July 2020

Can EEG Reveal Temporal Reformatting of Spatial Signals by the Oculomotor System?

Lab Meeting Update

Zhetuo Zhao, Michele A Cox

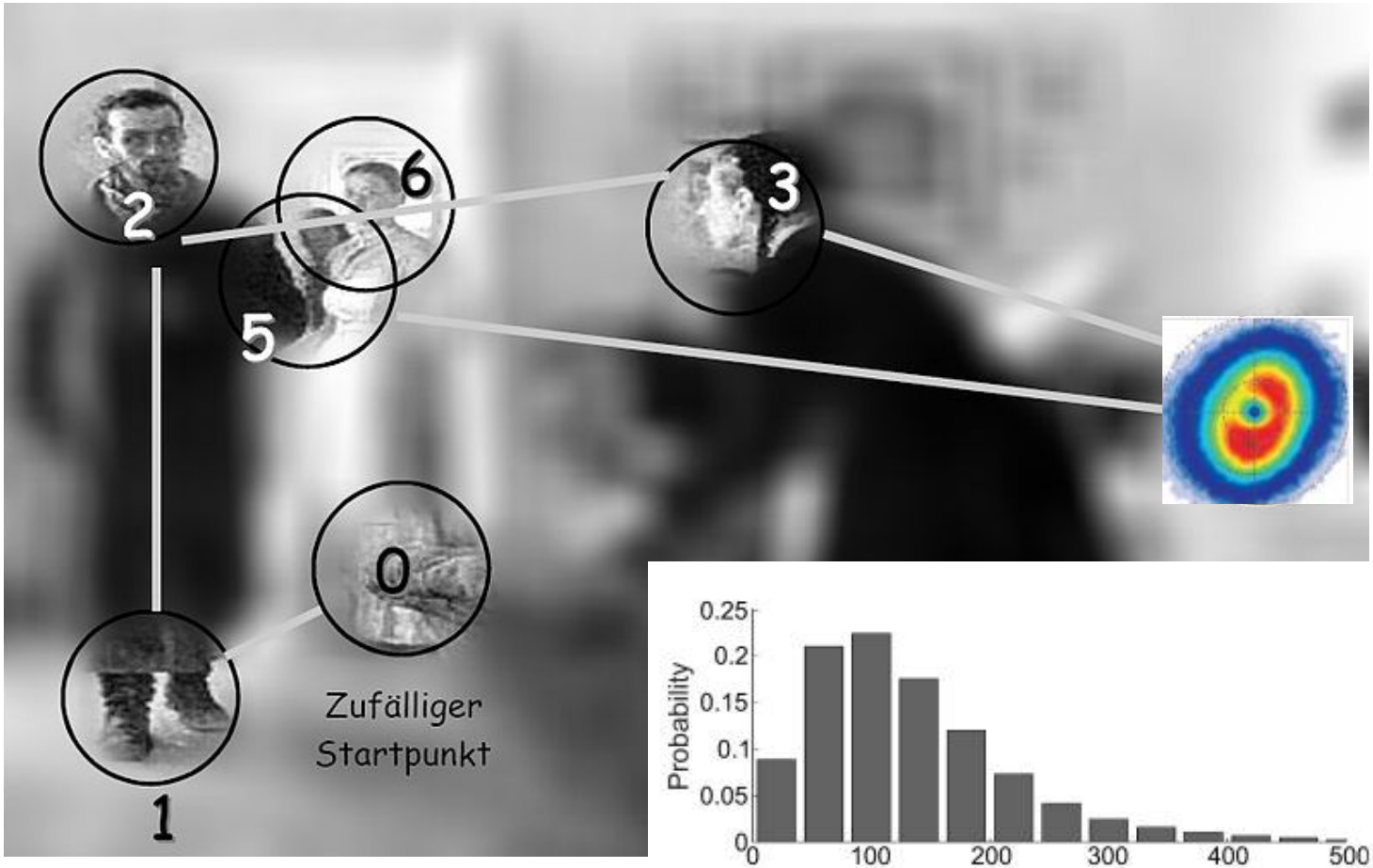
The Eyes are Always in Motion

Saccade-Fixation Cycle

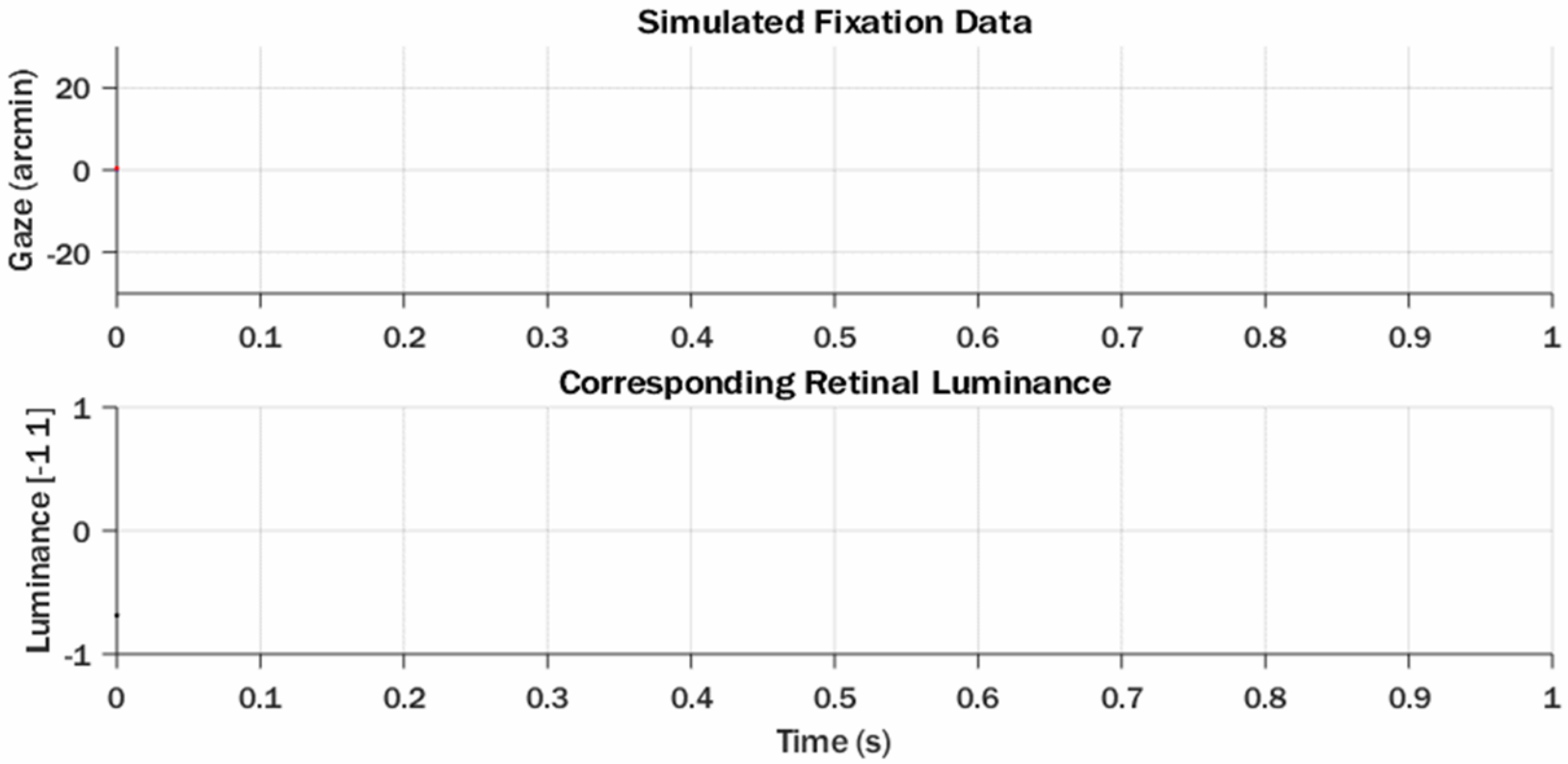
Jon Matthis

The Eyes are Always in Motion

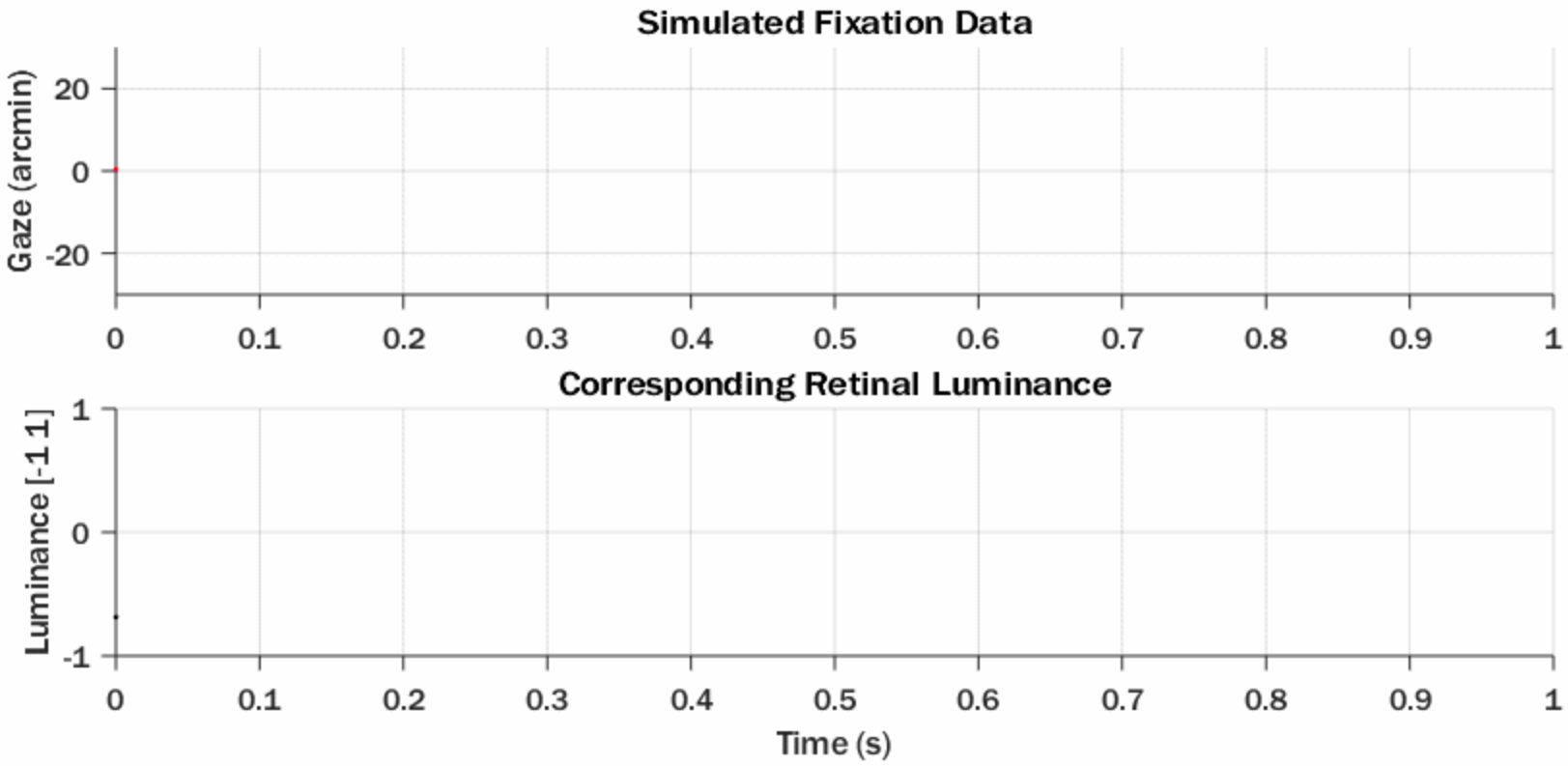
Saccade-Fixation Cycle



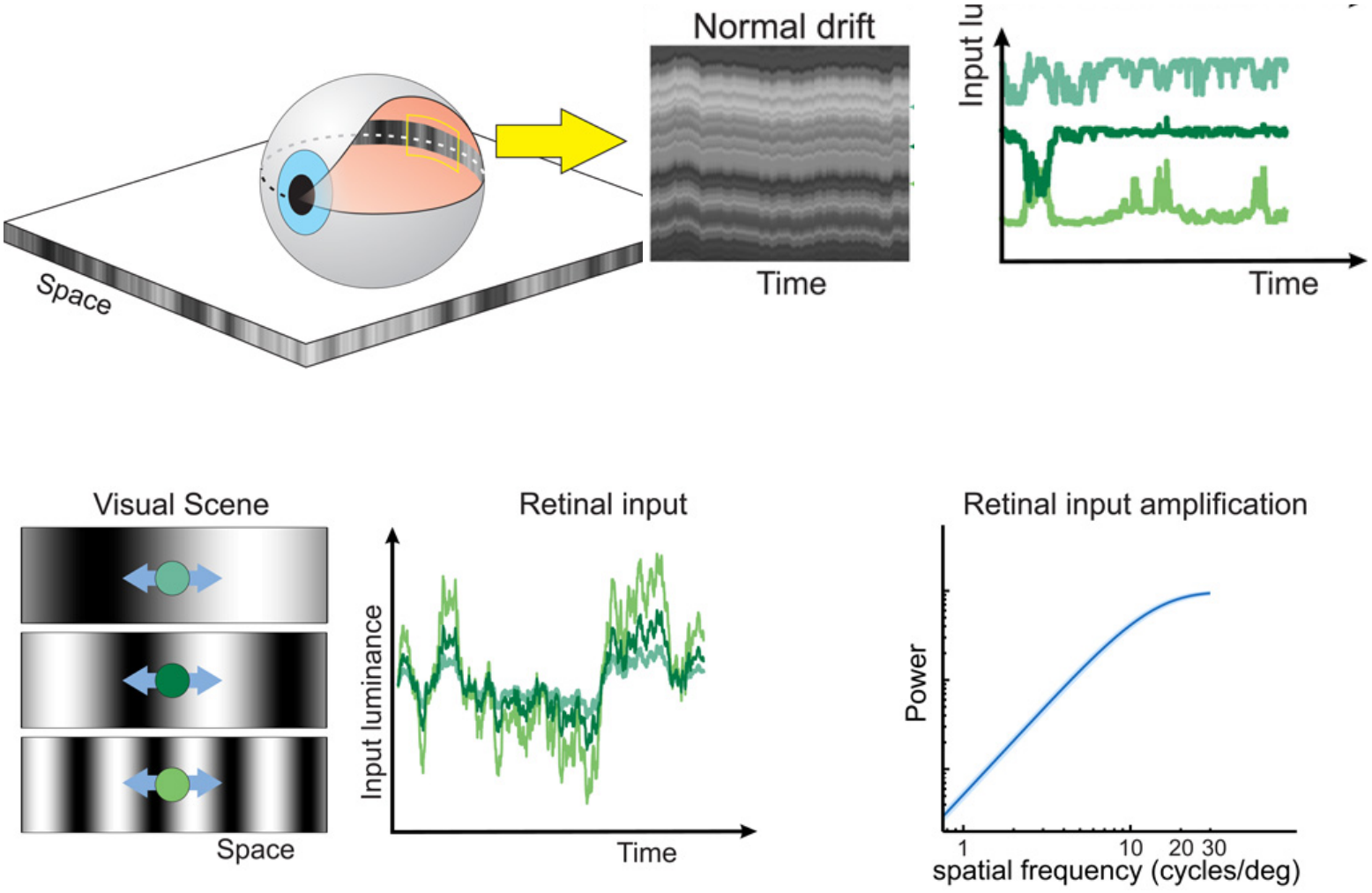
Eye Movements Impact the Retinal Image



Eye Movements Impact the Retinal Image

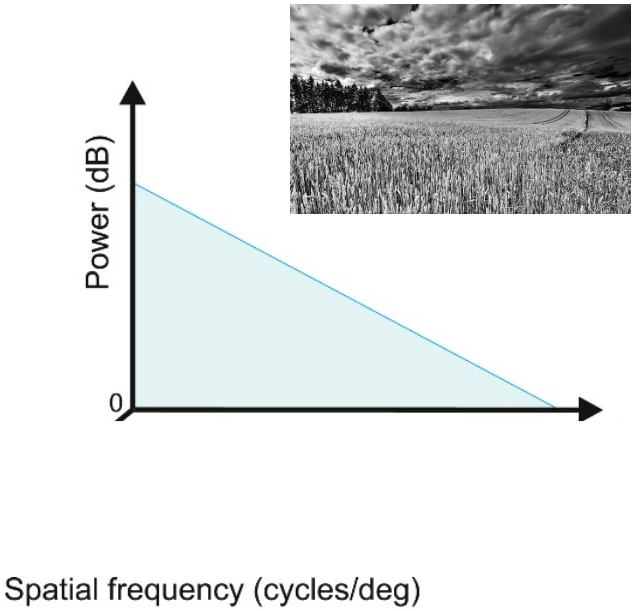


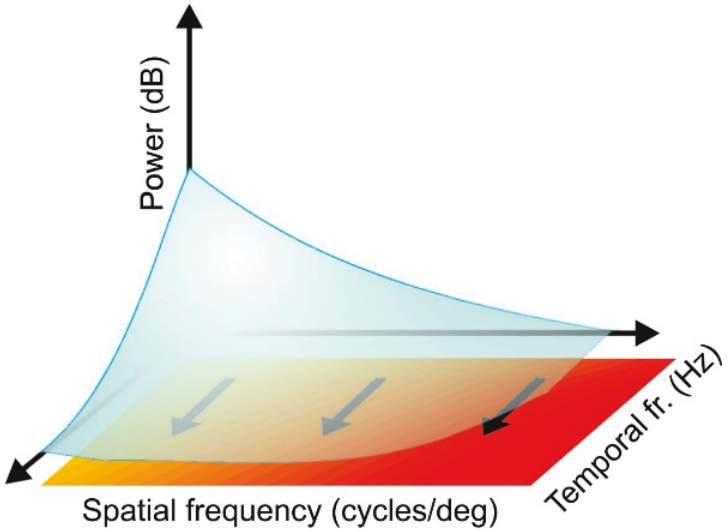
Eye Movements Impact the Retinal Image



Rucci & Victor, Trends Neurosci. 2015

Eye Movements Impact the Retinal Image



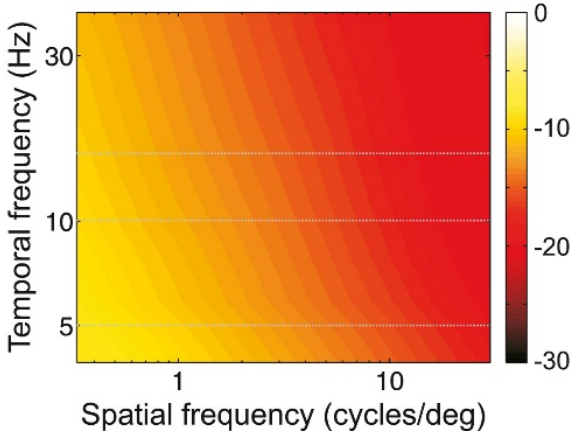


