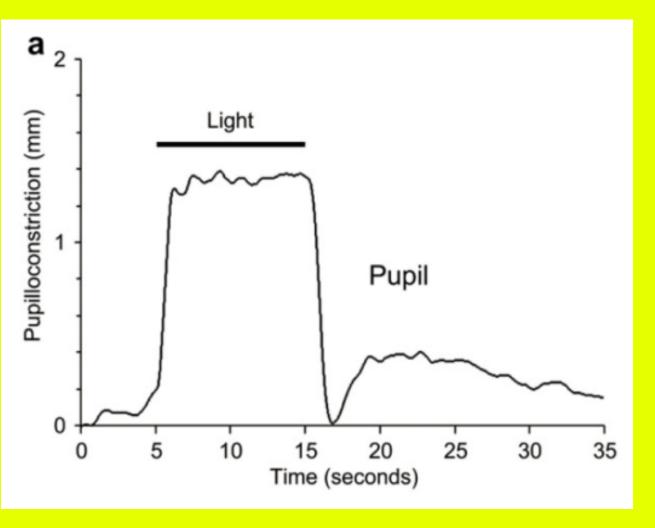


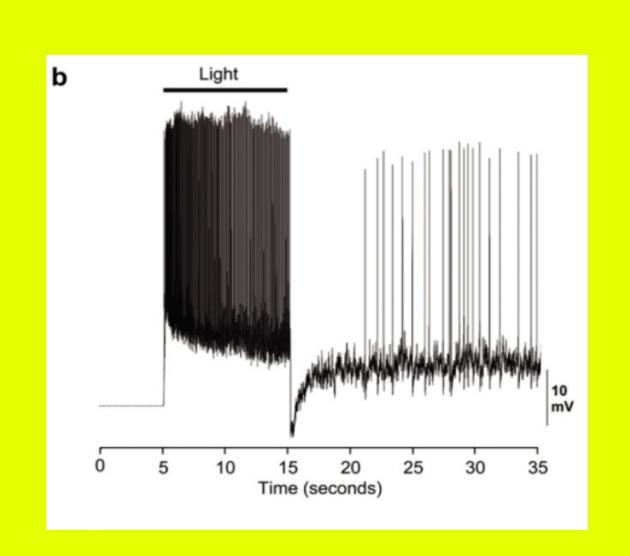


0 1 2 3 4 5

## Melanopsin and ipRGC's

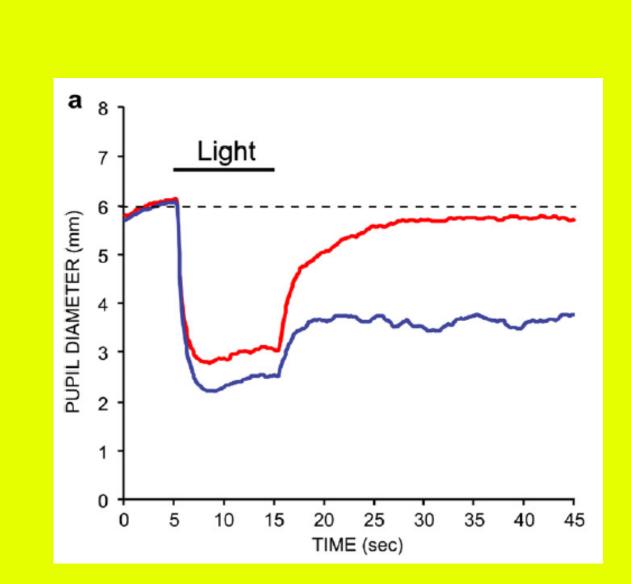
Sustained pupil response in macaque mimics activity of ipRGC's

