Temporal contrast sensitivity in the fovea

Janis Intoy + Ruitao Lin

February 2, 2021

Overview

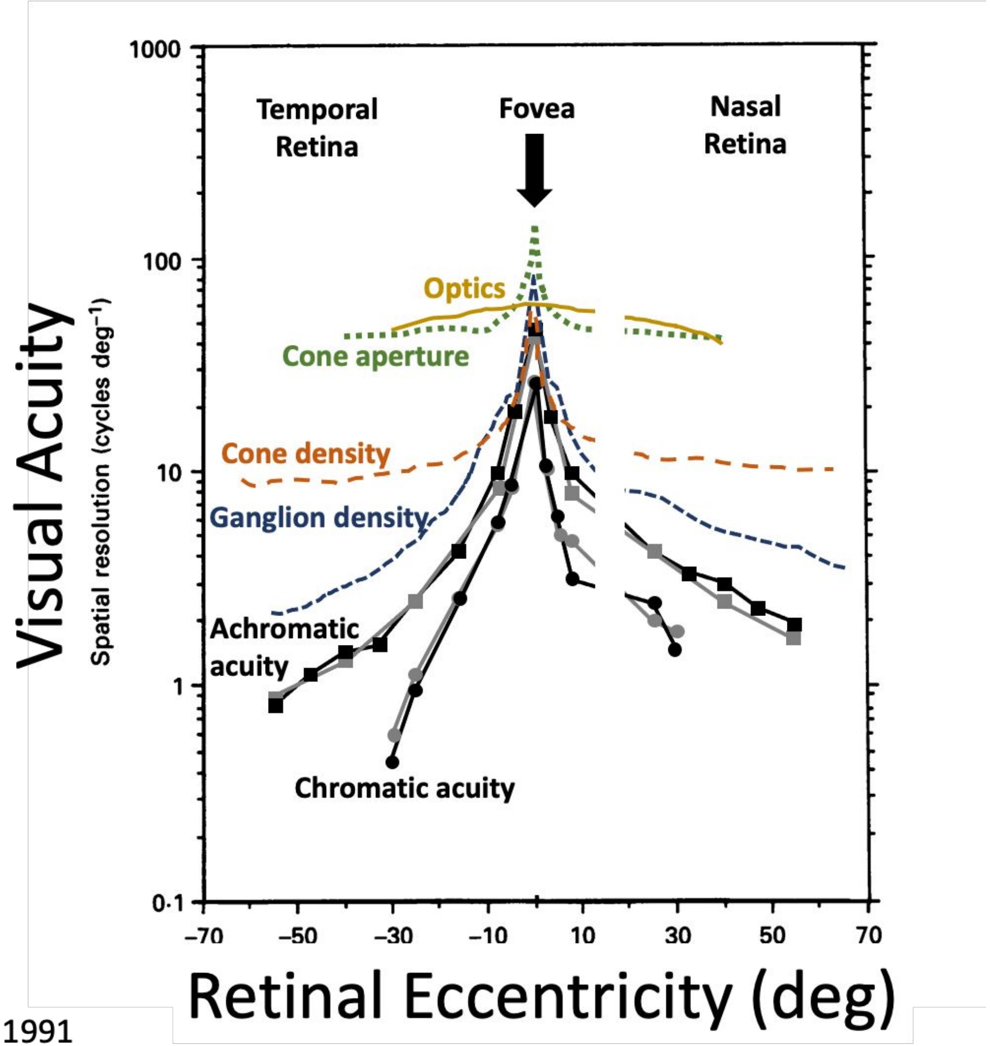
How do humans use the luminance modulations provided by eye movements?

Overarching goal: To characterize spatiotemporal contrast sensitivity across the retina.

This project focuses on temporal contrast sensitivity within the fovea.

1. Literature review: Is the visual field temporally homogeneous? What is known about foveal temporal contrast sensitivity?
2. Paradigm and caveats about ddpi-mk2 and (new) EyeRIS.
3. Pilot results
4. Ddpi-mk2: eye movement characteristics

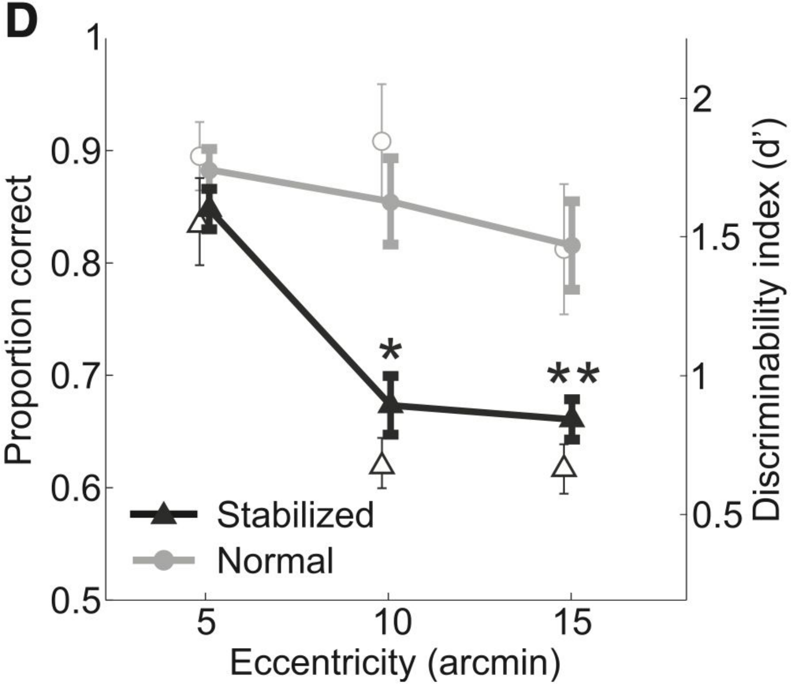
Vision is not uniform across the retina



Adapted from Anderson et al, 1991

Vision is not uniform in the foveola

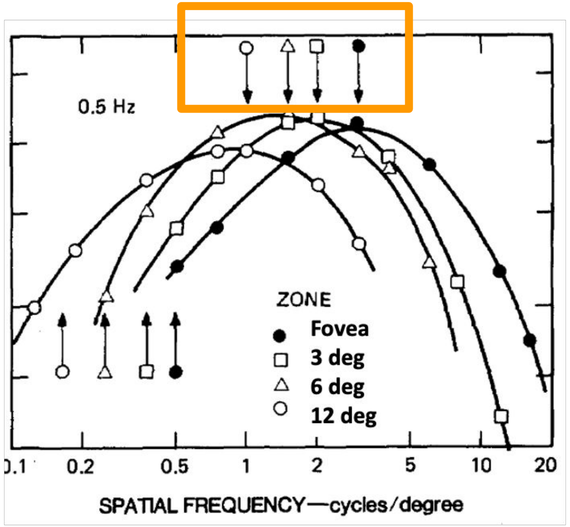
Visual performance falls with increasing eccentricity from the preferred retinal locus within the foveola (Rossi & Roorda, 2010; Poletti et al, 2013)

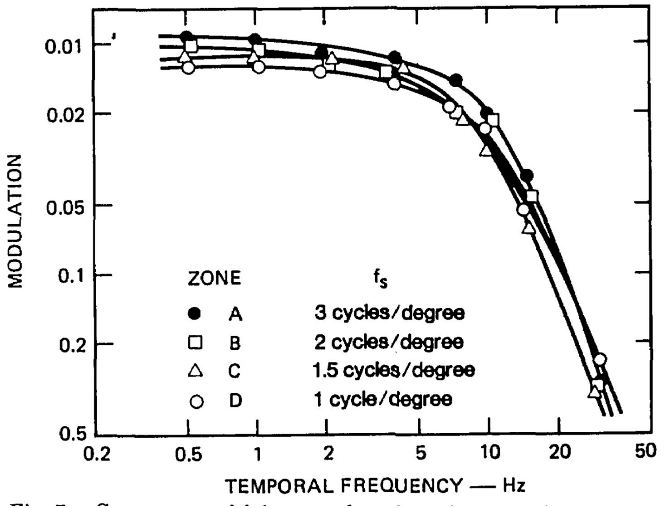


Poletti et al, 2013

Is the visual field temporally homogeneous?