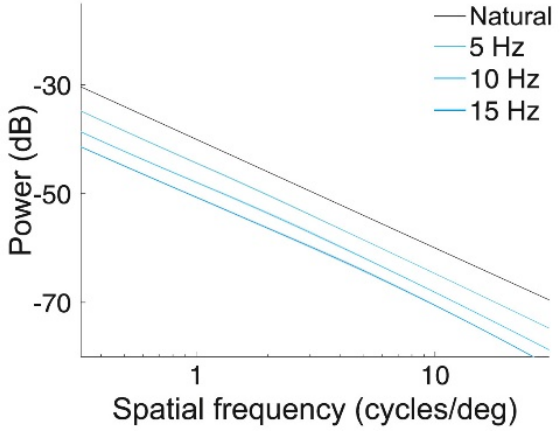
Eye movements transform spatial information in the scene into spatiotemporal modulations on the retina, redistributing the power at 0 Hz of a static scene across non-zero temporal frequencies

Boi et. al, Current Biology, 2017

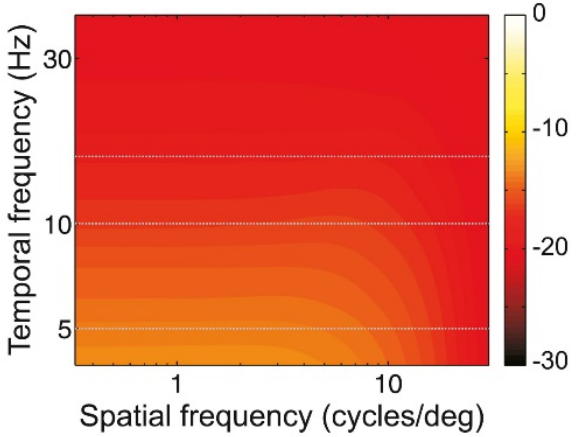
Eye Movements Impact the Retinal Image

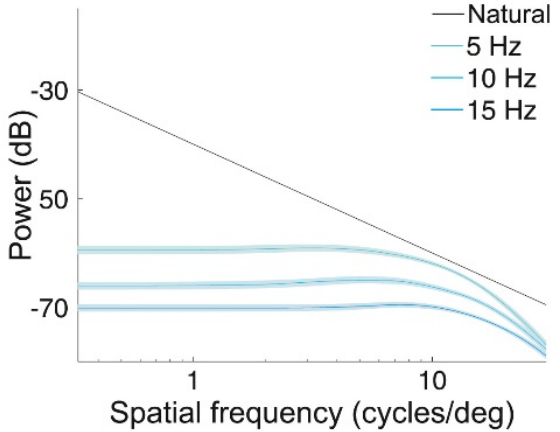
Early Fixation





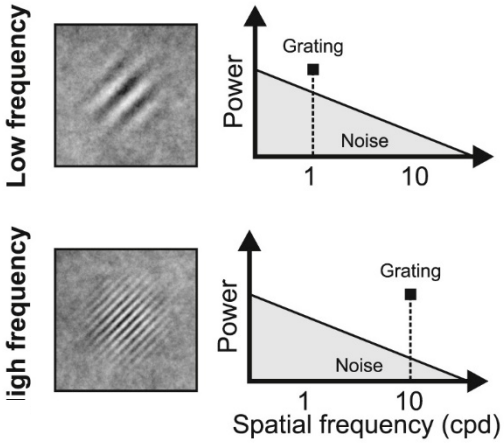
Late Fixation

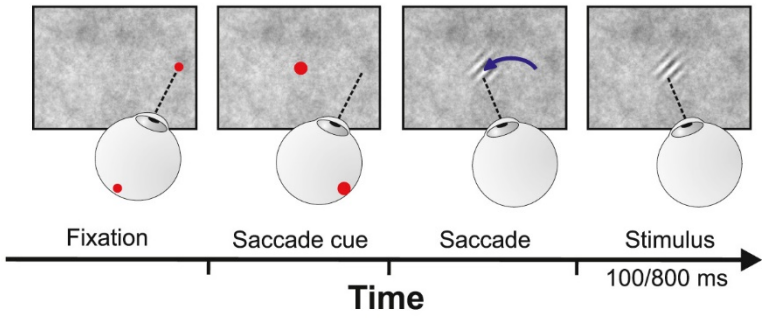


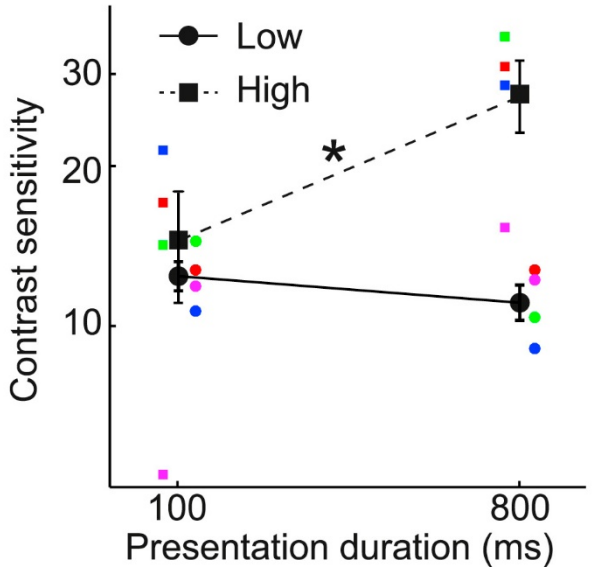


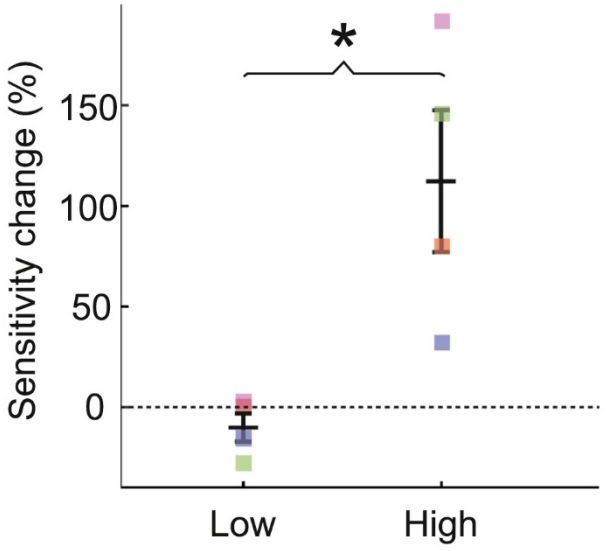
Boi et. al, Current Biology, 2017

Visual System is Sensitive Retinal Transients



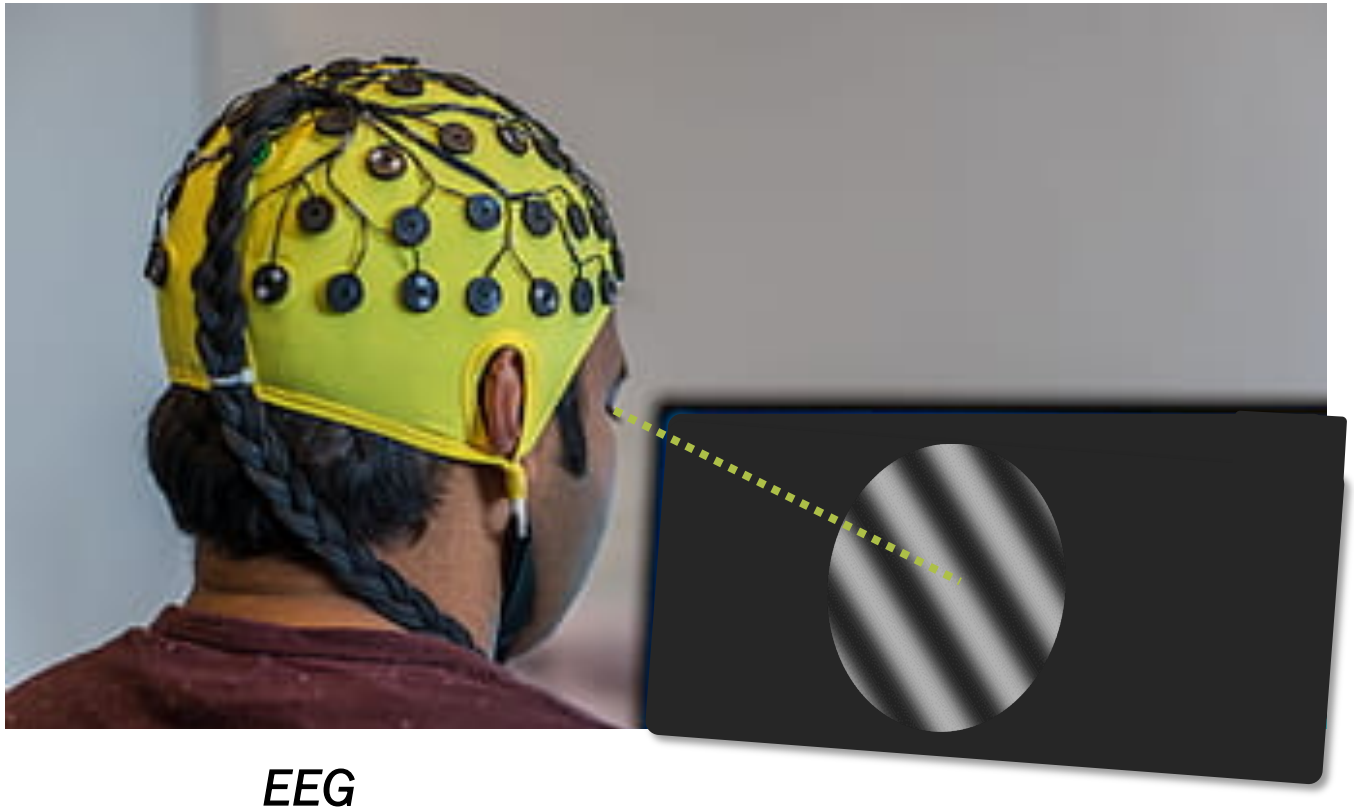






Boi et. al, Current Biology, 2017

Can We Find a Neuronal Correlate?