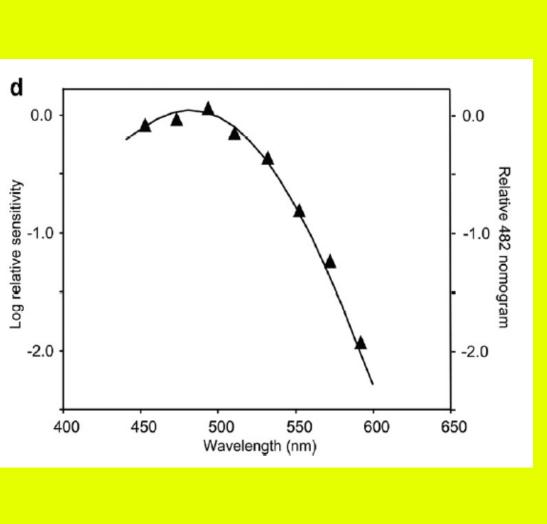




Figures from Gamlin et al. (2007)

Melanopsin action spectrum from sustained pupil response in human





Figures from Gamlin et al. (2007)

How can we use pupil measurements to assess

What are the effects of complex visual signals on

**Technical Challenges** 

State-related pupil changes are small, and may be swamped by other effects

as well as random fluctuations. Challenges exist both in the measurement

and interpretation of the signals. As can be seen in the upper right figure in

the panel to the leftt, the transient pupil dilation resulting from mental effort

**Technical approach** 

In this work we seek to increase our understanding of the pupillary system

using system identification methods first applied in this context by Stark in

1962. Stark studied the pupil by creating a situation in which the pupil system

ran "open loop," by focussing a beam of light down to a small spot at the pupil,

so that changes in pupil size did not influence the amount of light falling on the

retina (see lower left figures on panel to the left). We accomplished a similar

effect by using a real-time video pupillometer to control the intensity of a video

Typical video image used for pupillometry: The camera is a SONY EVI-D70

maximum optical zoom and fitted with an infrared filter and a +1 diopter close-

pan-tilt-zoom camera, located at about arm's length from the subject, set to

up lens. The illumination is provided by two groups of near-infrared LED's

(seen as the two highlights reflected in the cornea).

has a peak amplitude of approximately half a millimeter.

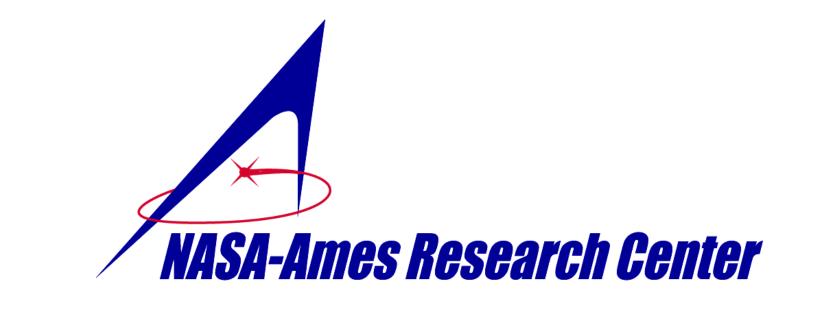
operator state (fatigue, alertness)?

**BIG QUESTIONS:** 

the pupil?