- Temporal sensitivity is uniform across the visual field *when spatial inhomogeneity is accounted for* (Virsu et al, 1980; Wright & Johnson, 1983; Kelly, 1984; Tyler, 1985)



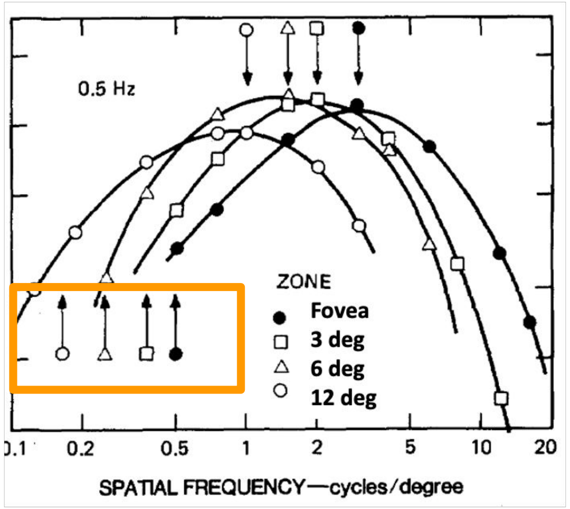


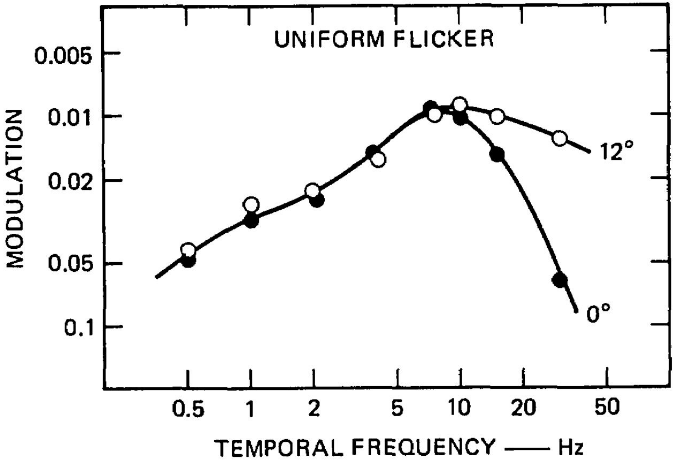
*only Kelly accounts for eye movements

Kelly, 1984

Is the visual field temporally homogeneous?

- Temporal sensitivity is uniform across the visual field *when spatial inhomogeneity is accounted for* (Virsu et al, 1980; Wright & Johnson, 1983; Kelly, 1984; Tyler, 1985)
- At low spatial frequencies, periphery becomes more sensitive to high temporal frequencies (Kelly, 1984; Wright, 1987; Snowden & Hess, 1992; Allen & Hess, 1992)



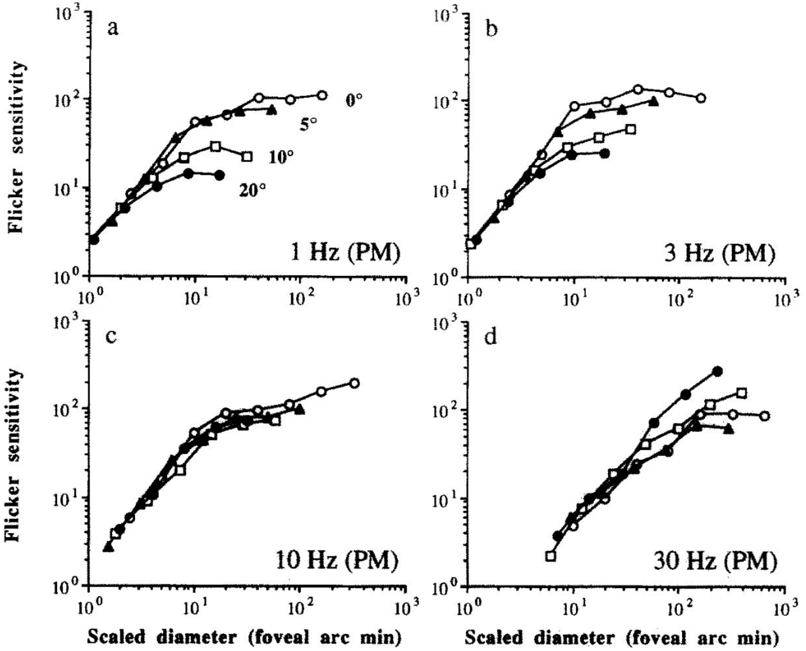


*only Kelly accounts for eye movements

Kelly, 1984

Is the visual field temporally homogeneous?

- Temporal sensitivity is uniform across the visual field *when spatial inhomogeneity is accounted for* (Virsu et al, 1980; Wright & Johnson, 1983; Kelly, 1984; Tyler, 1985)
- At low spatial frequencies, periphery becc more sensitive to high temporal frequenci (Kelly, 1984; Wright, 1987; Snowden & Hess, 1 Allen & Hess, 1992)
- Fovea is more sensitive to low temporal frequencies with small uniform disk stimuli, and periphery to high (Wright, 1987; Mäkelä et al, 1994; Tyler, 1985)



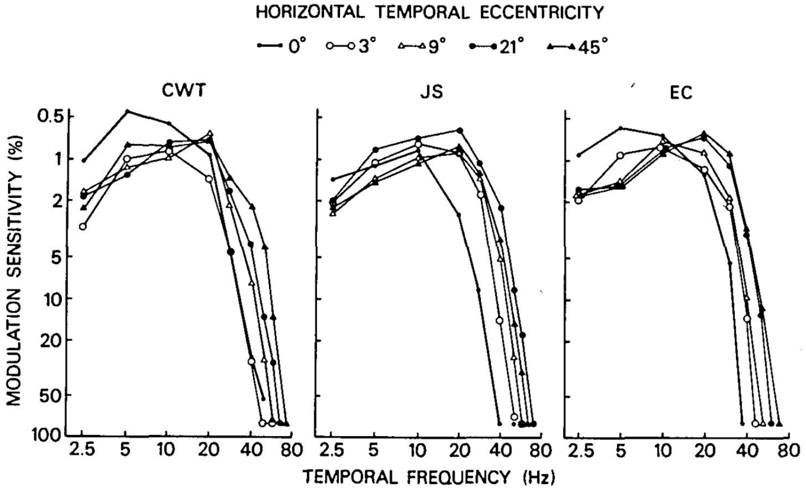
Mäkelä, Rovamu, Whitaker (1994)

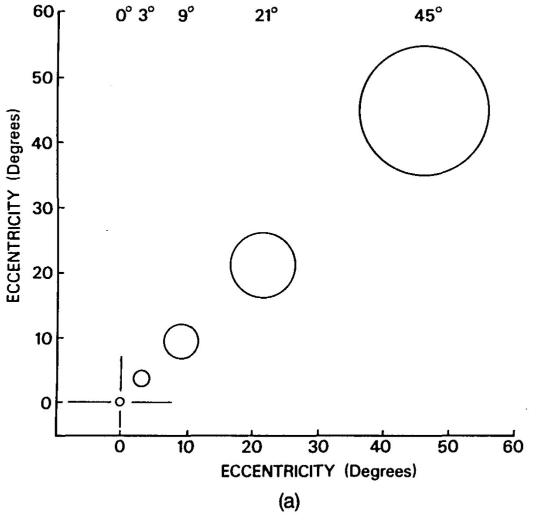
*only Kelly accounts for eye movements

Is the visual field temporally homogeneous?

Most studies used large stimuli to probe foveal temporal sensitivity (>1deg diameter).

Tyler (1985) used a smaller stimulus (0.3deg) and found some deviation in foveal temporal sensitivity.