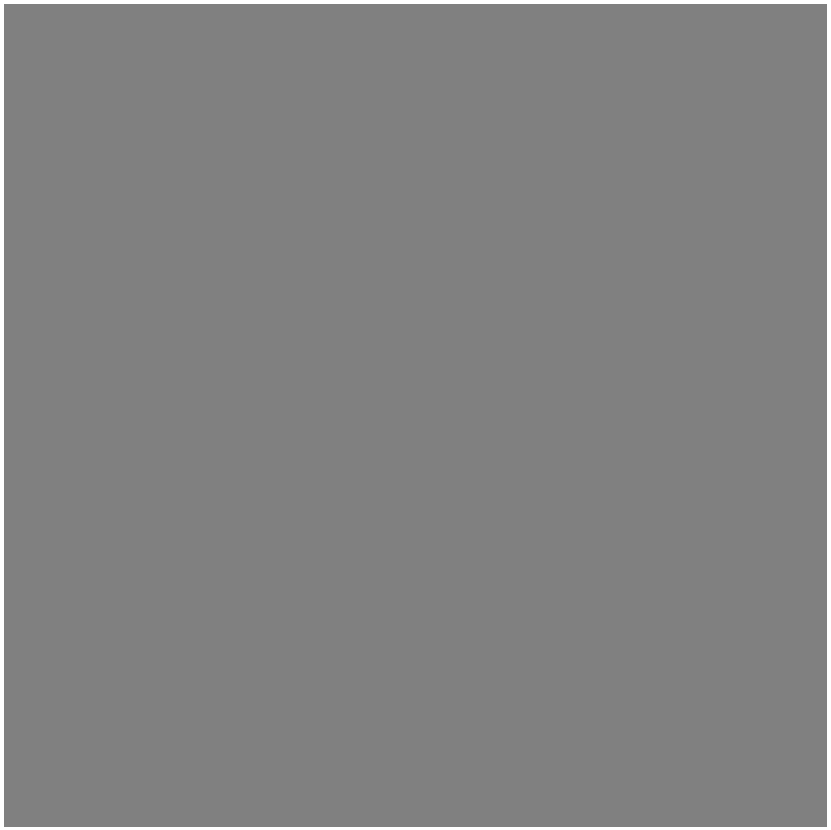


EEG

Spatial Temporal Stimulus

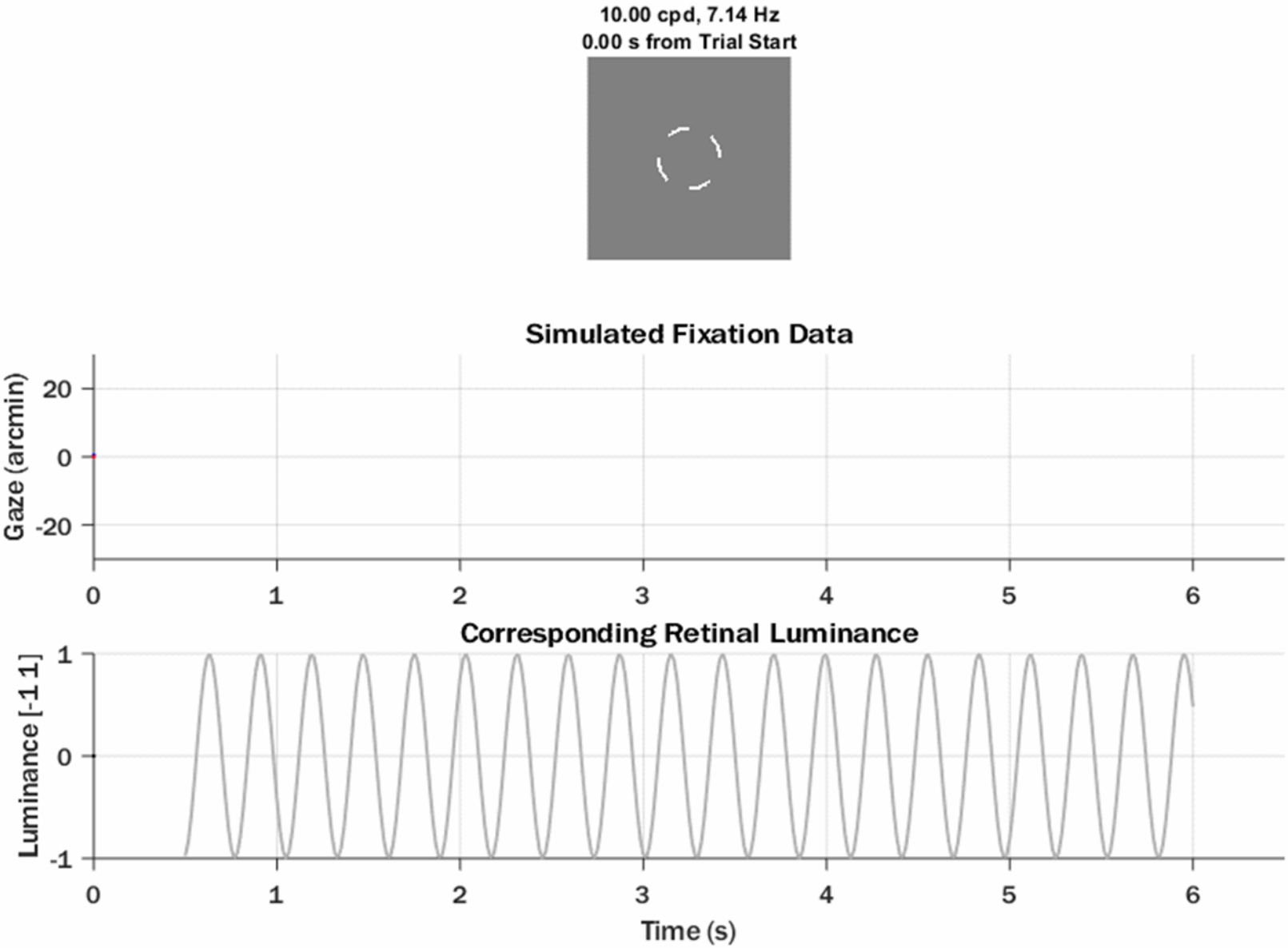
Approach: Visual Stimulation

10 cpd, 7.14 Hz

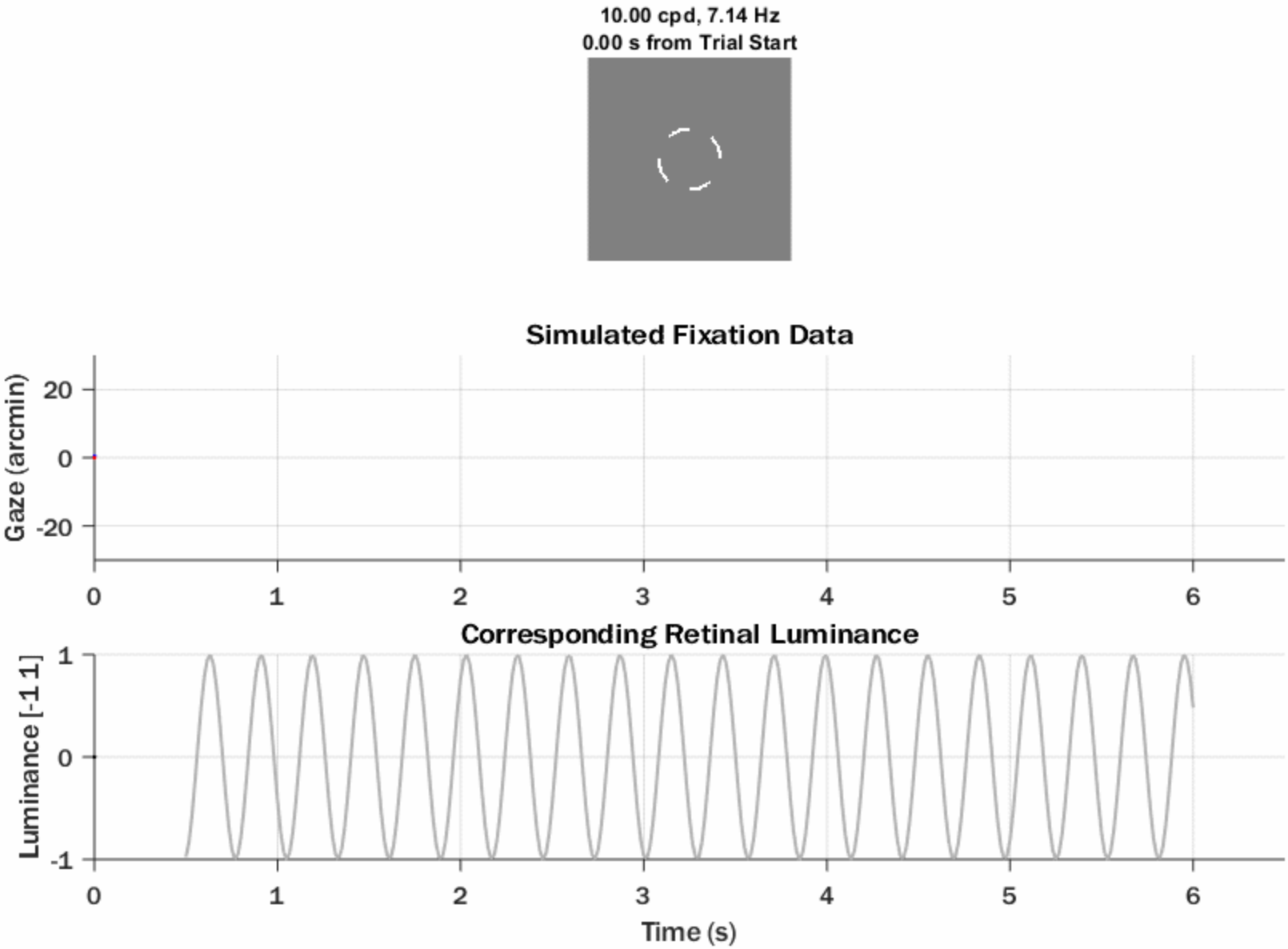


45 degrees tilted
7.76 degrees of visual angle
0.5 s fixation followed by 6 s of stimulation

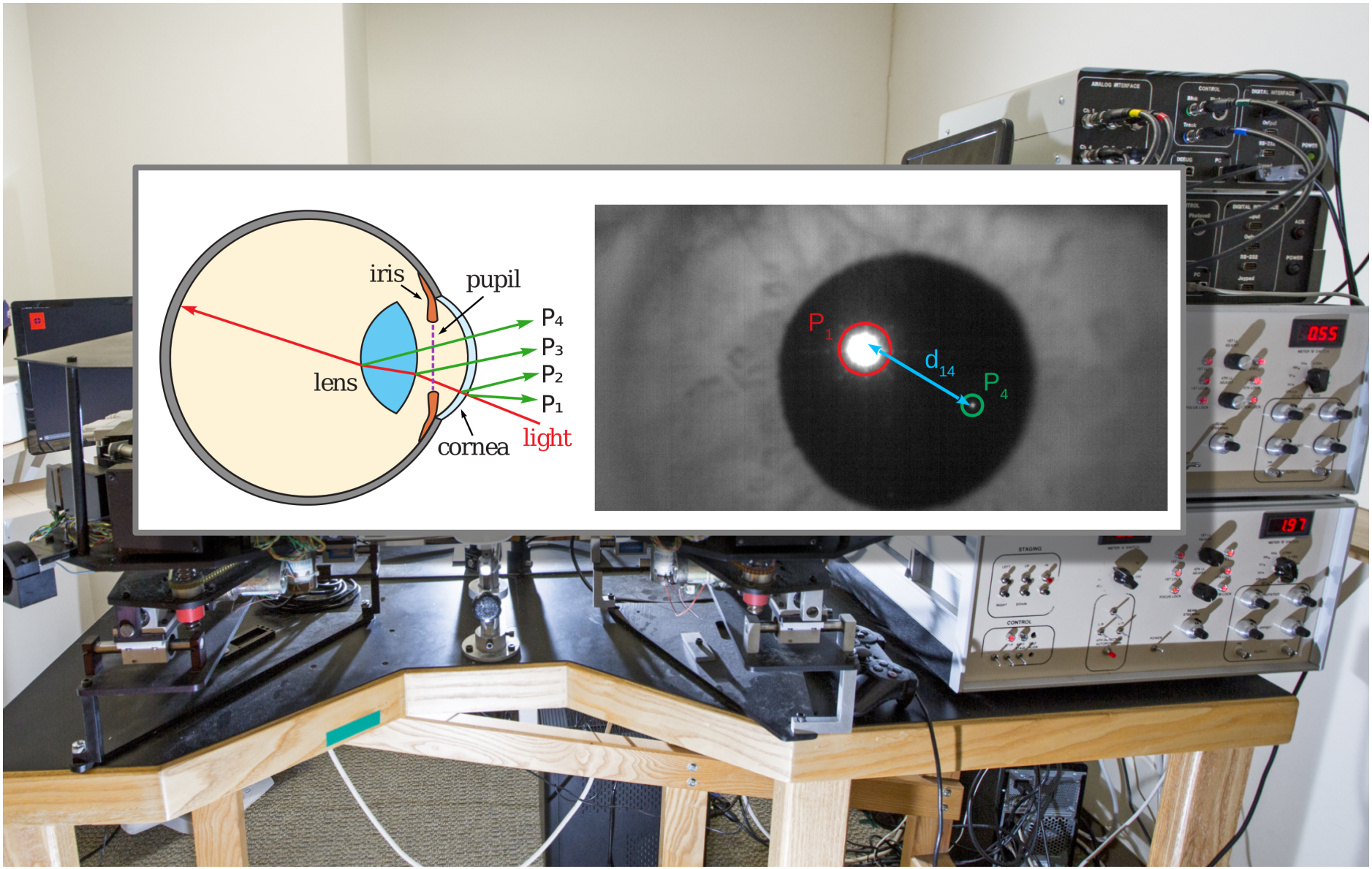
Approach: Visual Stimulation



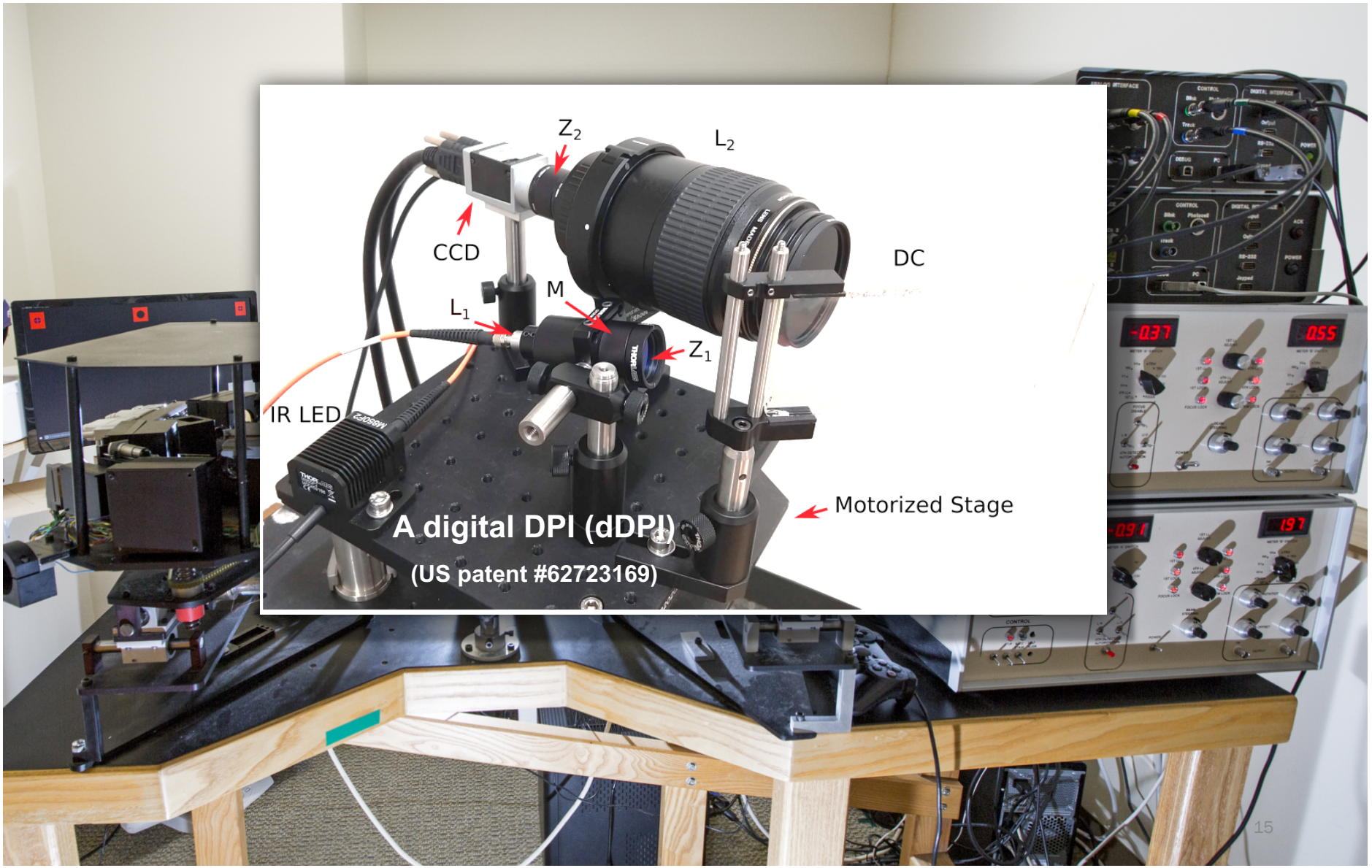
Approach: Visual Stimulation



Approach: Measuring Eye Movements

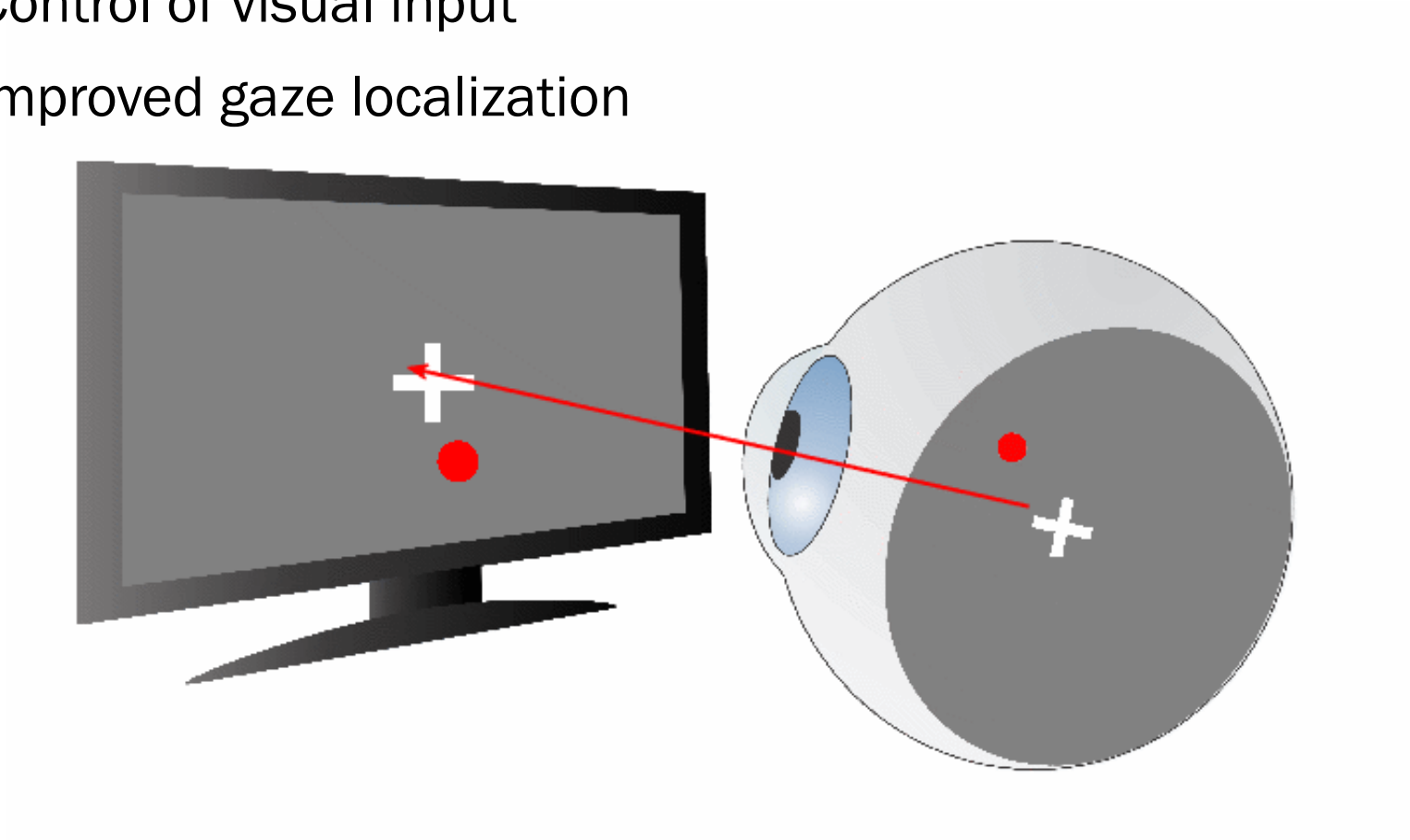


Approach: Measuring Eye Movements



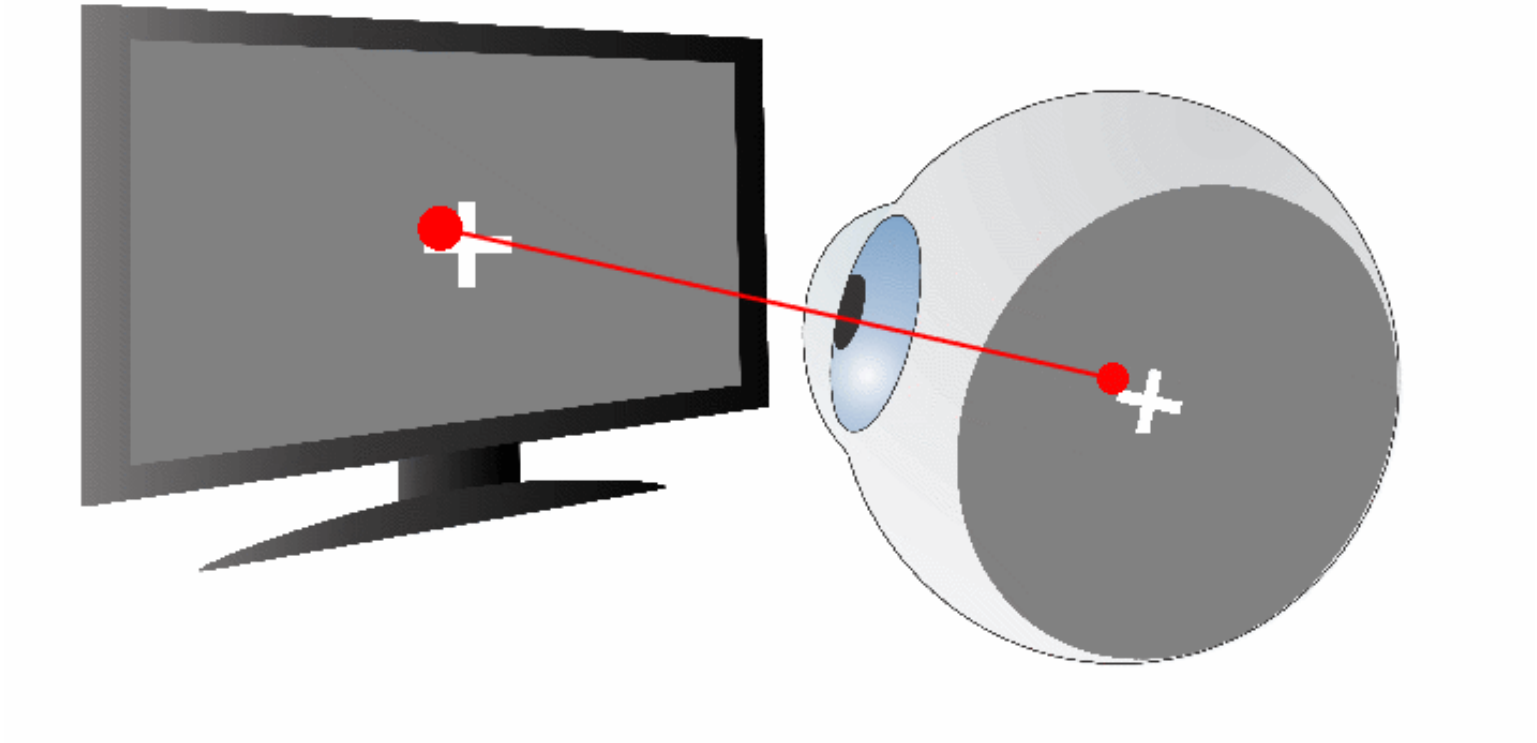
Approach: Measuring Eye Movements

- High sensitivity & precision
- Control of visual input
- Improved gaze localization