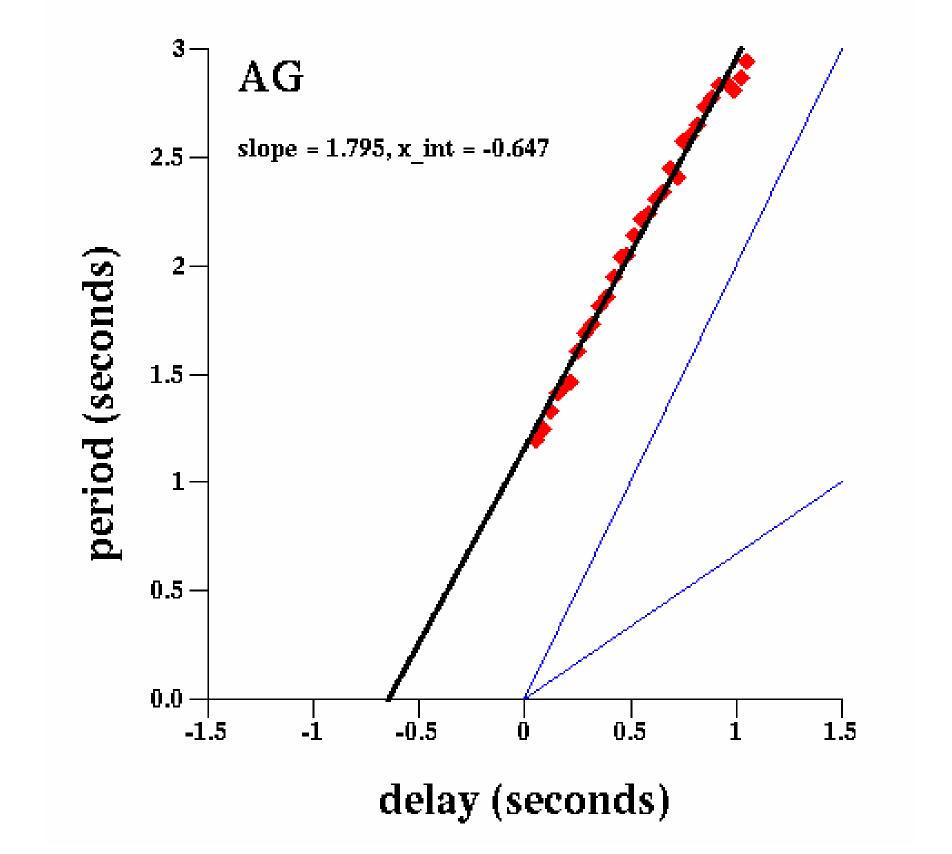
# Assessing visual delays using pupil oscillations

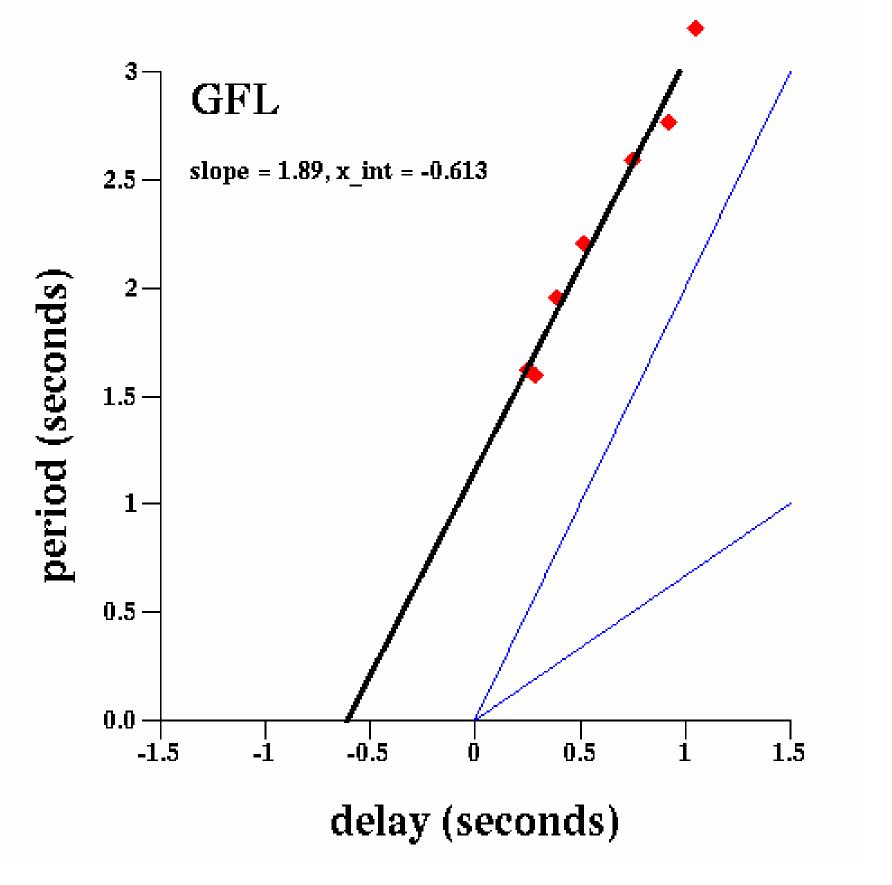
## Jeffrey B. Mulligan, NASA Ames Research Center