Tyler, 1985

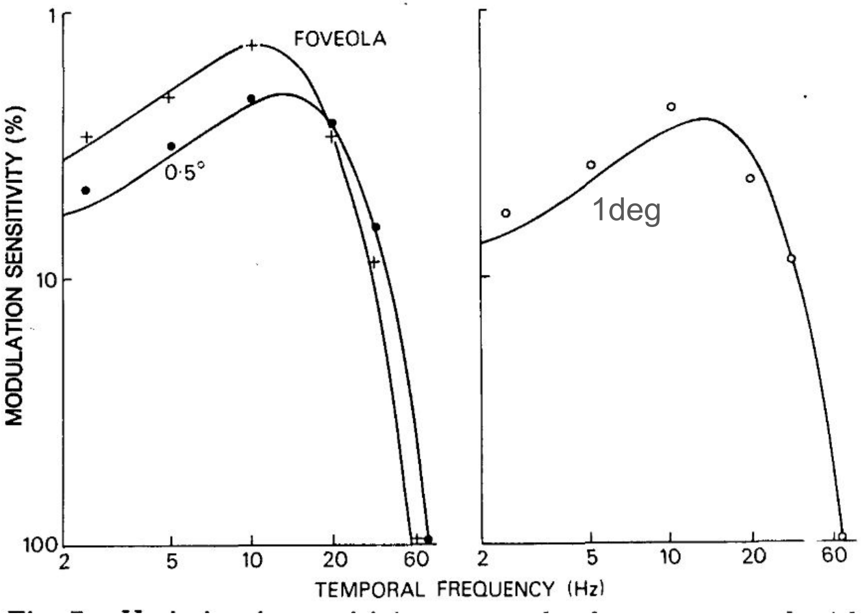
Is the fovea temporally homogeneous?

Temporal sensitivity at different foveal eccentricities:

Stimulus diameter = 0.3 deg

Solid lines are predicted sensitivity

The peak temporal frequency seems to increase with foveal eccentricity.

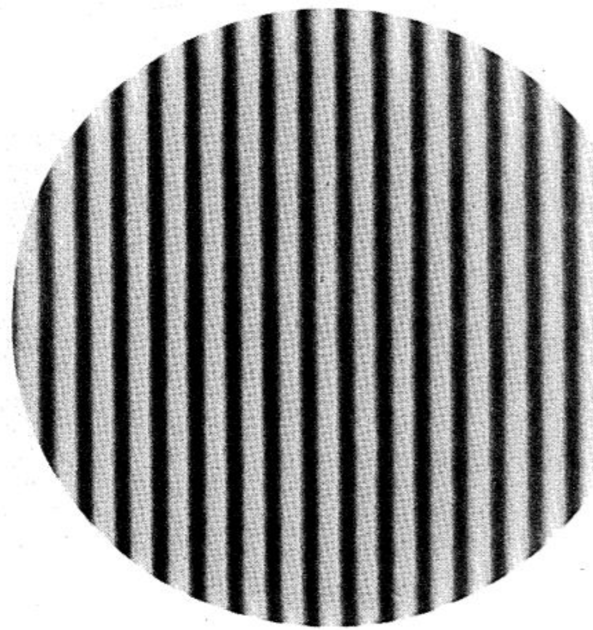


Tyler, 1985

Kelly (1979), I & II: Measuring contrast sensitivity under retinal stabilization

Contrast sensitivity under stabilization

- At 0° eccentricity
- Sinusoidal grating behind 7.5° circular aperture

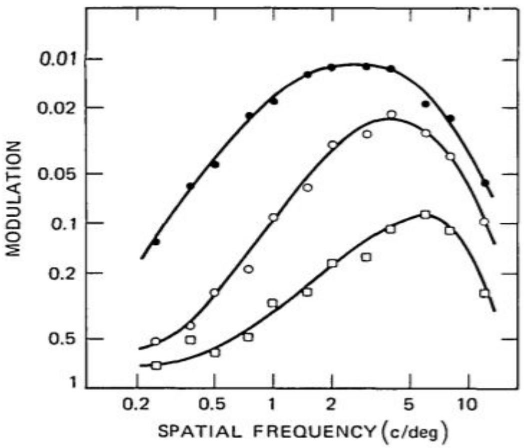


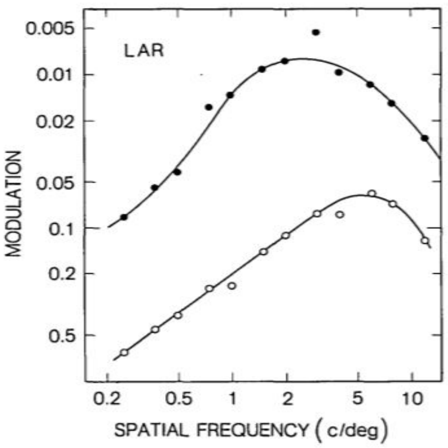
- Method of adjustment
  - Subjective criterion
  - Steady-state threshold

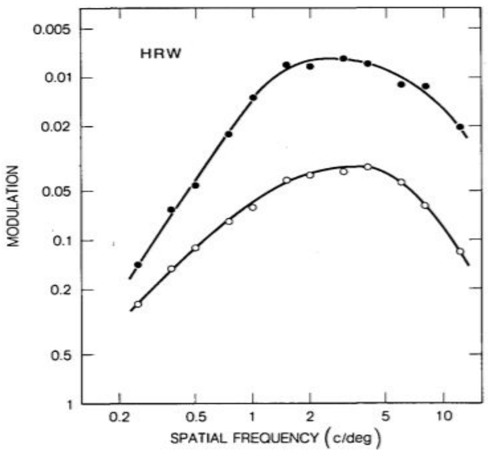
Kelly, 1979

Contrast sensitivity under stabilization

- Stabilization reduces contrast sensitivity at all spatial frequencies
- The better the stabilization technique is, the higher the threshold elevation