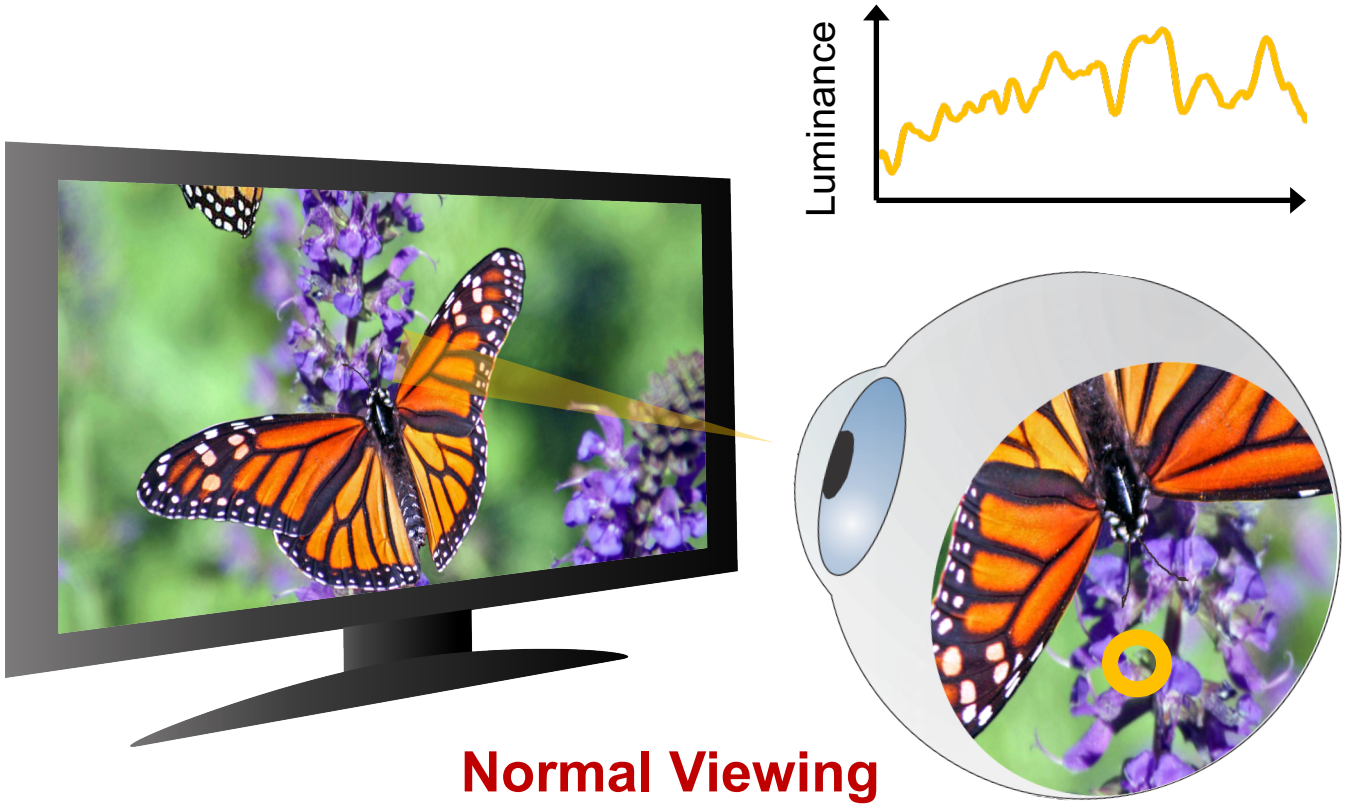


Approach: Measuring Eye Movements

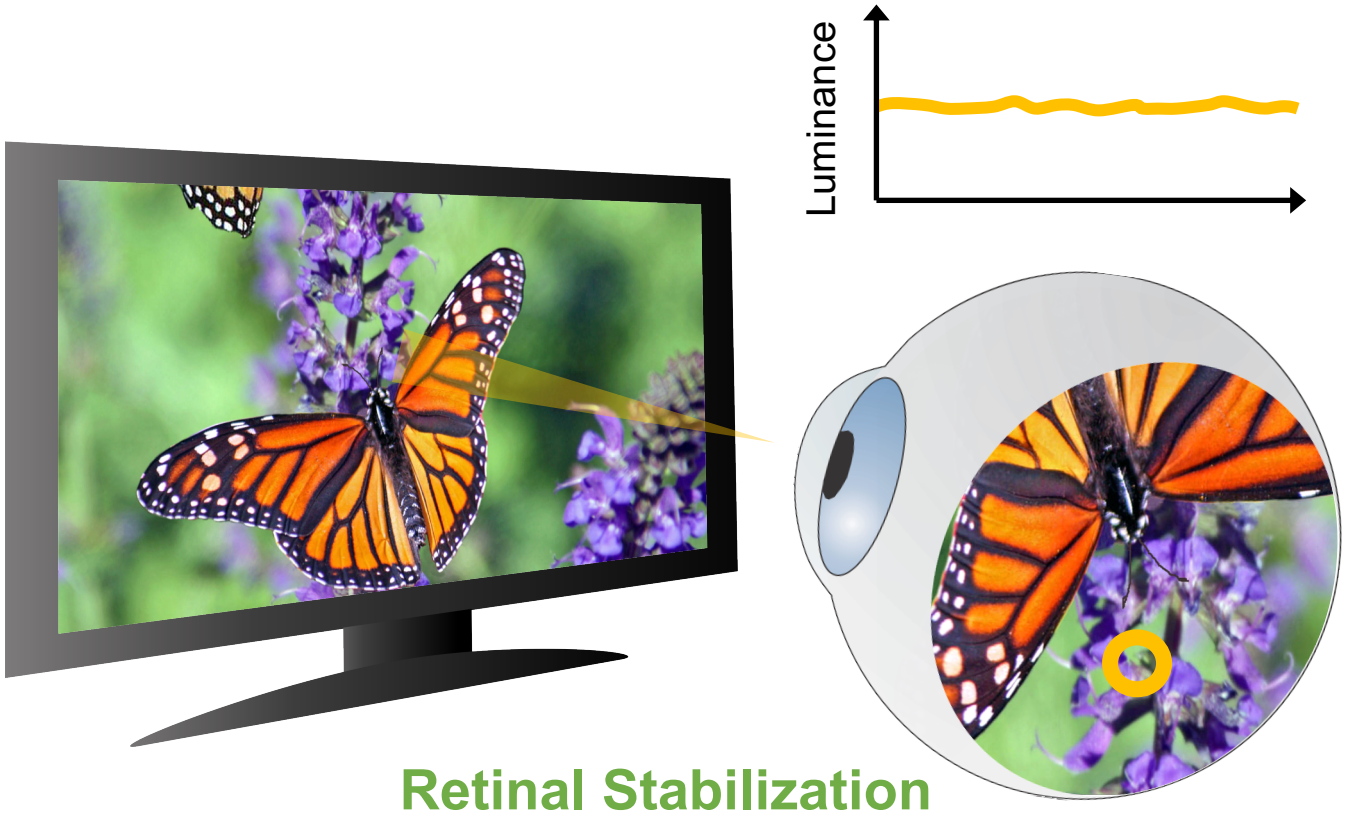
- High sensitivity & precision
- Control of visual input
- Improved gaze localization