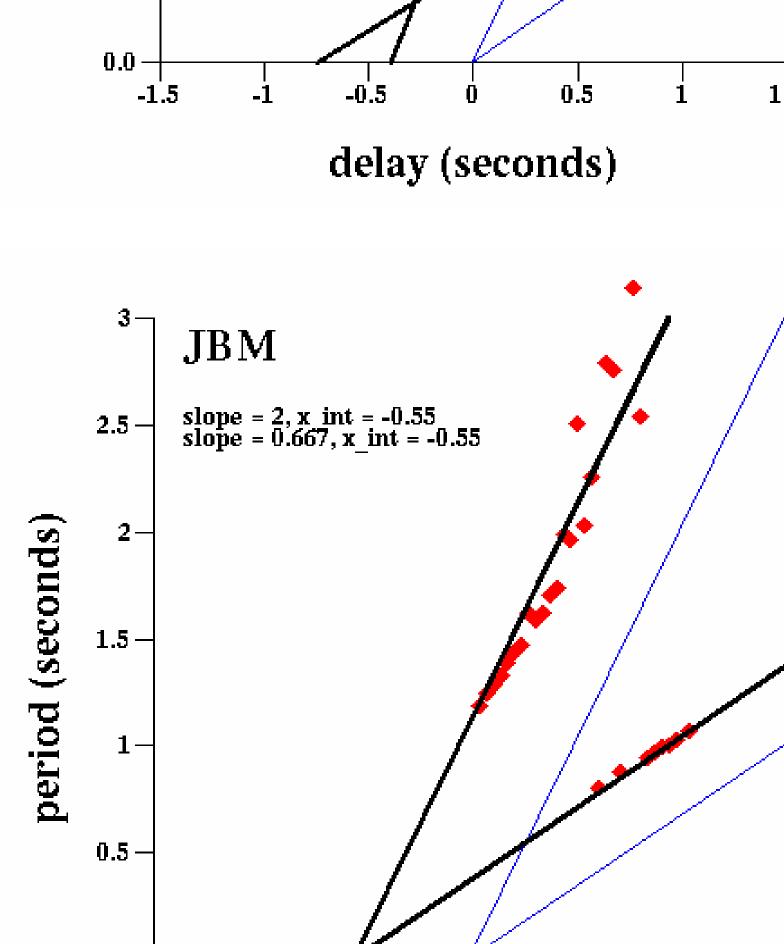
## Results: Oscillations produced by delayed feedback