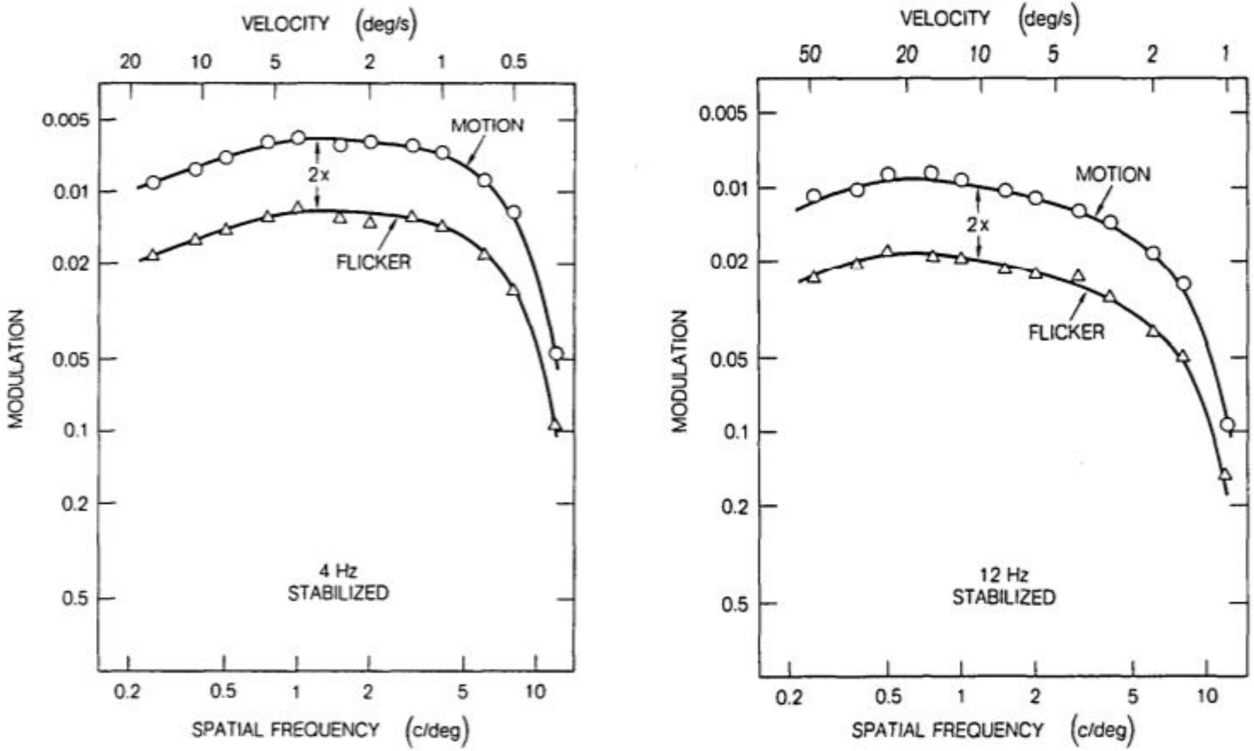




Kelly, 1979

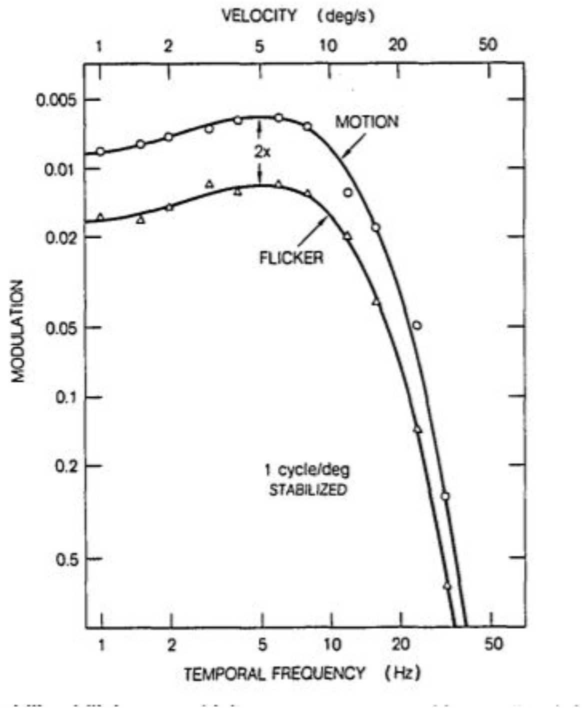
Spatiotemporal contrast sensitivity under stabilization

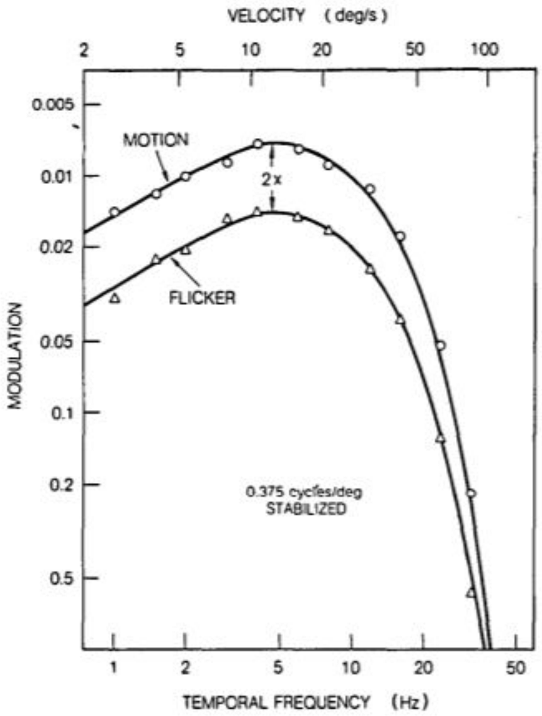
- Fixed temporal frequencies
- Sensitivity curve becomes more band-pass at high temporal frequency



Spatiotemporal contrast sensitivity under stabilization

- Fixed spatial frequencies
- Sensitivity curve becomes more bandpass at high spatial frequency

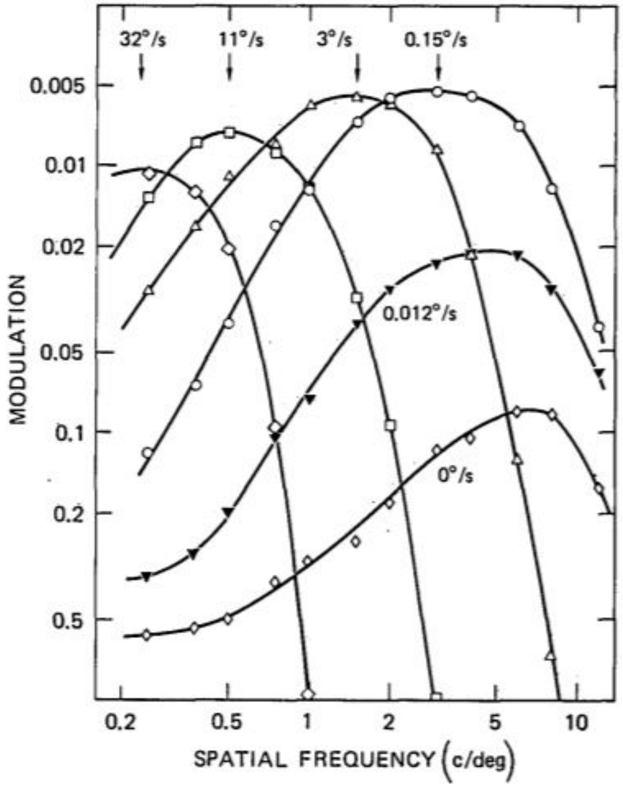




Kelly, 1979

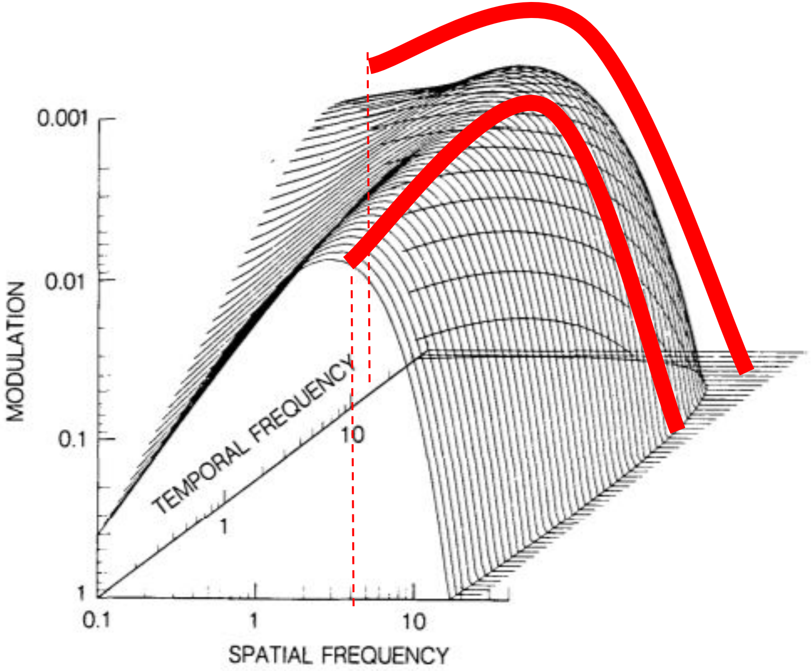
Spatiotemporal contrast sensitivity under stabilization

- High drifting velocities = high temporal frequencies
- Peak spatial frequency becomes lower with increasing velocity.