Approach: Controlling Retinal Luminance

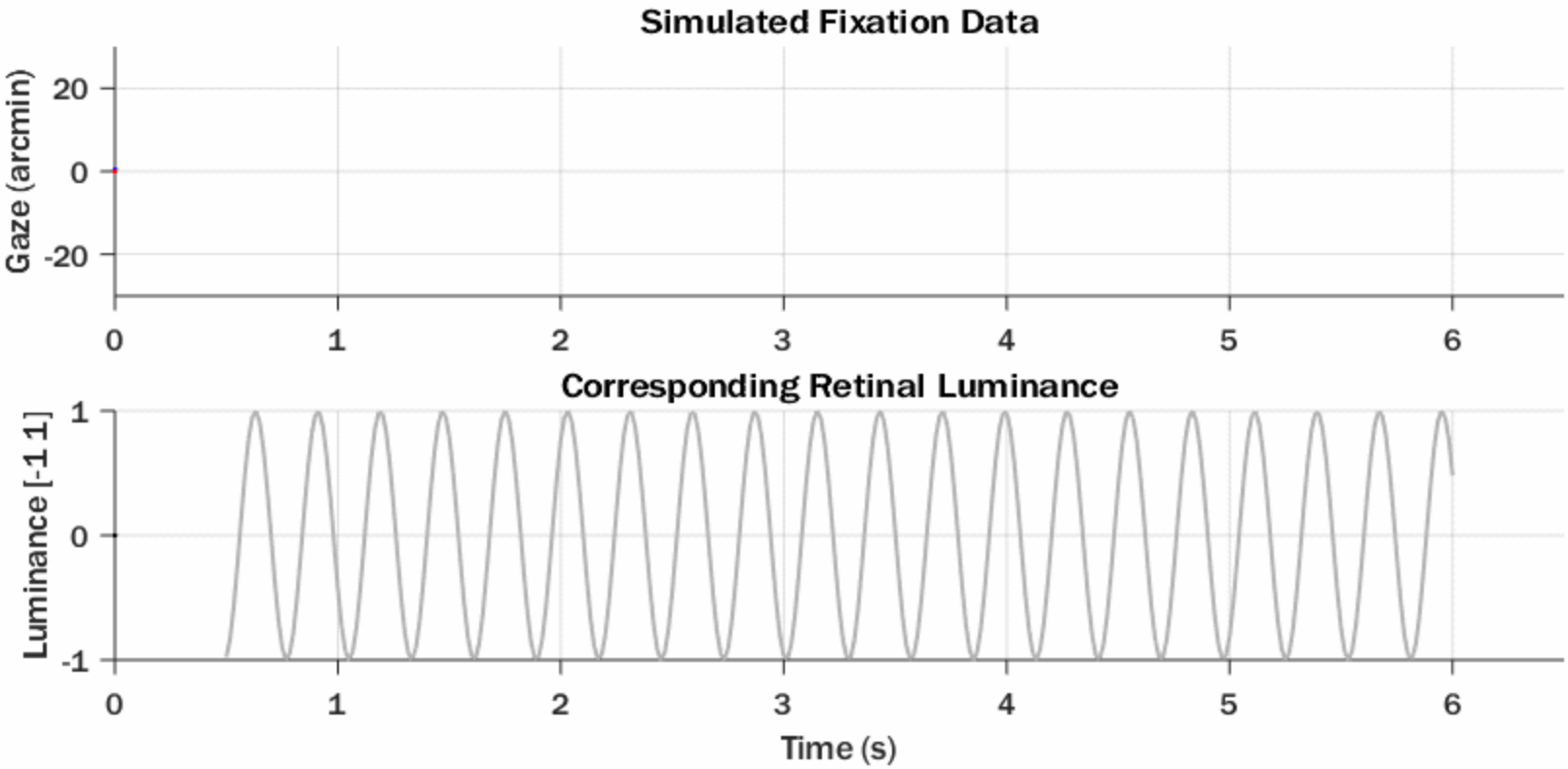


Approach: Controlling Retinal Luminance



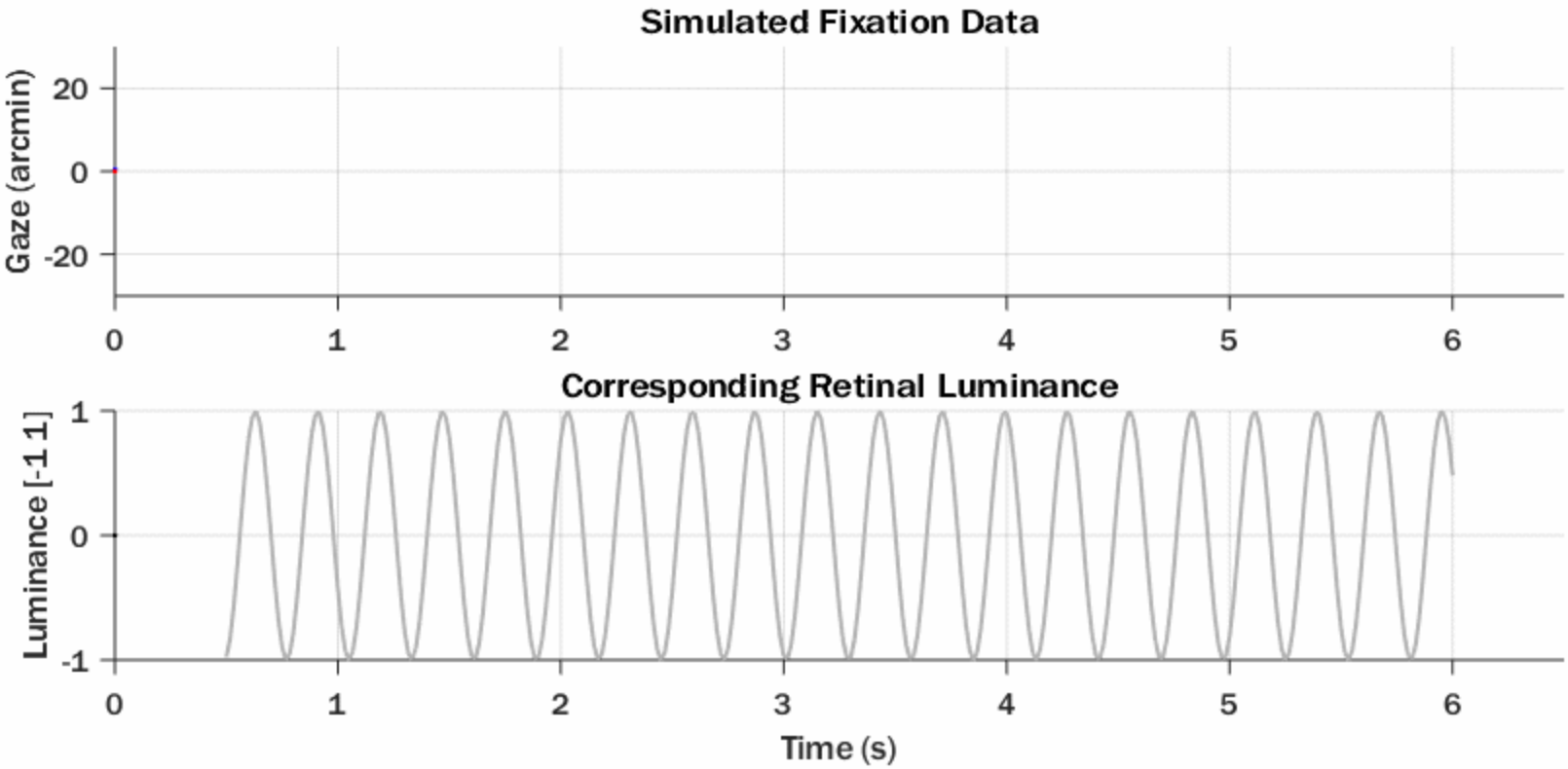
Approach: Visual Stimulation

Normal Viewing



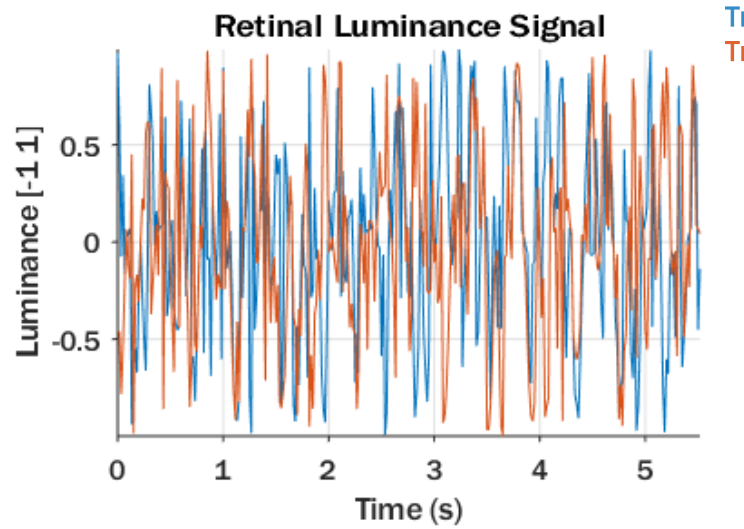
Approach: Visual Stimulation

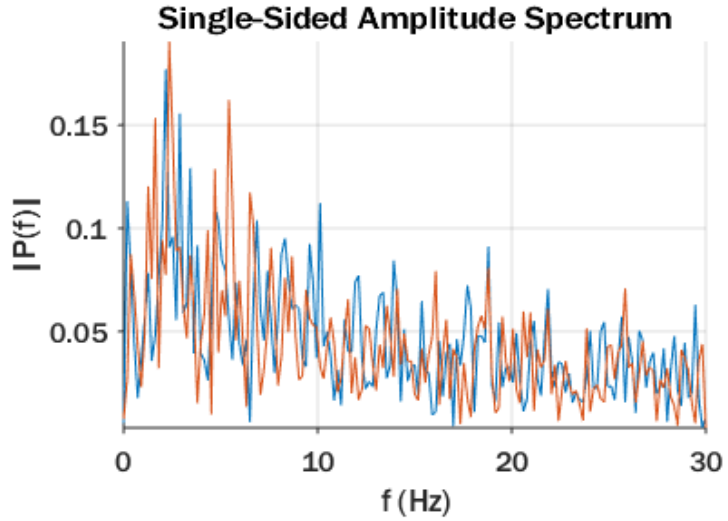
Retinal Stabilization



Expectations

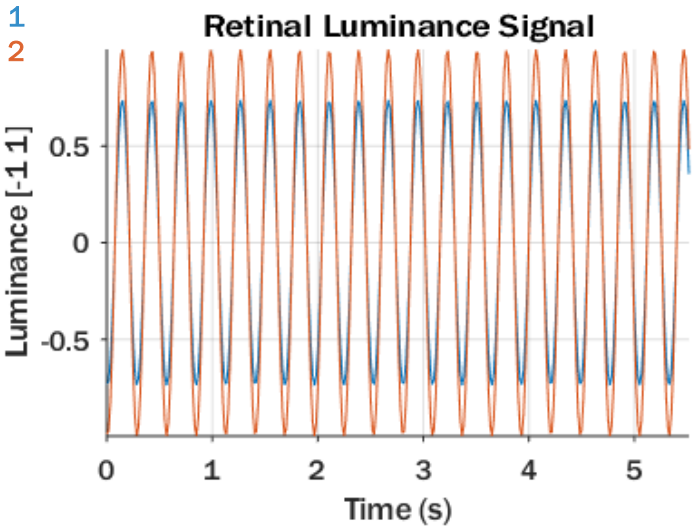
Normal Viewing

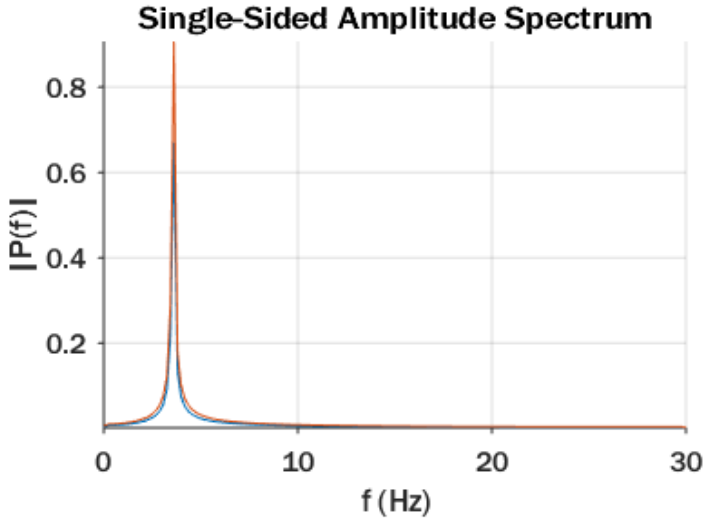




Retinal Stabilization

Trial 1
Trial 2





Expectations: Model Neurons

Neurons at 40 positions

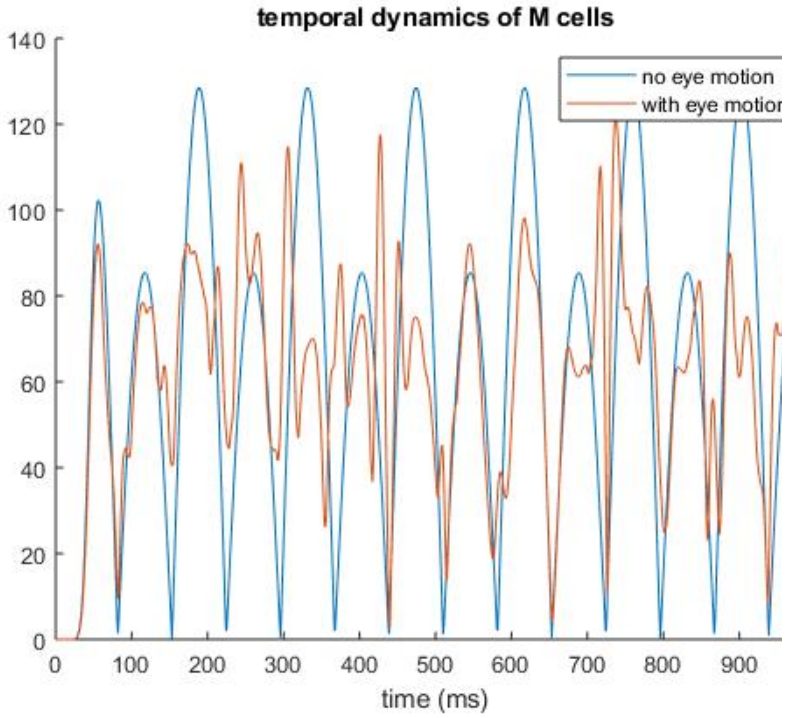
Each position has 1 simple cell with a random phase in {0 pi/2, pi, 2pi/3})

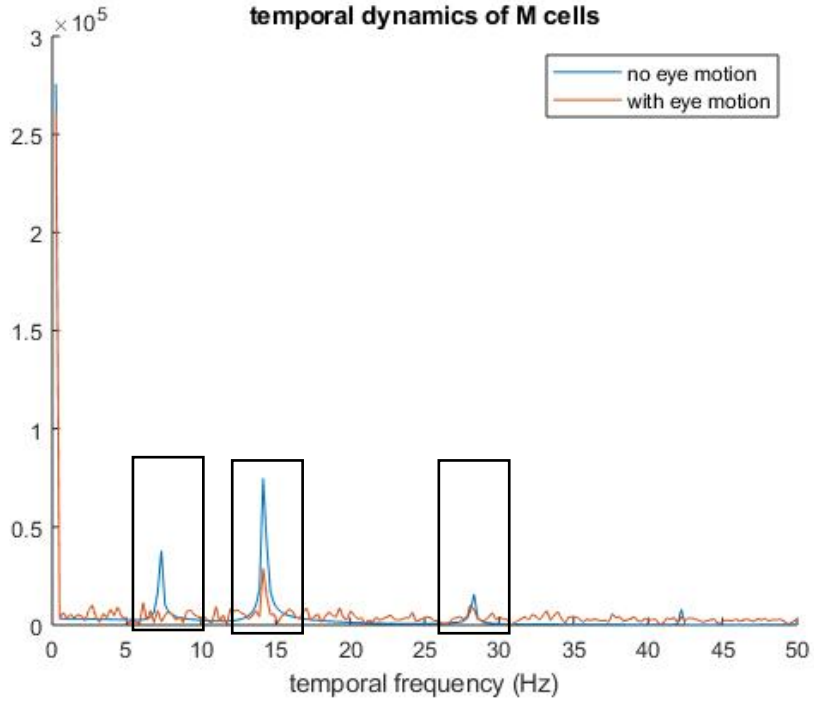
Luminance Input

Retinal Stabilization

Normal Viewing

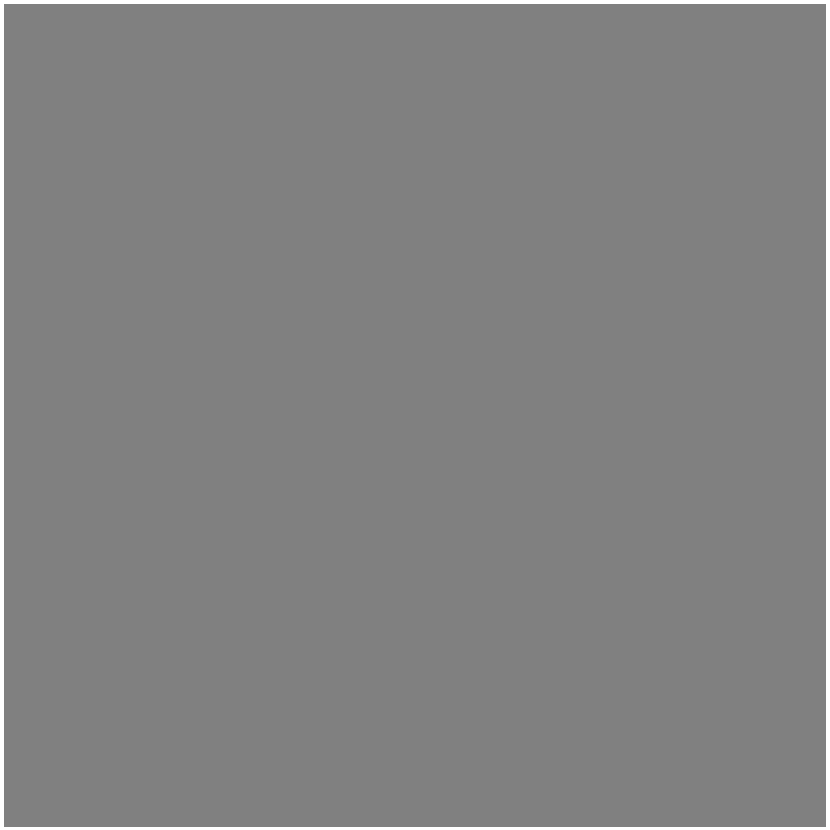
Power Spectrum





Approach: Visual Stimulation

10 cpd, 7.14 Hz



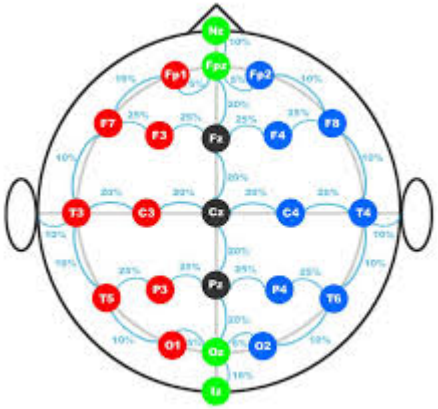
45 degrees tilted
7.76 degrees of visual angle
0.5 s fixation followed by 6 s of stimulation

Why this particular stimulus?

- **10 cpd ->** the higher the spatial frequency, the more power is redistributed from modulated temporal frequency by ocular drift.
- **7.14 Hz** -> harmonic falls outside the alpha band (8 – 12 Hz, arousal) and away from 60 Hz (electronic noise)
- **6 s** -> short enough that subject are be able to suppress blinks and saccades but long enough to give gives enough resolution in the temporal frequency domain in the power spectrum analysis.

Approach: EEG Data Analysis

- EEG signal of Oz, O1, O2, POz, PO8, PO4, PO7, PO3 are included in the analysis.
- EEG signal starting from 0.5 sec after stimulus onset is used in the PSD estimation.
- PSD estimation is conducted using multitaper method (2 tapers).
  - PSD is calculated first before being averaged across trials or channels.



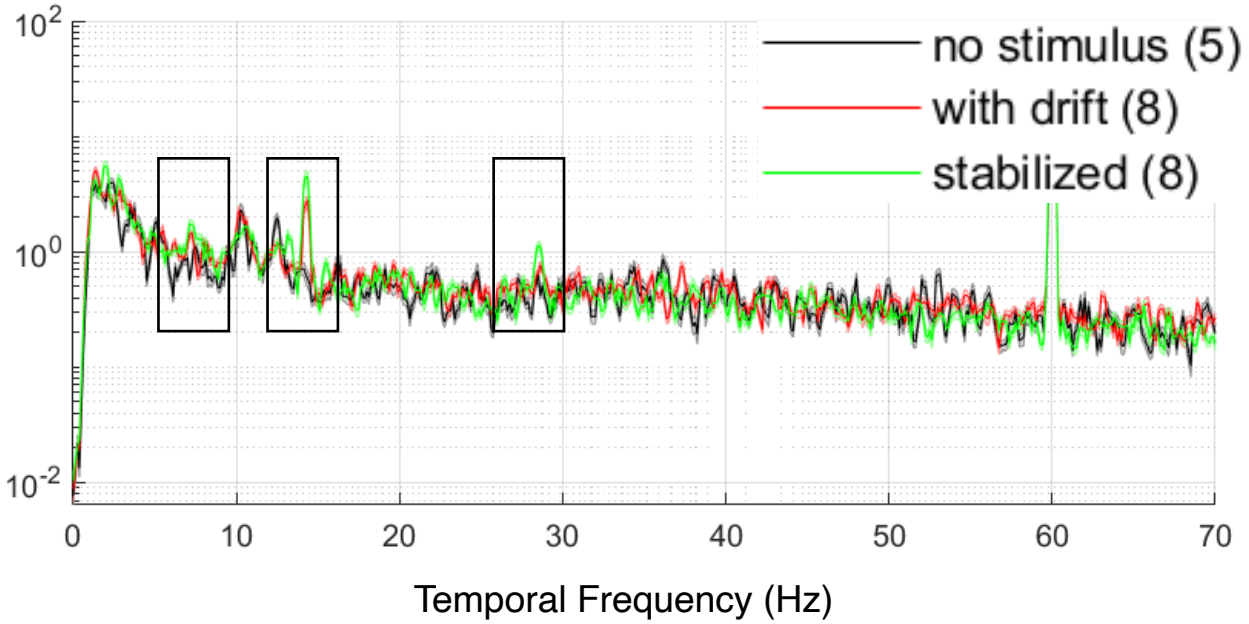
Approach: Subjects

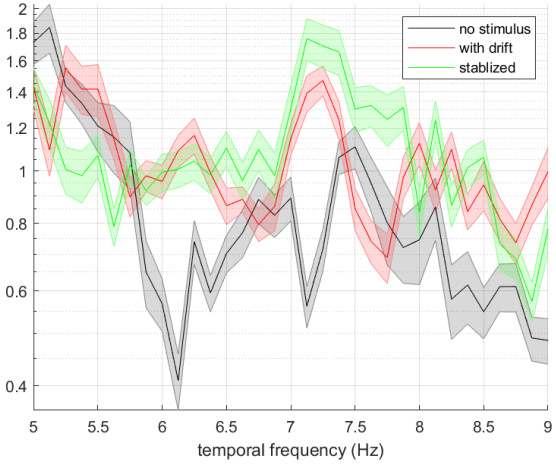
	total	EEG_artifacts	microsaccades	saccades	bad_stabilize	off_center	drift_only
A021	92	19	41	4	1	4	17
A059	167	3	122	29	19	18	12
A084	113	10	99	50	36	4	5
Bin	281	42	216	105	82	28	23

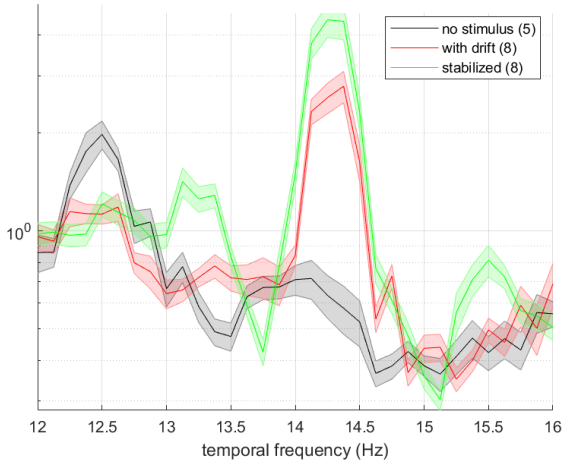
Select trials based on several criteria

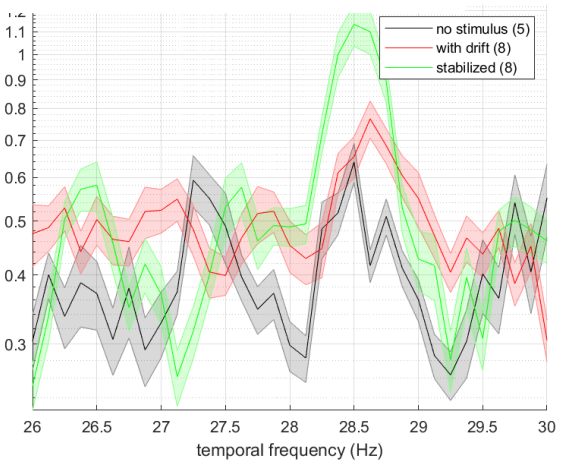
- Free of EEG artifacts (EOG, EMG)
- Free of saccades
  - Less than 5 microsaccades
- The gaze contingent control needs to work well
- Gaze cannot drift too far away center