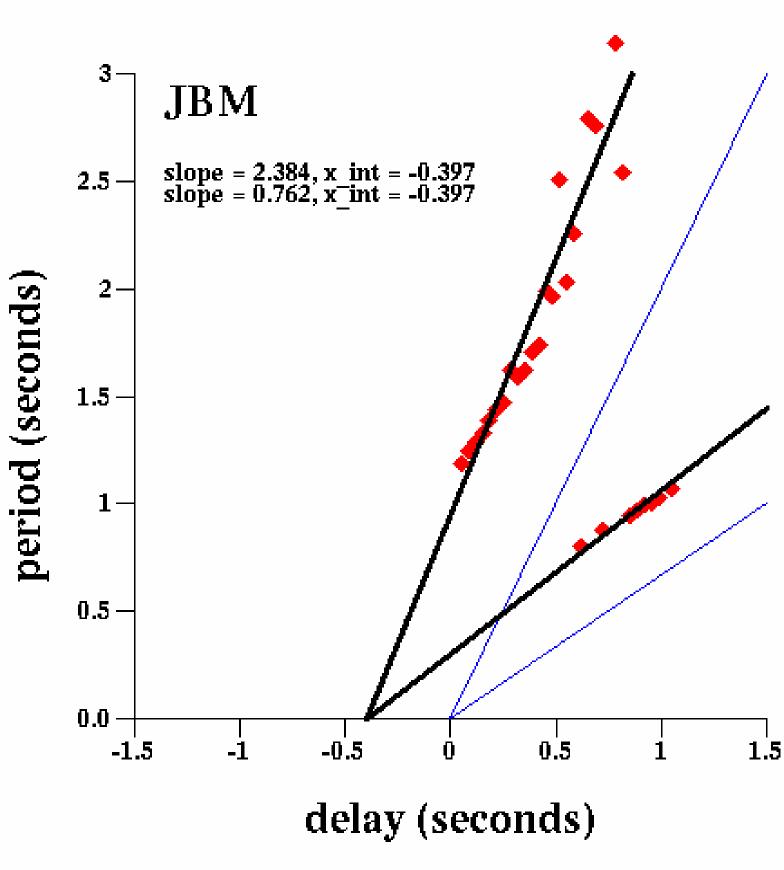


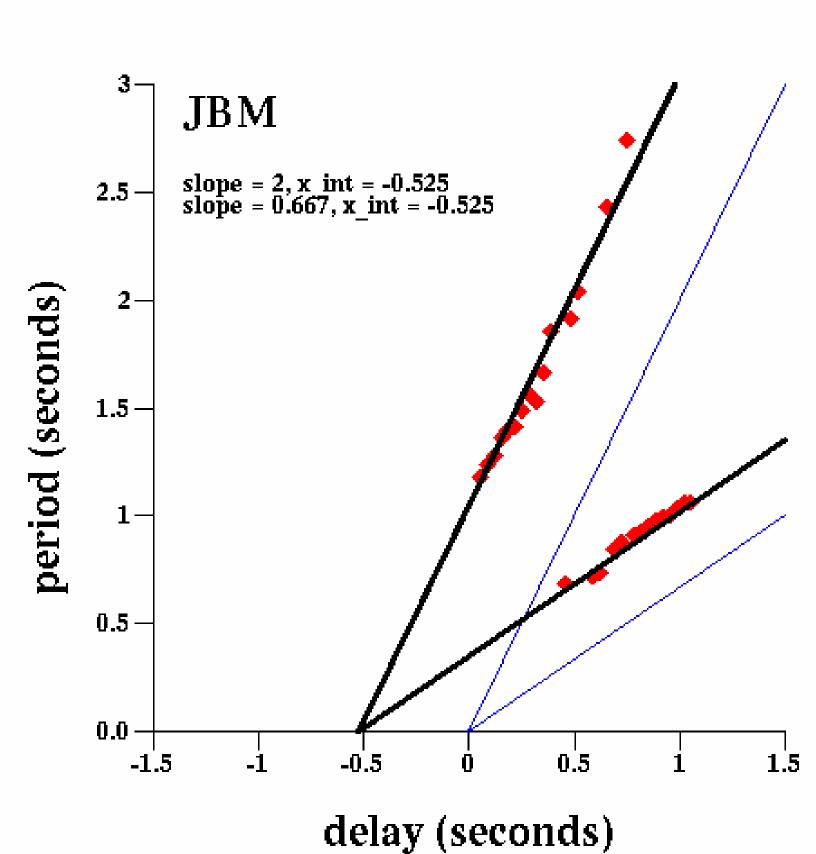
Pupil oscillations were induced by stimulating the eye with a light intensity proportional to pupil area, with a variable delay. A simple control law predicts period-vs-delay slopes of 2, as seen in data from two subjects (above). Subject JBM (below) show two branches; the lower branch (predicted slope=2/3) occurs at longer delays when an unstable pupil becomes entrained with an extra cycle of phase delay. The upper left panel shows a 4 DOF fit in which the two branches are fit independently, while in the upper right panel the fits were constrained to share a common xintercept. The lower two panels show 1 DOF fits in which the slopes were constrained to the theoretical predictions, and only the x-intercept was free to vary. The two lower panels show two replications, with a 5% discrepancy in their estimates of the internal delay.