Spatiotemporal sensitivity contour map

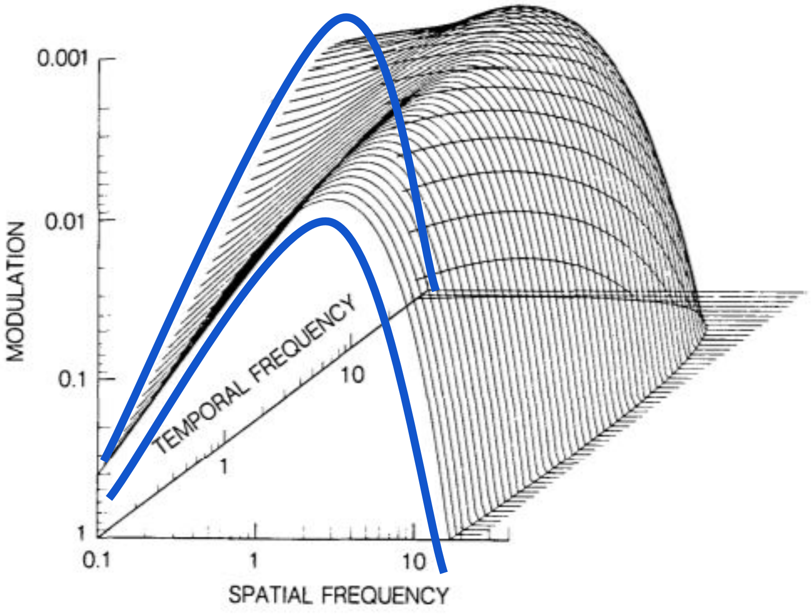
- High spatial/temporal frequencies
  - Sensitivity curve is bandpass



Kelly, 1979

Spatiotemporal sensitivity contour map

- High spatial/temporal frequencies
  - Sensitivity curve is bandpass
- Low spatial/temporal frequencies
  - Sensitivity curve is high pass

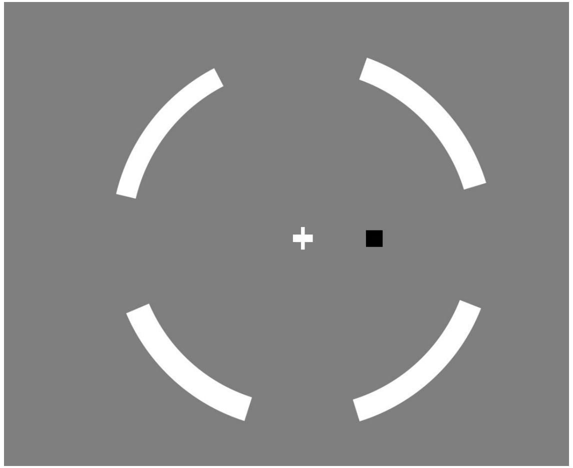


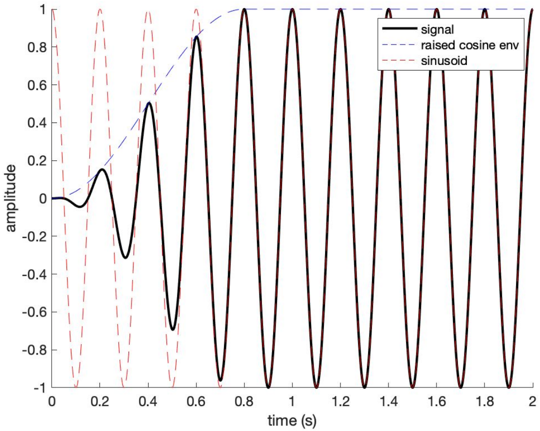
Kelly, 1979

Measuring temporal contrast sensitivity in the fovea

Foveal temporal sensitivity

- Stimulus was a square probe that was sinusoidally modulated in time.
- Foveal eccentricities: [0, 10, 20, 30, 60] arcmin
- Modulation frequencies: [0, 1, 5, 10, 15] Hz
- Probe was stabilized on the retina to maintain retinal eccentricity and minimize other temporal transients
- Fixation aids:
  - Arcs with 2.5deg diameter
  - Cross at center of display was shown only for eccentricity > 10arcmin