A084

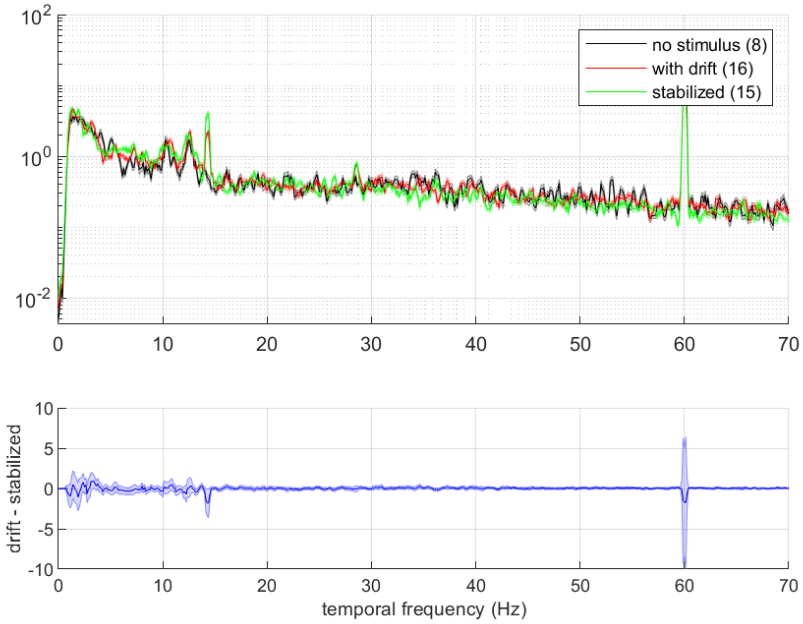

no stimulus (5)
with drift (8)
stabilized (8)
Temporal Frequency (Hz)

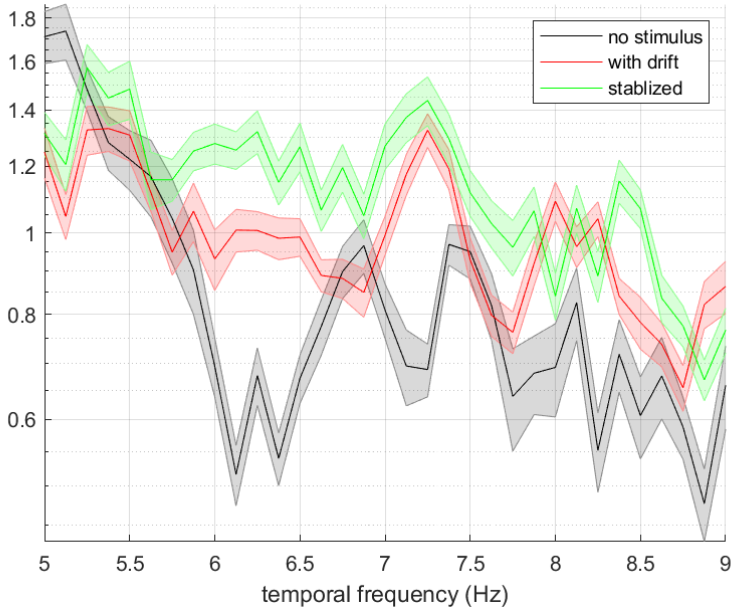

no stimulus
with drift
stablized
temporal frequency (Hz)

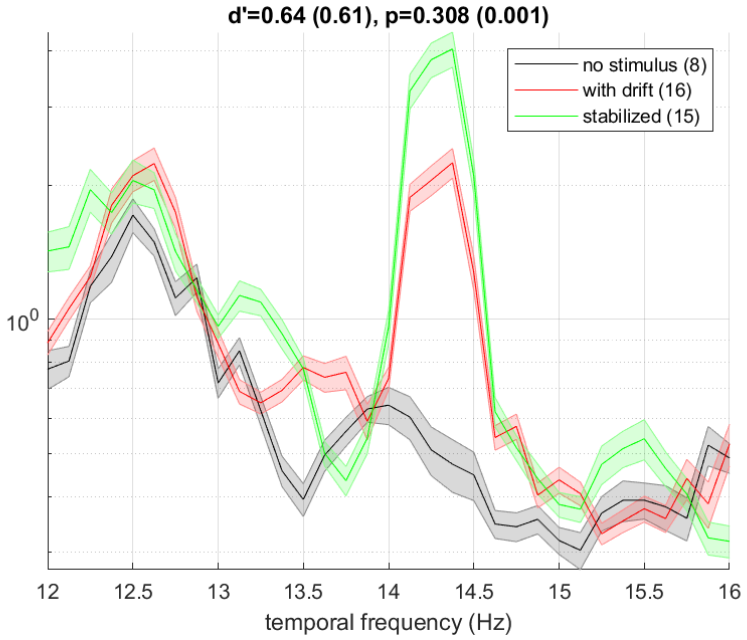

no stimulus (5)
with drift (8)
stabilized (8)
temporal frequency (Hz)

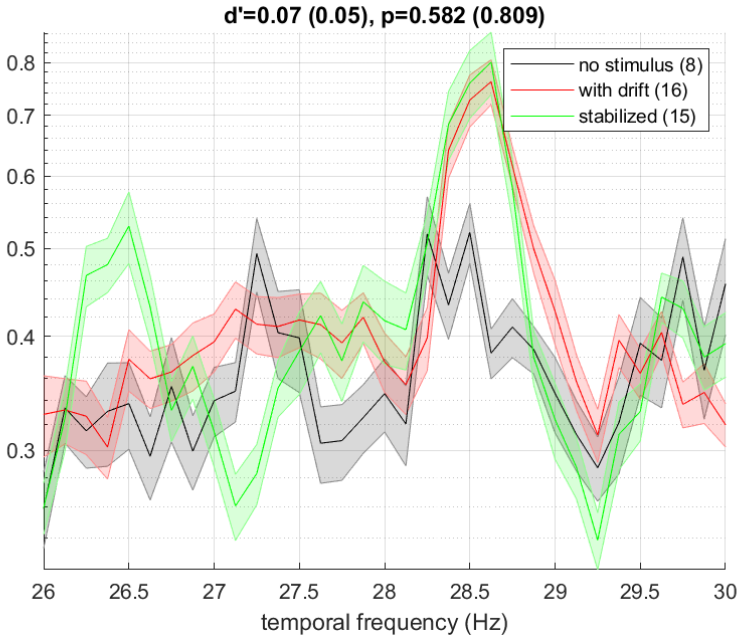

no stimulus (5)
with drift (8)
stabilized (8)
temporal frequency (Hz)

BIN

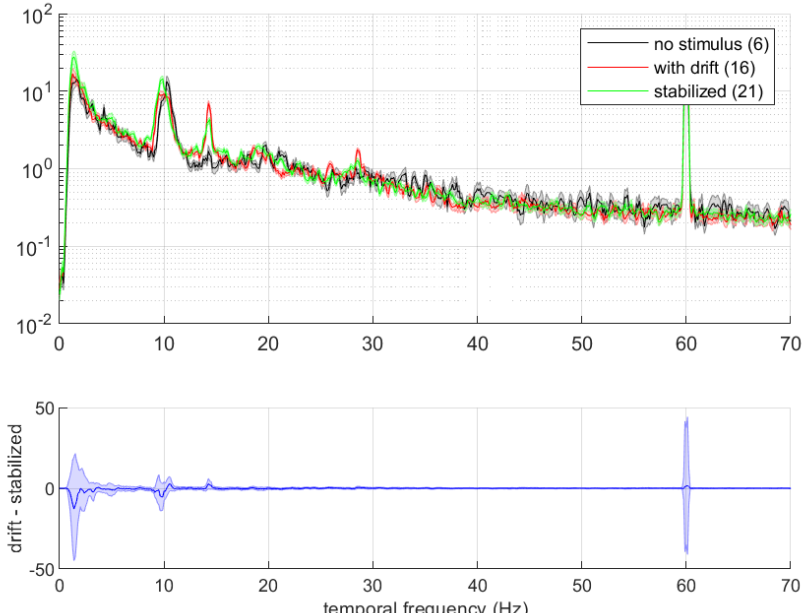

no stimulus (8)
with drift (16)
stabilized (15)
drift - stabilized
temporal frequency (Hz)

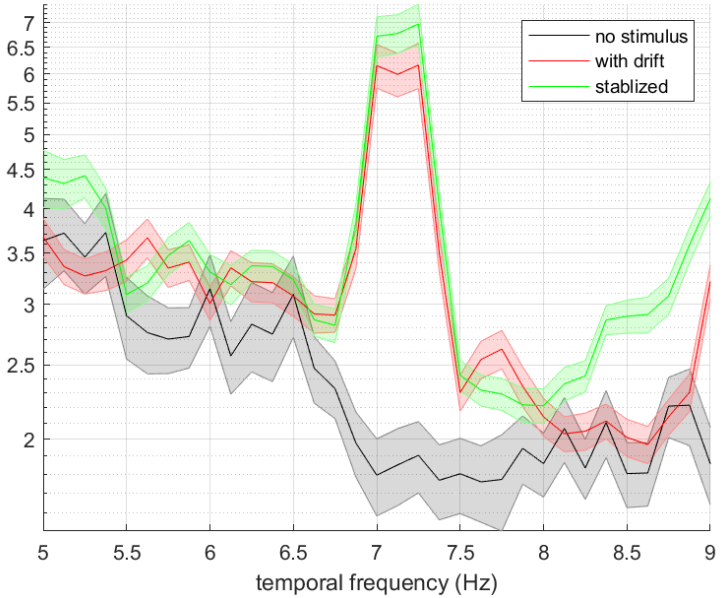

no stimulus
with drift
stablized
temporal frequency (Hz)

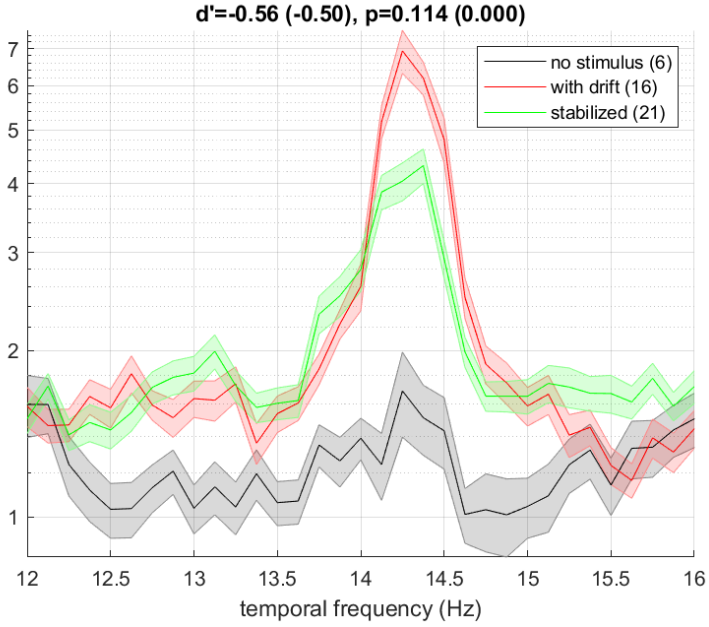

d'=0.64 (0.61), p=0.308 (0.001)
no stimulus (8)
with drift (16)
stabilized (15)
temporal frequency (Hz)

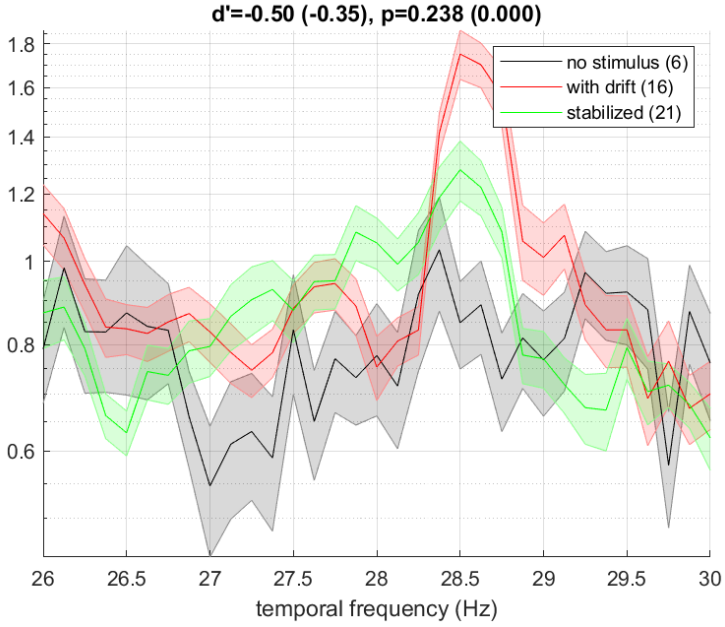

d'=0.07 (0.05), p=0.582 (0.809)
no stimulus (8)
with drift (16)
stabilized (15)
temporal frequency (Hz)

A021

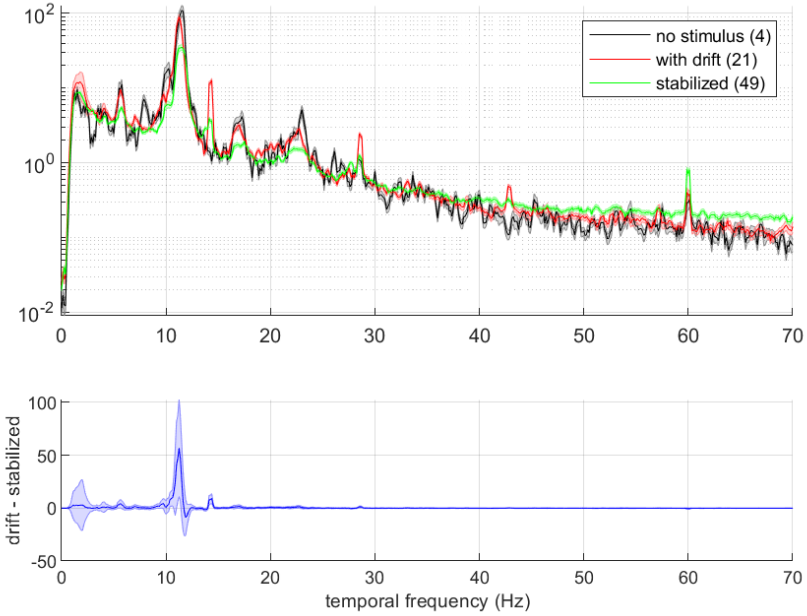

no stimulus (6)
with drift (16)
stabilized (21)
drift - stabilized
temporal frequency (Hz)

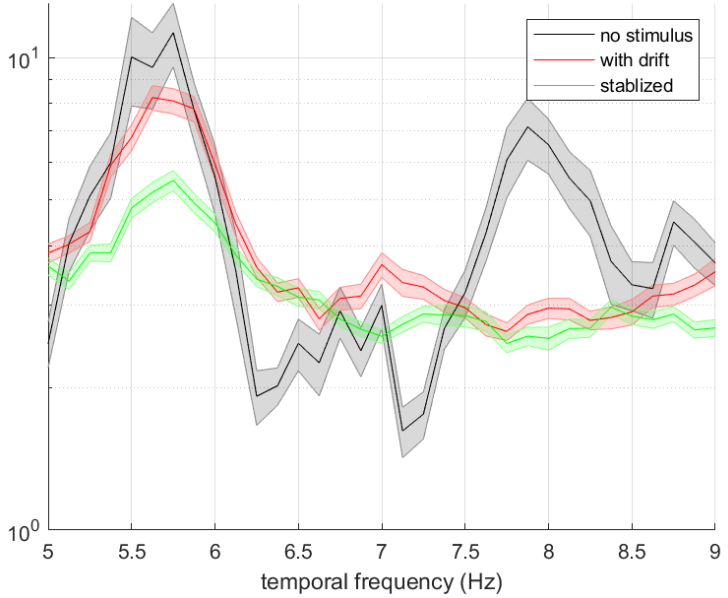

no stimulus
with drift
stablized
temporal frequency (Hz)