# 2.5 = slope = 2.39, x int = -0.395 slope = 0.6, x\_int = -0.744 delay (seconds)

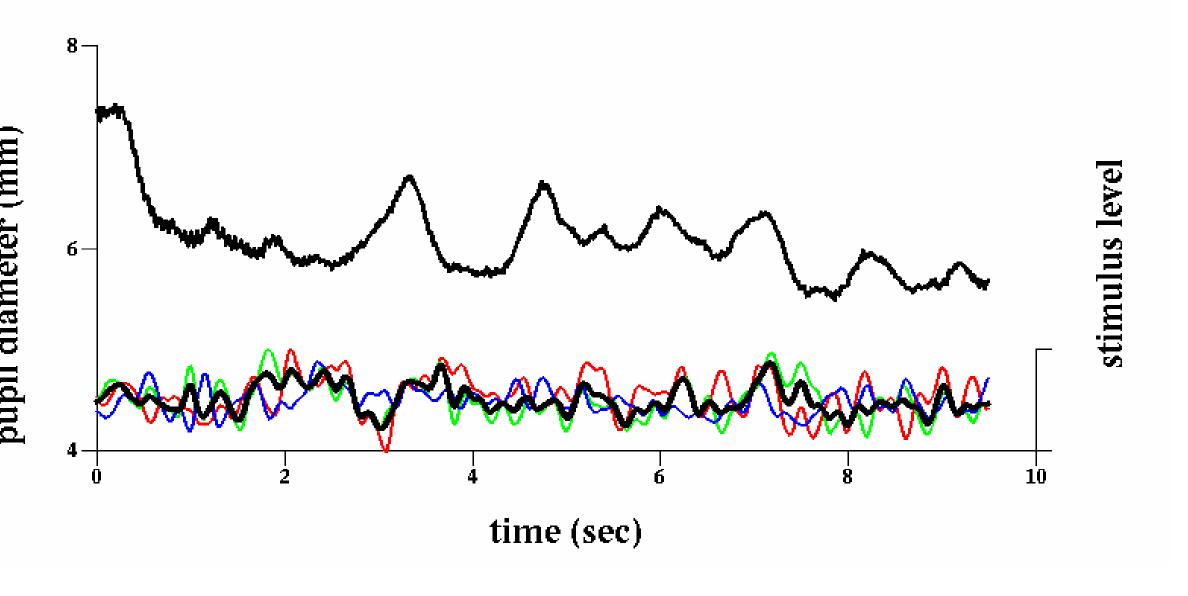


delay (seconds)