Procedure

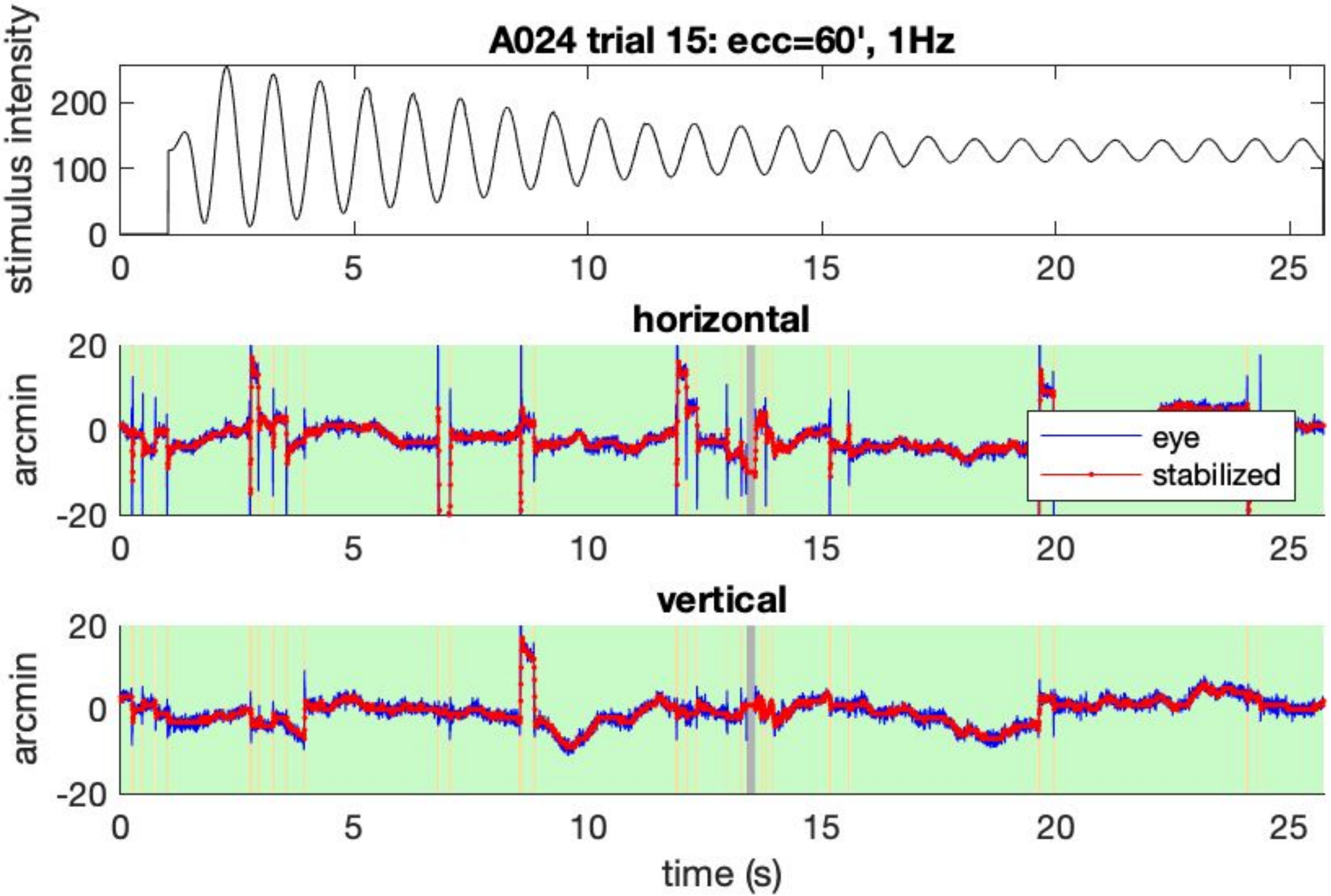
Method of Adjustment

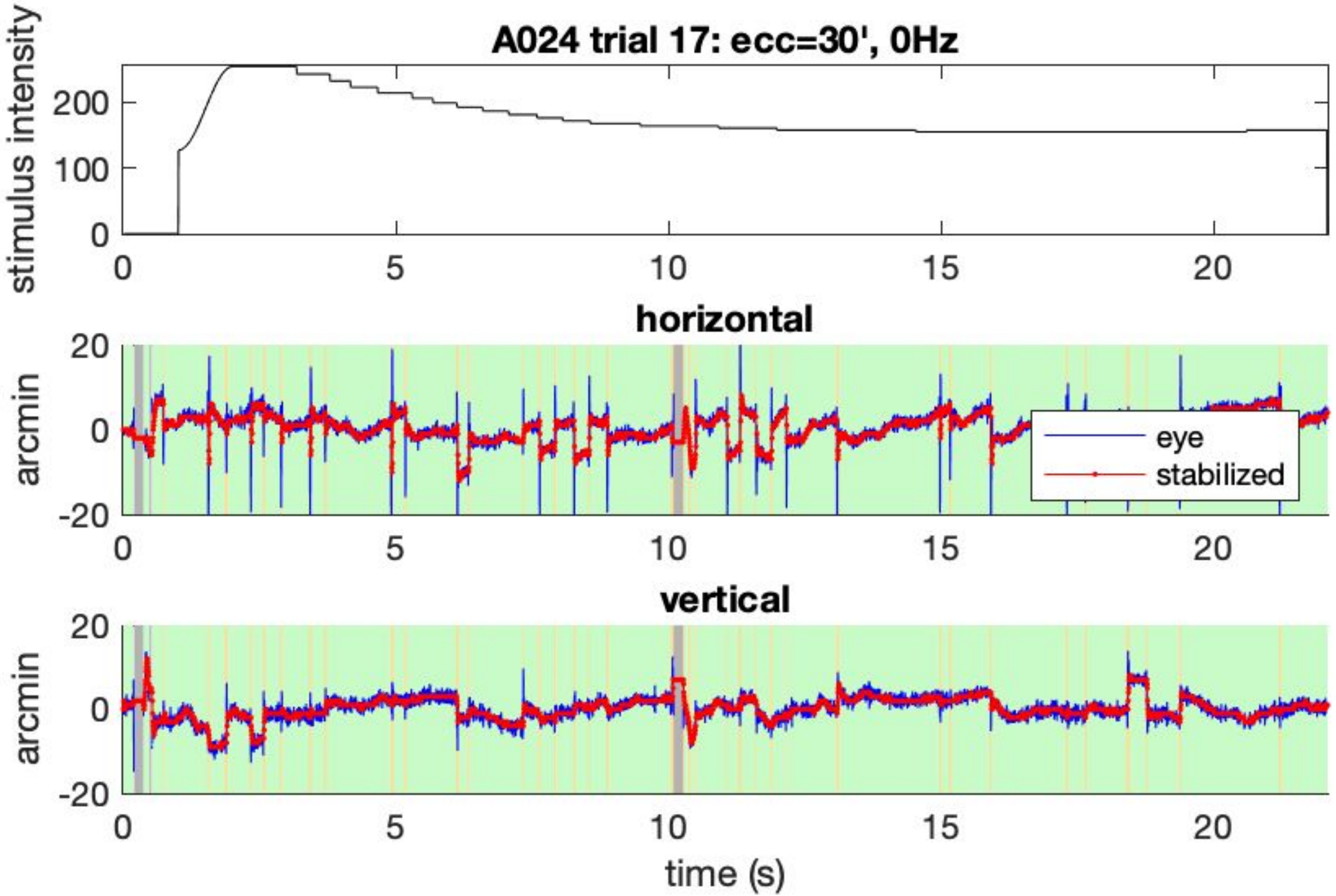
Detection task

Stimulus contrast could start either very low or very high.

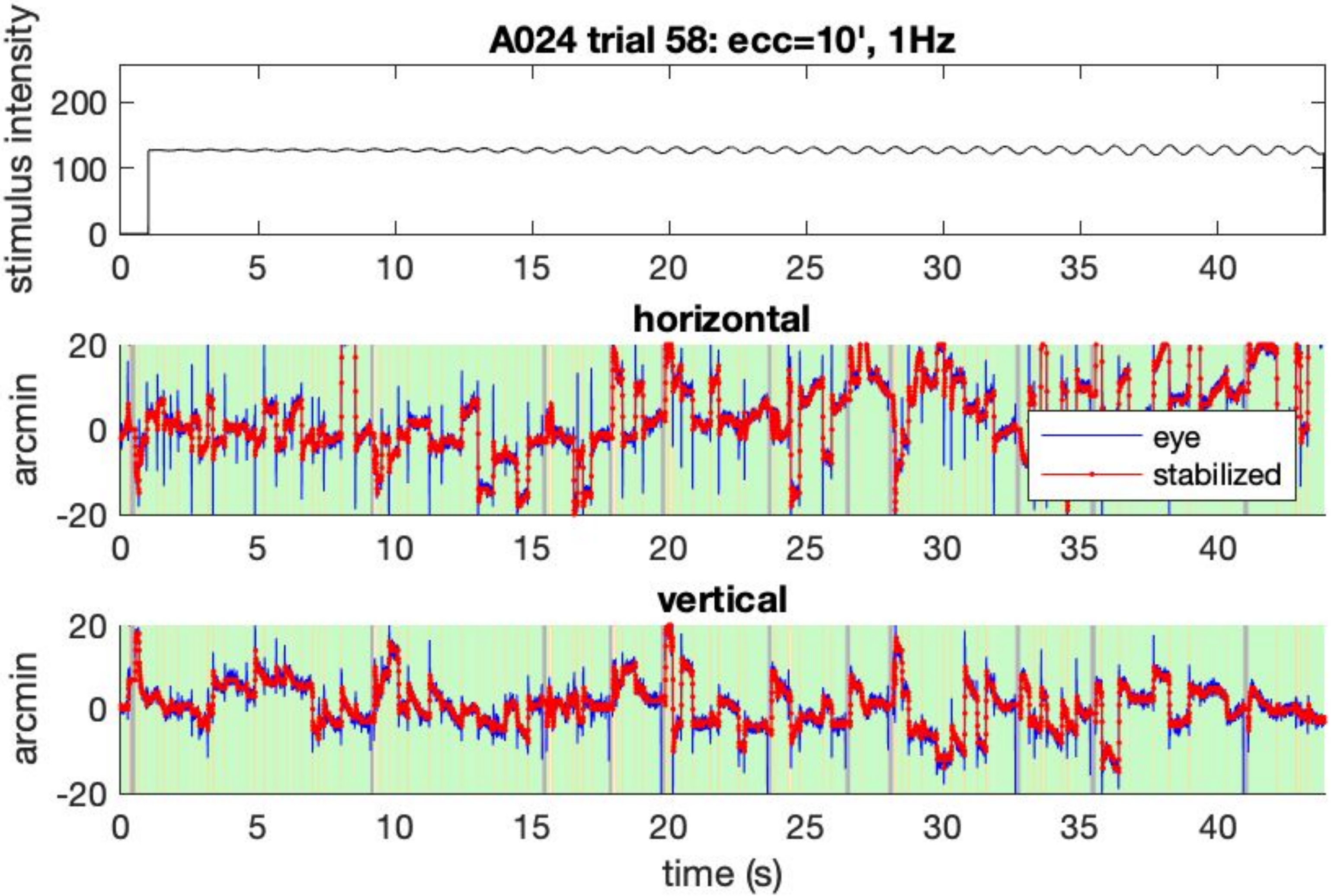
Instructions if stimulus starts high:

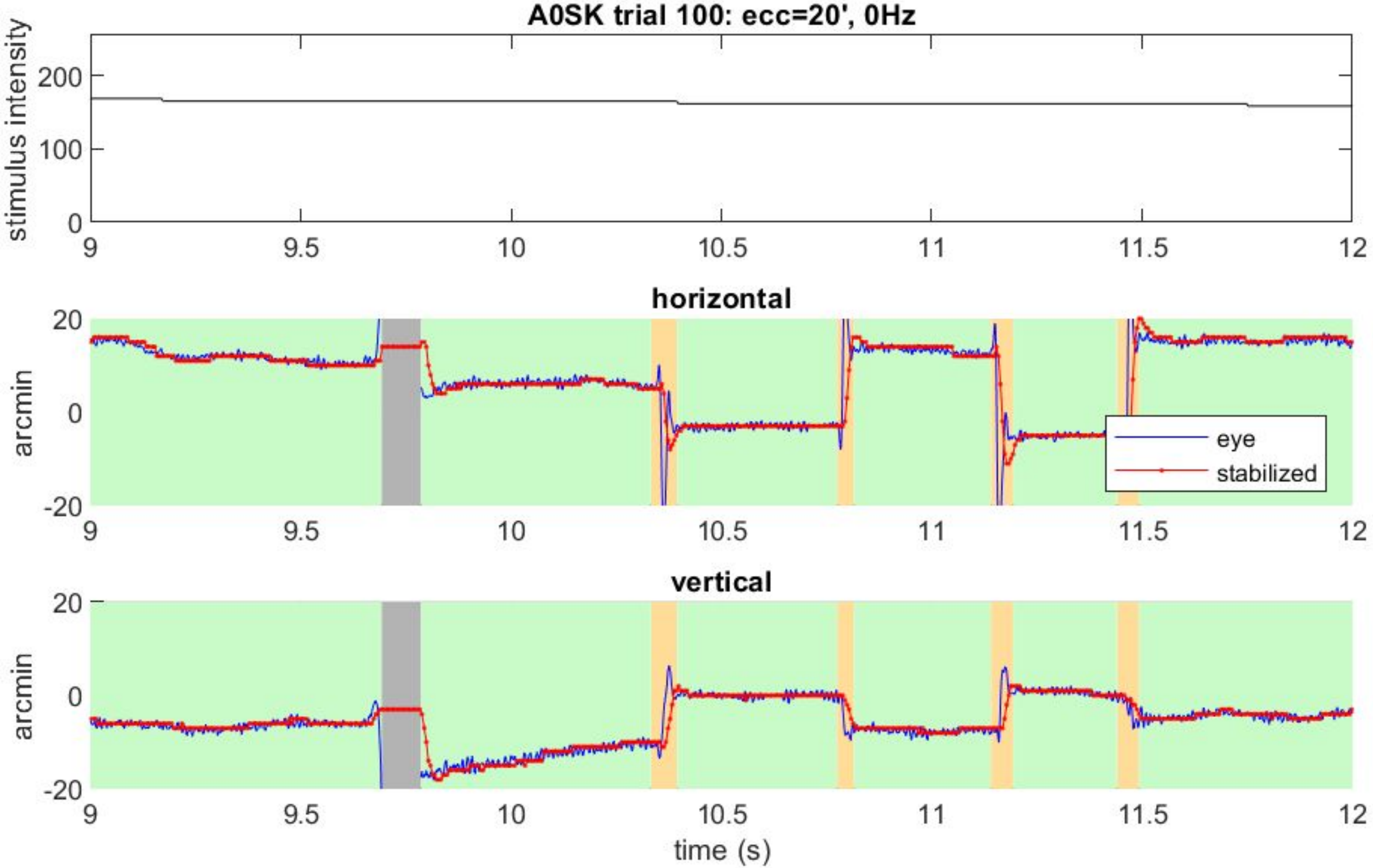
> If you detect a small square, repeatedly and *slowly* press the DOWN button to decrease its contrast. Stop as soon as you can no longer detect the square. When you are sure you cannot detect the square press UP once. Pause for 2 seconds: If you now notice the square, press R2 to end the trial. Otherwise, continue to press UP until you detect the square, then press R2.


A024 trial 15: ecc=60', 1Hz
stimulus intensity
200
100
0
0
5
10
15
20
25
horizontal
arcmin
20
0
-20
eye
stabilized
vertical
time (s)

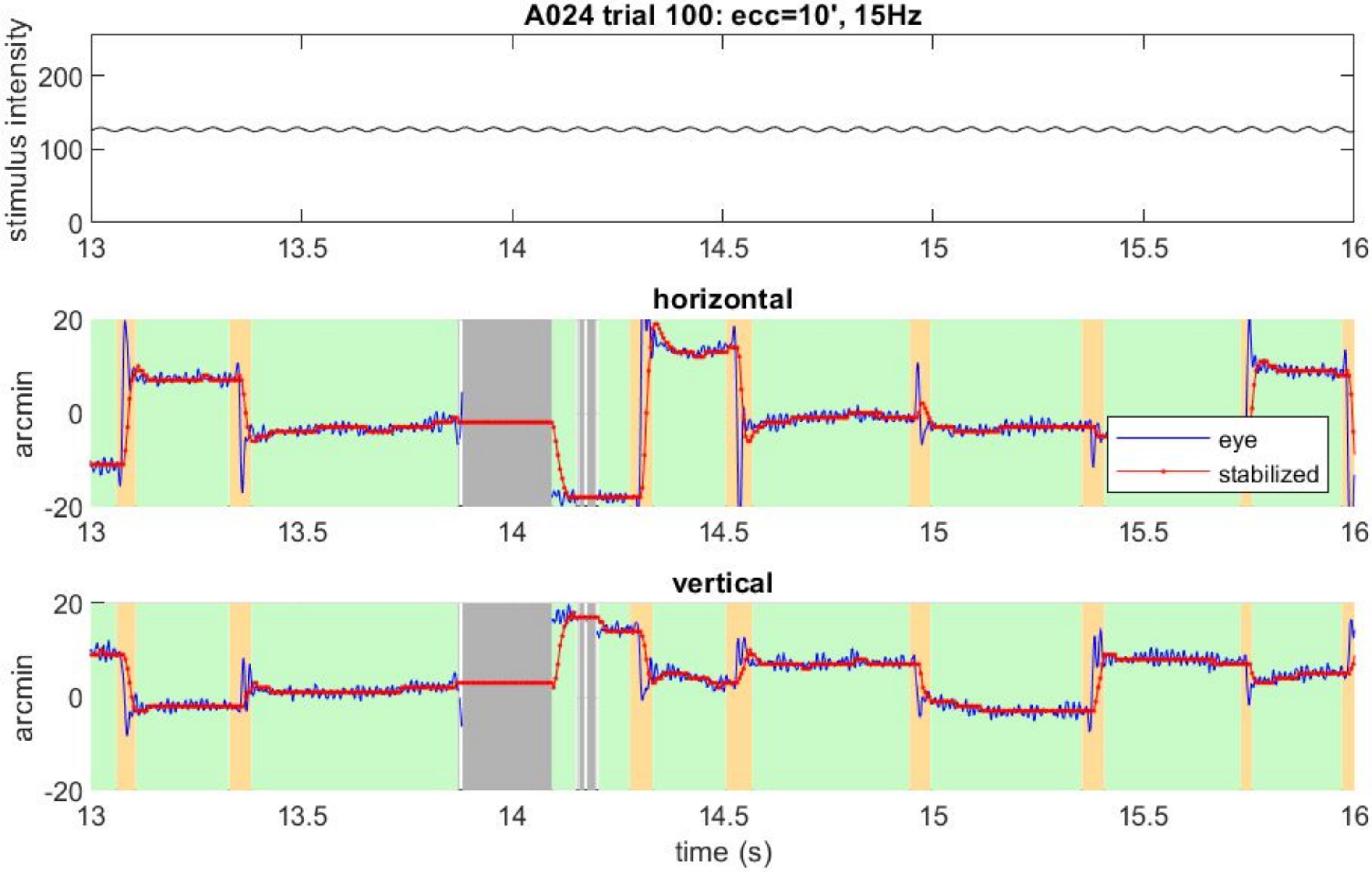


A024 trial 17: ecc=30', 0Hz
stimulus intensity
200
100
0
0
5
10
15
20
horizontal
arcmin
20
0
-20
eye
stabilized
vertical
time (s)


A024 trial 58: ecc=10', 1Hz
stimulus intensity
200
100
0
0 5 10 15 20 25 30 35 40
horizontal
arcmin
20
0
-20
eye
stabilized
vertical
time (s)