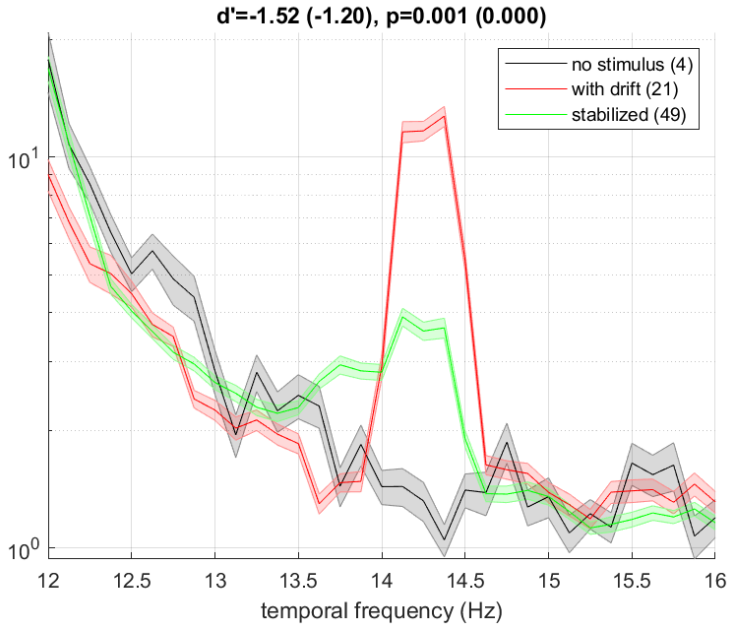

d'=-0.56 (-0.50), p=0.114 (0.000)
no stimulus (6)
with drift (16)
stabilized (21)
temporal frequency (Hz)

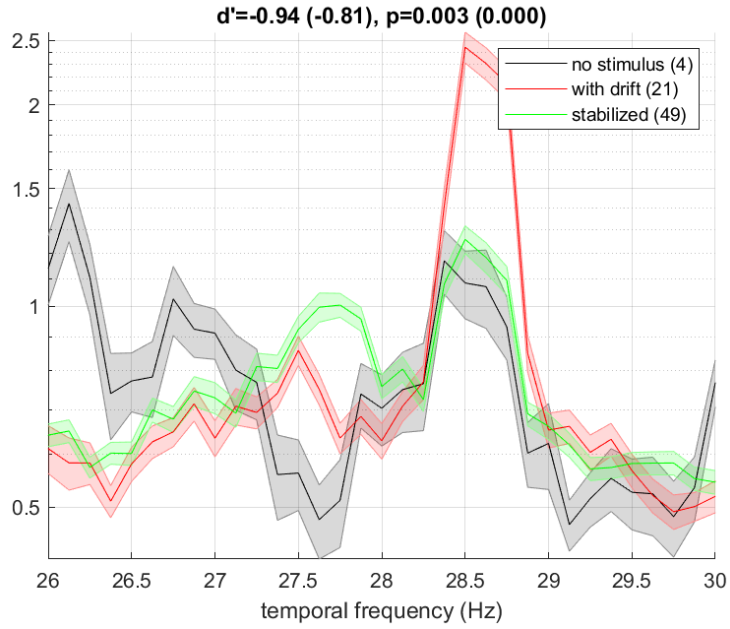

d'=-0.50 (-0.35), p=0.238 (0.000)
no stimulus (6)
with drift (16)
stabilized (21)
temporal frequency (Hz)

A059

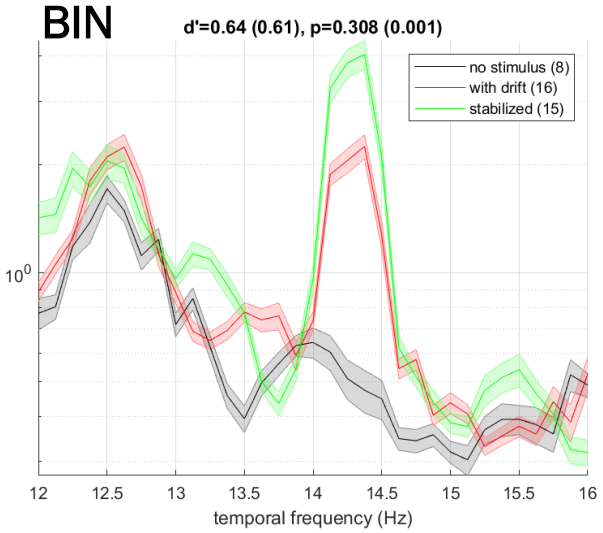

no stimulus (4)
with drift (21)
stabilized (49)
drift - stabilized
temporal frequency (Hz)

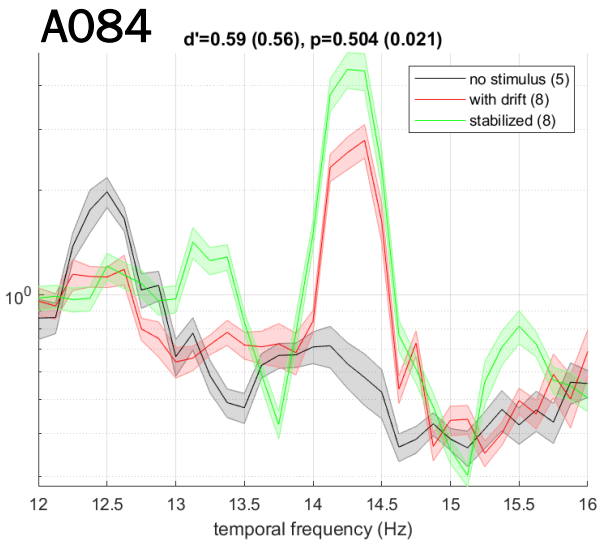

no stimulus
with drift
stablized
temporal frequency (Hz)

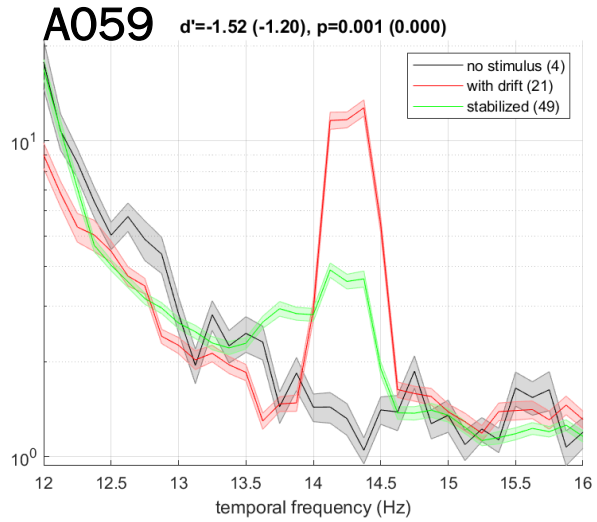

d'=-1.52 (-1.20), p=0.001 (0.000)
no stimulus (4)
with drift (21)
stabilized (49)
temporal frequency (Hz)

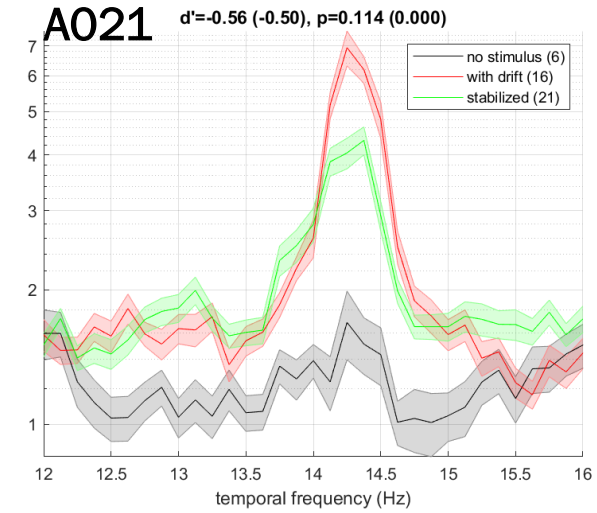

d'=-0.94 (-0.81), p=0.003 (0.000)
no stimulus (4)
with drift (21)
stabilized (49)
temporal frequency (Hz)

Why The Inconsistency?







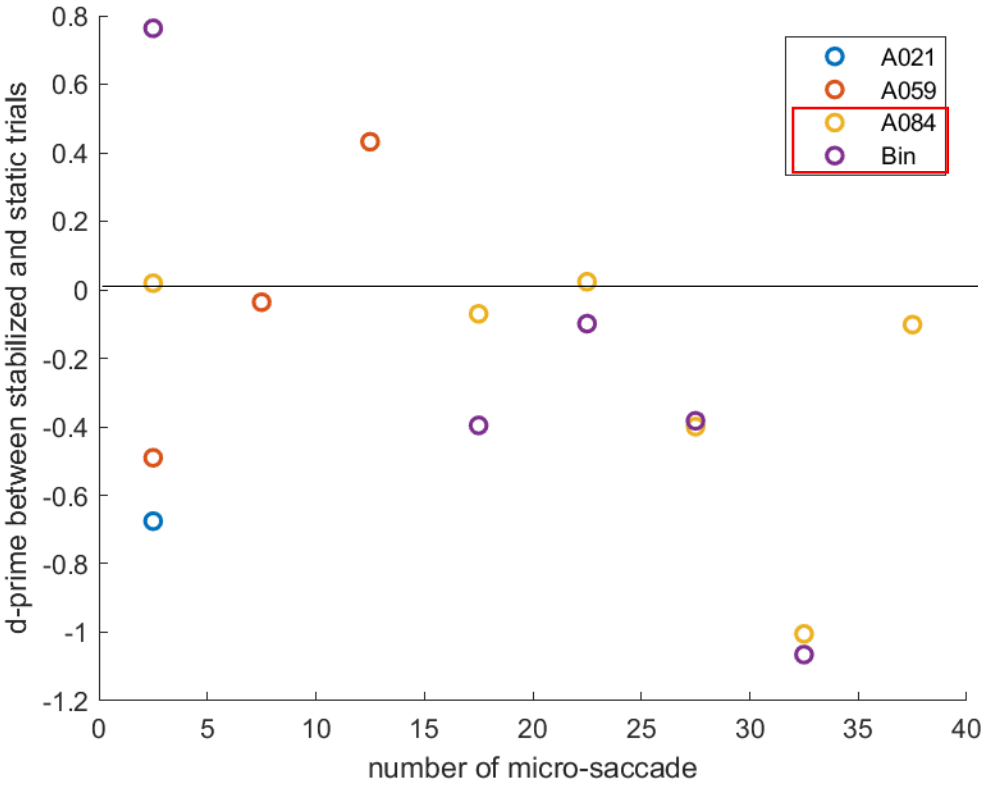


Why The Inconsistency?

1. Subject's eye movements
    - Stabilization does not work well for microsaccades
    - Subject differences in microscaade rate

Positive d'
Stabilized > Static

Each point is binned along abscissa with a minimum of 5 trials per point



Subject that show expected result:

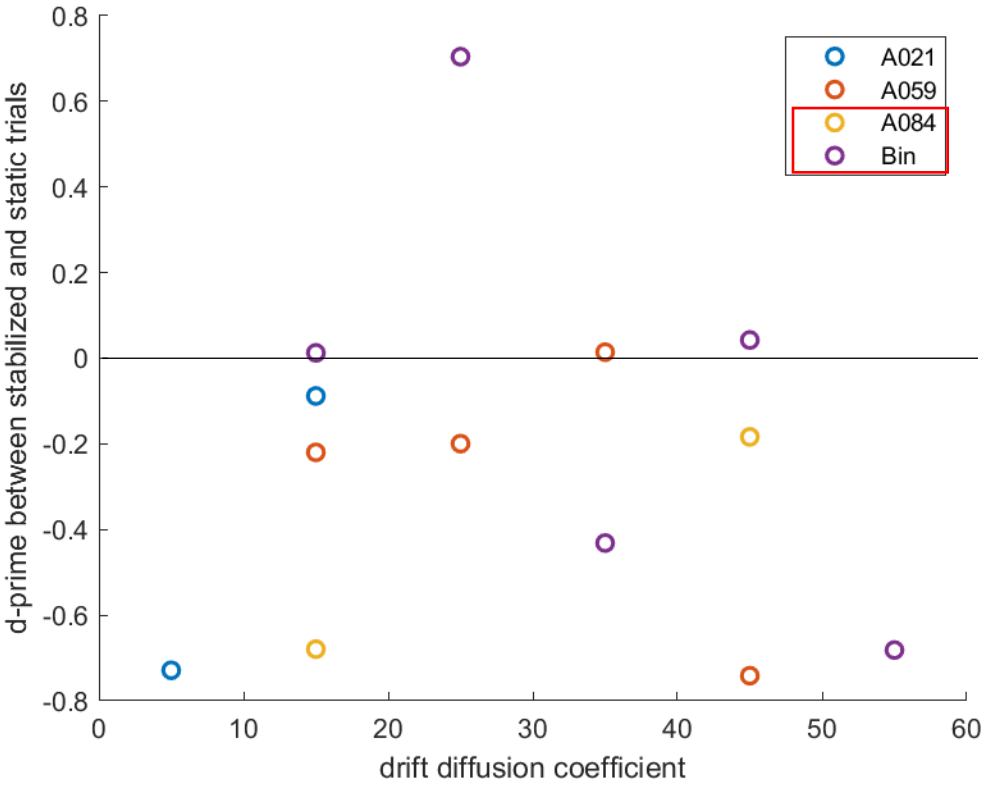
- A084
- Bin

Why The Inconsistency?

1. Subject's eye movements
    - Subject differences in ocular drift

Positive d'
Stabilized > Static

Each point is binned along abscissa with a minimum of 5 trials per point



Subject that show expected result:

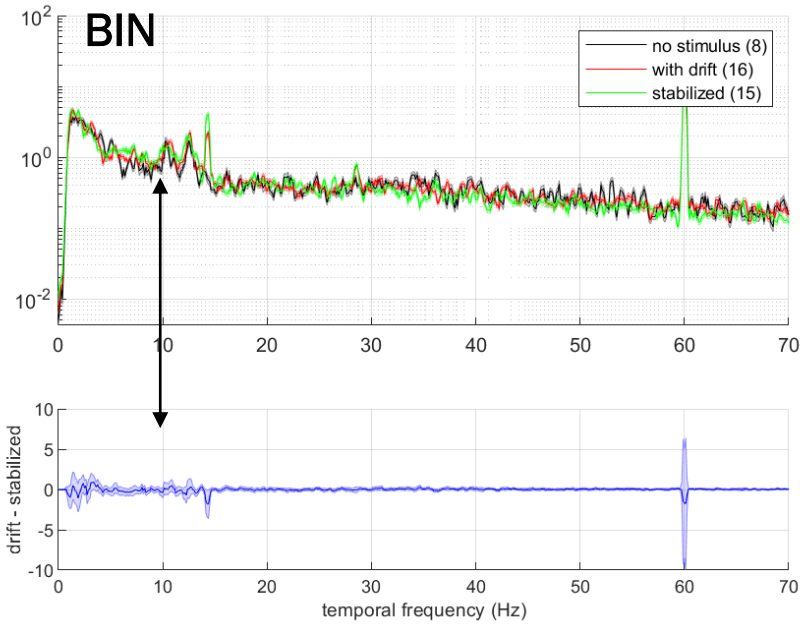
- A084
- Bin

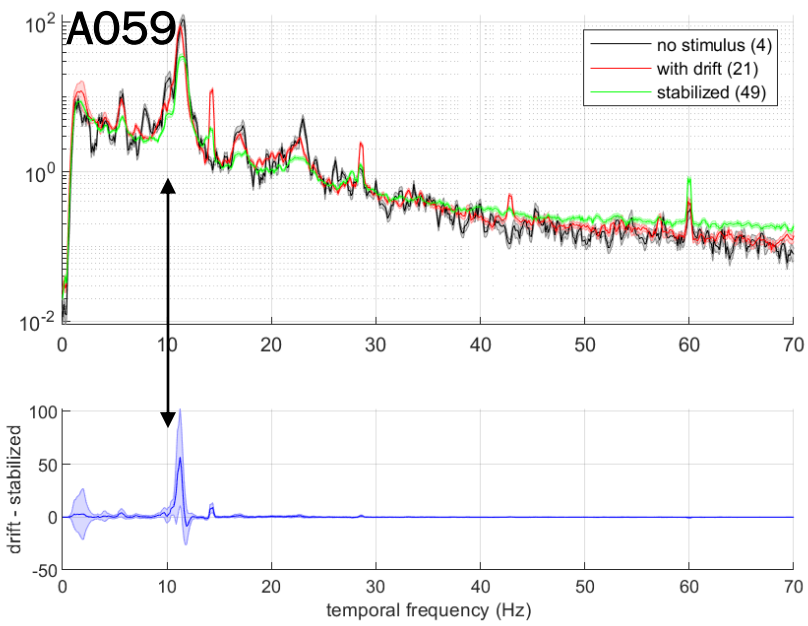
Why The Inconsistency?