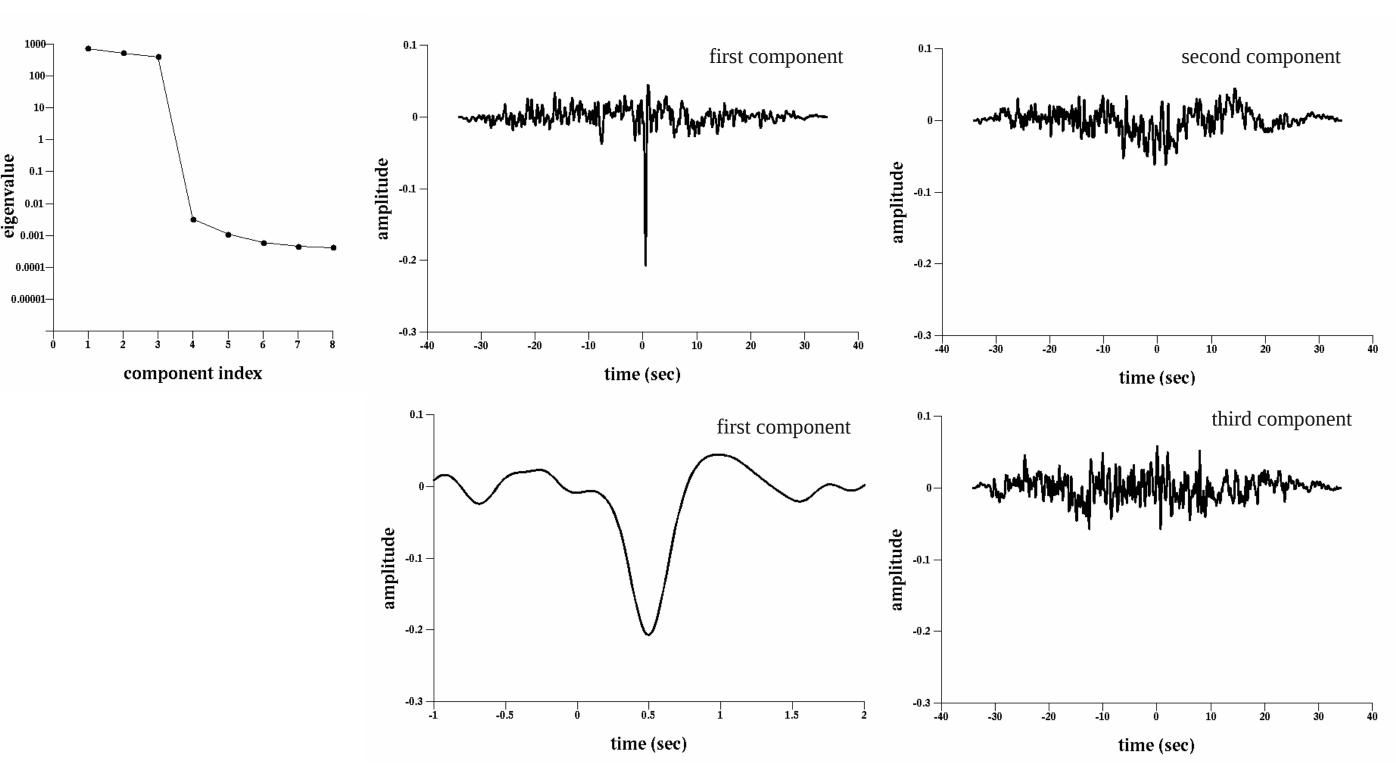




## More results: white noise analysis



In addition to replicating Stark's results using open-loop stimulation and delayed feedback, we are extending the use of white-noise analysis to the case of full-color stimuli, in the hope of identifying a component due to ipRGC's with a different spectral and temporal signature. The figure above shows the pupil response (upper black trace) to independent random signals applied to the red, blue and green components of a video screen (luminance shown in black). This is a pilot experiment intended to demonstrate proof-of-concept; in order to produce a stimulus capable of independently stimulating the three cone photoreceptors, rods and ipRGC's, a stimulator with at least 5 primaries will be required, perhaps by combining two video displays with different primaries using a beam-splitter.



The data were analyzed by cross-correlating the response with the projection of the stimulus in a variety of color directions. Principle Components Analysis (PCA) was then applied to the tableau of resulting kernels. Because the inherent dimensionality of the stimulus space is 3, only the first 3 components have eigenvalues that are larger than the noise floor. These are shown above; the phosphor loadings on the first component correspond to the luminance direction, while the second two components appear to soak up the rest of the noise without displaying any clear causality. The latency of the peak of the first component is in good agreement with the estimate obtained from the period-vs-delay functions.

Disappointingly, we failed to observe pupil oscillations when using delayed feedback to control grating contrast (rather than luminance), although the efforts to date fall somewhat short of heroic. Similarly, to date the extended white noise analysis has not revealed mechanisms beyond the basic luminance input to the pupil system. Given the extremely long

Barbur, JL and Stockman, A (2010) Photopic, Mesopic, and Scotopic Vision and Changes in Visual Performance. In: Dartt, D and Besharse, J and Dana, R, (eds.) *Encyclopedia of the Eye.* (323 - 331). Academic Press: Oxford. Kahneman, D., Peavler, W. S., and Onuska, L. (1968) Effects of verbalization and incentive on the pupil response to mental activity. *Canadian* Journal of Psychology, 22:186-196. Gamlin, P. D. R., McDougal, D. H., Pokorny, J., Smith, V. C., Yau, K., and Dacey, D. (2007) Human and macaque pupil responses driven by

melanopsin-containing retinal ganglion cells. *Vision Research* **47**:946-954. Stark, L. (1962) Environmental Clamping of Biological Systems: Pupil Servomechanism. *Journal of the Optical Society of America*, **52**:925-929.

Supported by the System-wide Safety Assurance Technologies (SSAT) project of NASA's Aviation Safety Program.

## Conclusion

sustained response seen in ipRGC's, this method may not be the most efficient.