**there is a lot to say about alpha beyond this, but outside our scope for today*

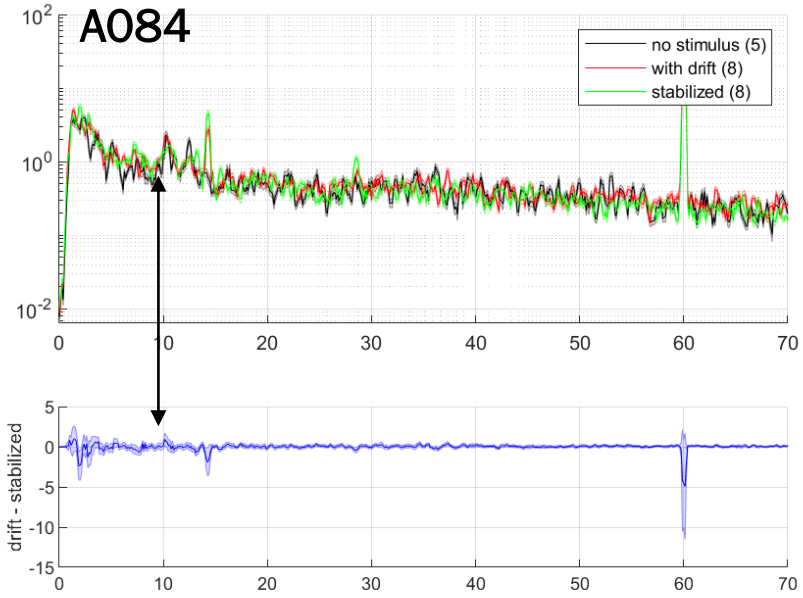
2. Subject's attention and/or arousal

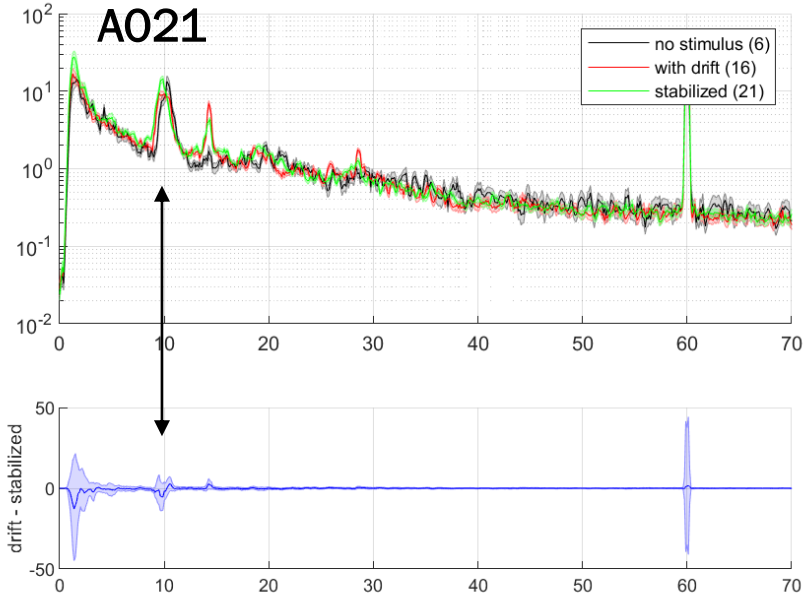
- EEG activity in the alpha band (8-12 Hz) responds to stimulus and/or task demands with either a decrease or increase in amplitude/power.
- e.g., alpha* amplitudes are **large when the eyes are closed, <u>suppressed when eyes are opened</u>**

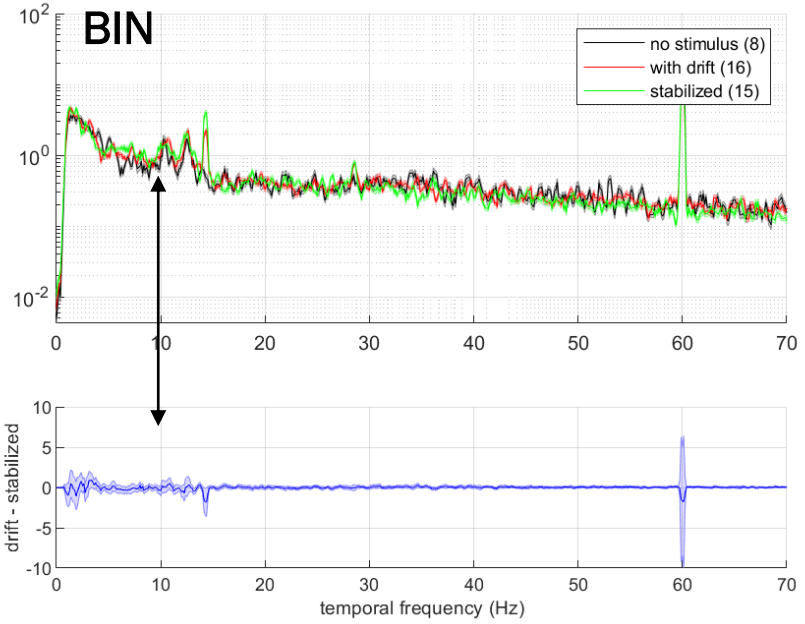


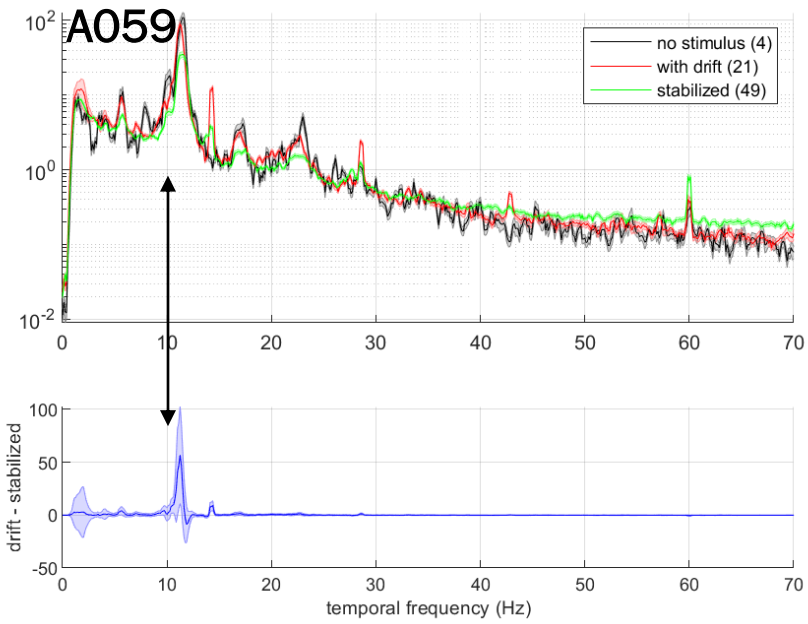


Why The Inconsistency?









Why the Inconsistency?

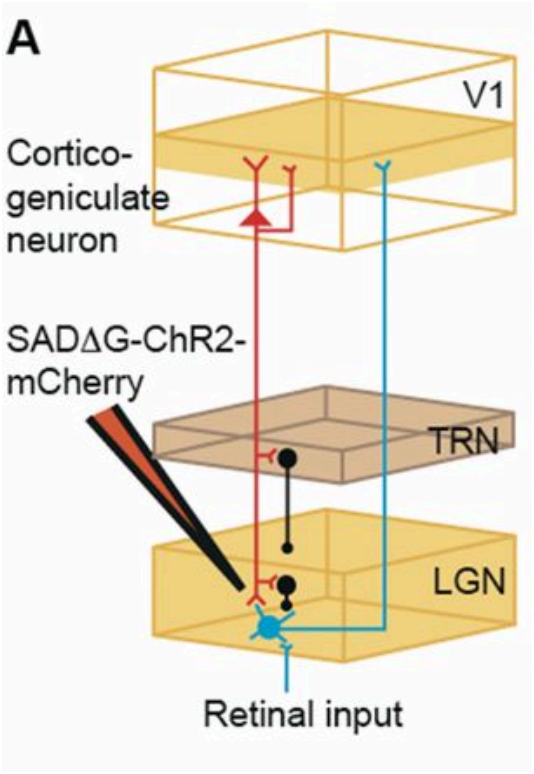
V1 to LGN feedback increases spike-timing precision

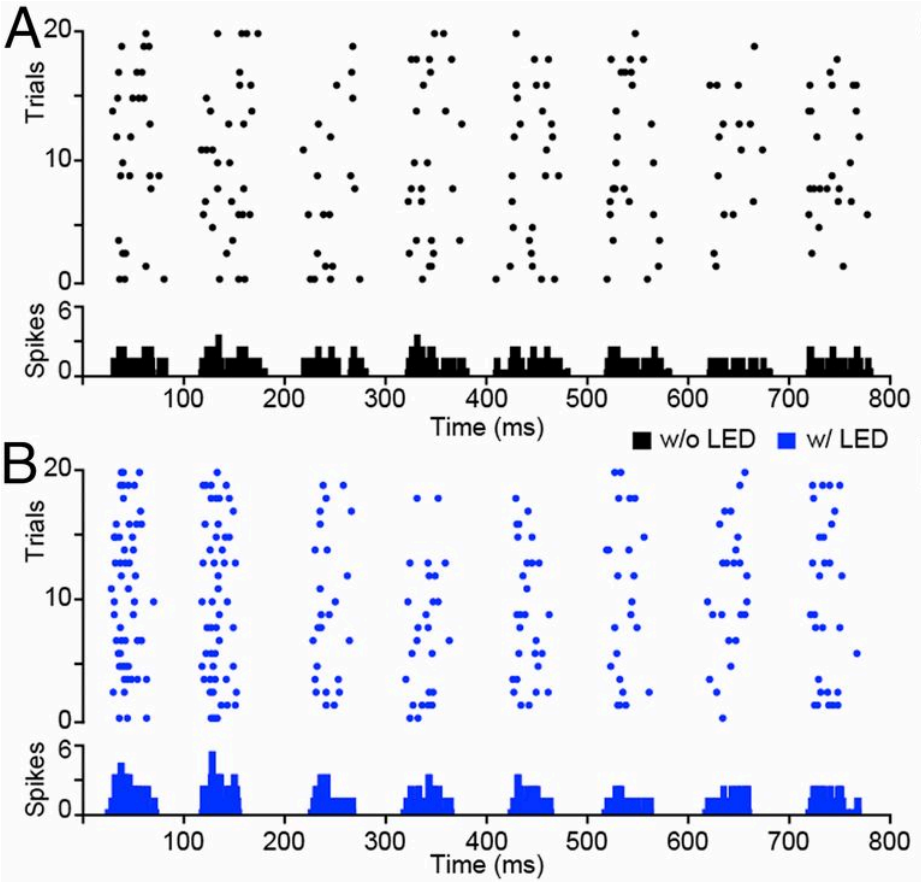
- *Thought to be a main target of attention*

Corticogeniculate feedback sharpens the temporal precision and spatial resolution of visual signals in the ferret

J. Michael Hasse and Farran Briggs

PNAS July 25, 2017 114 (30) E6222-E6230; first published July 11, 2017 https://doi.org/10.1073/pnas.1704524114





Why The Inconsistency?

3. Visual stimulus is not recruiting enough of V1 to create a significantly strong signal

   a) Stimulus is Monocular

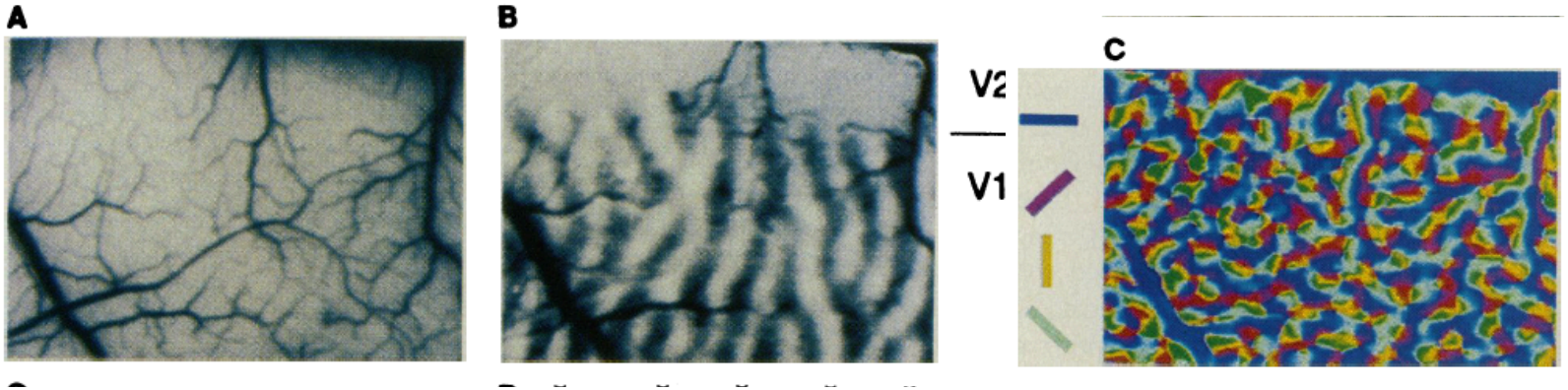
   - Monocular stimuli only stimulating ½ of the input into V1
   - V1 neurons demonstrate plasticity under short-term monocular deprivation, typical 1–3hrs of monocular patching
   - In one study, 1.5 hrs of monocular deprivation shifted the the latency of early VEPs by as much as 100ms
   - 7.14 Hz = period of 140.0560 ms

Lunghi, C., Berchicci, M., Morrone, M. C., & Di Russo, F. (2015). Short-term monocular deprivation alters early components of visual evoked potentials. *The Journal of physiology*, *593*(19), 4361-4372.

Why The Inconsistency?

3. Visual stimulus is not recruiting enough of V1 to create a significantly strong signal

    a) Stimulus is narrow bandpass in both the spatial frequency and orientation domain



Ts'o, D. Y., Frostig, R. D., Lieke, E. E., & Grinvald, A. (1990). Functional organization of primate visual cortex revealed by high resolution optical imaging. *Science*, *249*(4967), 417-420.

Why The Inconsistency?

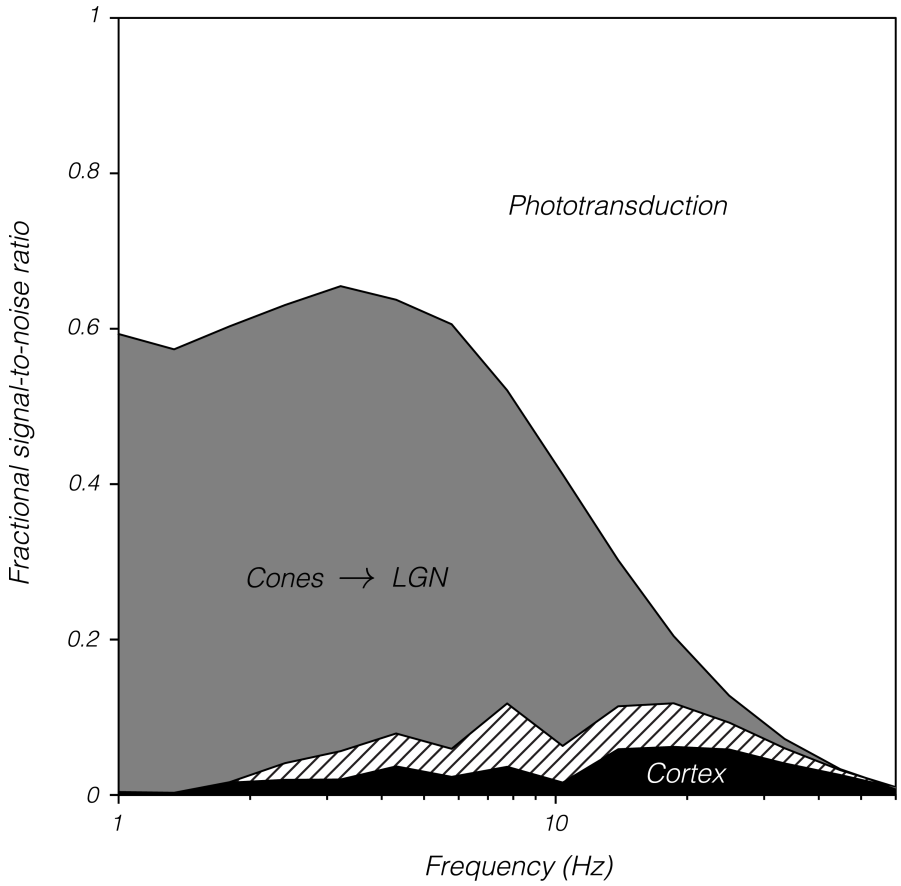
4. Multiple layers of nonlinearity between retinal and cortex may distort the signal, making it difficult to measure with EEG.

RESEARCH ARTICLE

Temporal information loss in the macaque early visual system

Gregory D. Horwitz*

- low temporal frequency information is lost primarily between the cones and the LGN
- high temporal frequency information is lost primarily within the cones, with a small additional loss downstream of the LGN



Why The Inconsistency?

1. Subject's eye movements
   - More correlation analysis
2. Subject's attention and/or arousal
   - More correlation analysis
3. Visual stimulus is not recruiting enough of V1 to create a significantly strong signal
   - Simulations, but what are the non-stimulated V1 neurons "doing"?
4. Multiple layers of nonlinearity between retinal and cortex may distort the signal, making it difficult to measure with EEG.
   - Simulations
   - Analysis methods that might let us bias the EEG signal to early V1 neurons

Thank You

What to do next?

- Additional data collection
  - Leave the paradigm unchanged, see if 2 additional subjects resolve the discrepancy
  - Add a behavioral task increase the subject's arousal/attention
  - Shorten the trials to minimize saccades
  - Change the stimulus to recruit more of V1
    - Binocular, wider bandpass sf range, more orientations
- Try to focus on the EEG components most influenced by foveal V1 and the LGN
  - There are methods for this, specifically current source density, but the spatial resolution of EEG is inherently limited

”An fMRI study of the selective activation of human extrastriate form vision areas by radial and concentric gratings”, Wilkinson et al., 2000. Current Biology.

- Five subjects
- Unspecific # of trials
- Stimuli used were concentric, radial, and parallel geometric patterns
- Main result:
  - Significant activation in V4 with the use of concentric and radial stimuli compared to baseline activation. While all three stimuli used resulted in increased V1 activation, there was so significant difference between the effects of the three.