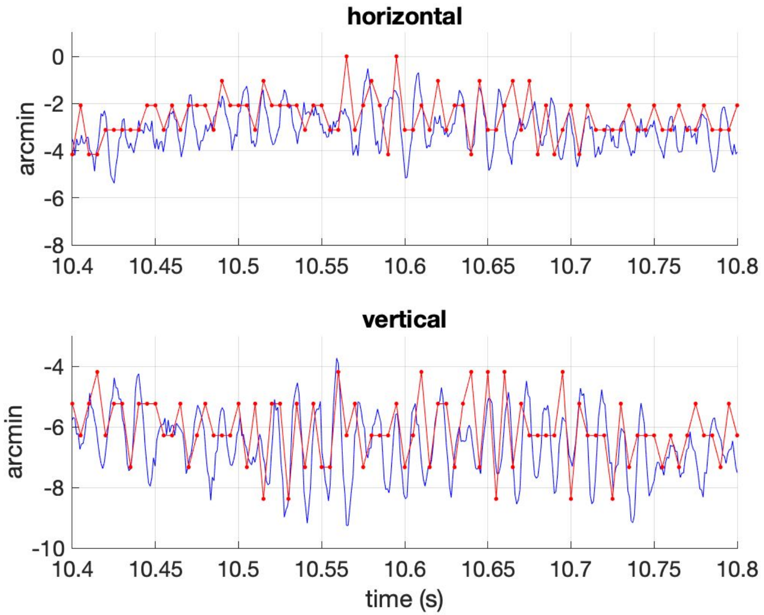


A0SK trial 100: ecc=20', 0Hz
stimulus intensity
200
100
0
9
9.5
10
10.5
11
11.5
12
horizontal
arcmin
20
0
-20
eye
stabilized
vertical
time (s)

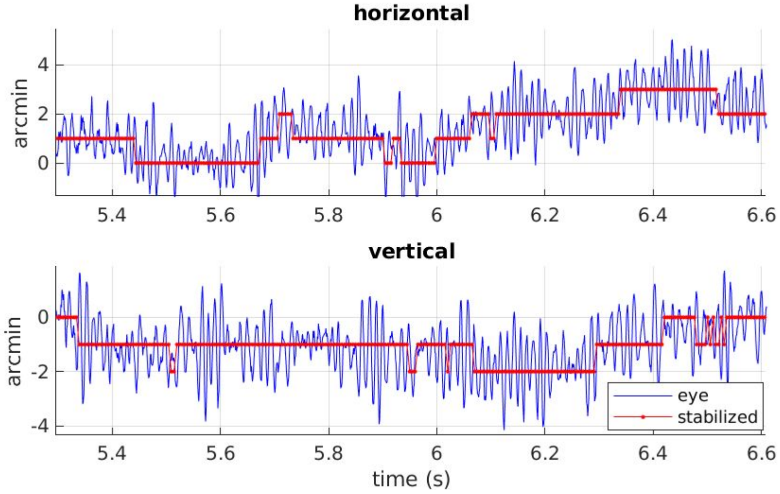


A024 trial 100: ecc=10', 15Hz
stimulus intensity
200
100
0
13
13.5
14
14.5
15
15.5
16
horizontal
arcmin
20
0
-20
eye
stabilized
vertical
time (s)

Technical Problem: Slow stabilization (solved)



Fast stabilization (note timing between eye and stabilized traces are not correct)



Slow stabilization (30Hz cutoff) applied during both saccades and drift

Caveats: Unsolved technical problems

1. Screen tearing: The stimulus is likely not being rendered at 200Hz so there is an error in retinal stabilization
2. Monitor linearization: We are not sure if EyeRIS is applying the gamma corrections to linearize the luminance of the monitor. The monitor settings *may* have been changing between data collection sessions, but the luminance is linear in the range we are interested in regardless of specific screen setting.
3. Additional transients are introduced by stabilization errors around the times of blinks and saccades.
4. Subjects completed only autocalibration and re-calibrations, not manual calibration.

Data Collection

Probe size = 10 arcmin

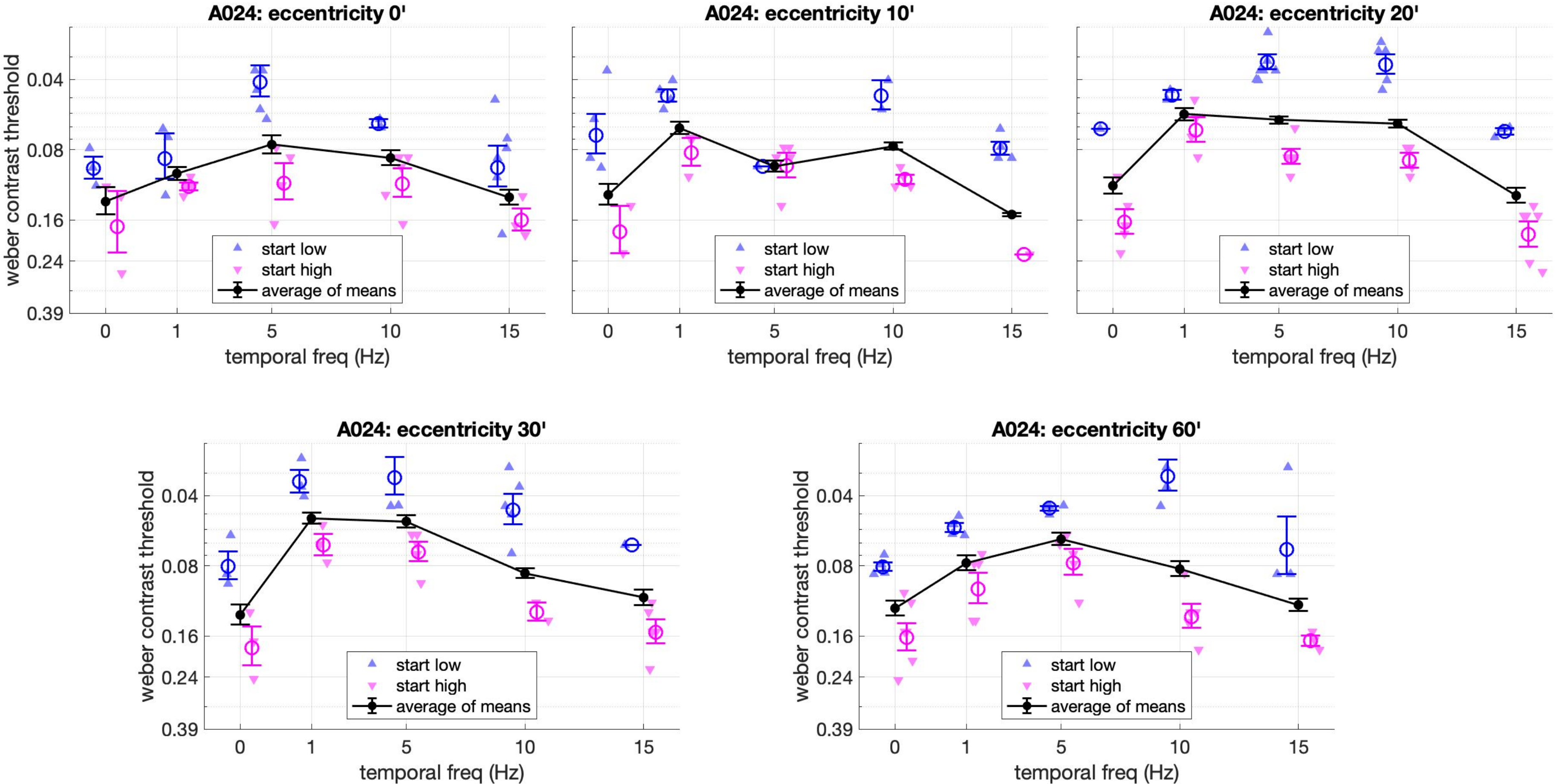
A024					
# sessions = 4 Total Time = 91.18 minutes Total Trials = 214 Excluded Trials = 20 Aborted = 12, Bad Fixation = 1, Flagged = 7 Valid Trial Time = 85.72min, 26.51±9.48s per trial					
	0′	10′	20′	30′	60′
0Hz	**6** (3-3)	**6** (4-2)	**6** (1-5)	**6** (3-3)	**10** (4-6)
1Hz	**7** (3-4)	**7** (4-3)	**6** (2-4)	**6** (3-3)	**9** (4-5)
5Hz	**10** (6-4)	**6** (1-5)	**13** (8-5)	**9** (4-5)	**9** (4-5)
10Hz	**7** (2-5)	**6** (2-4)	**9** (5-4)	**7** (5-2)	**9** (4-5)
15Hz	**9** (6-3)	**5** (4-1)	**9** (3-6)	**6** (1-5)	**6** (3-3)

Probe size = 6 arcmin

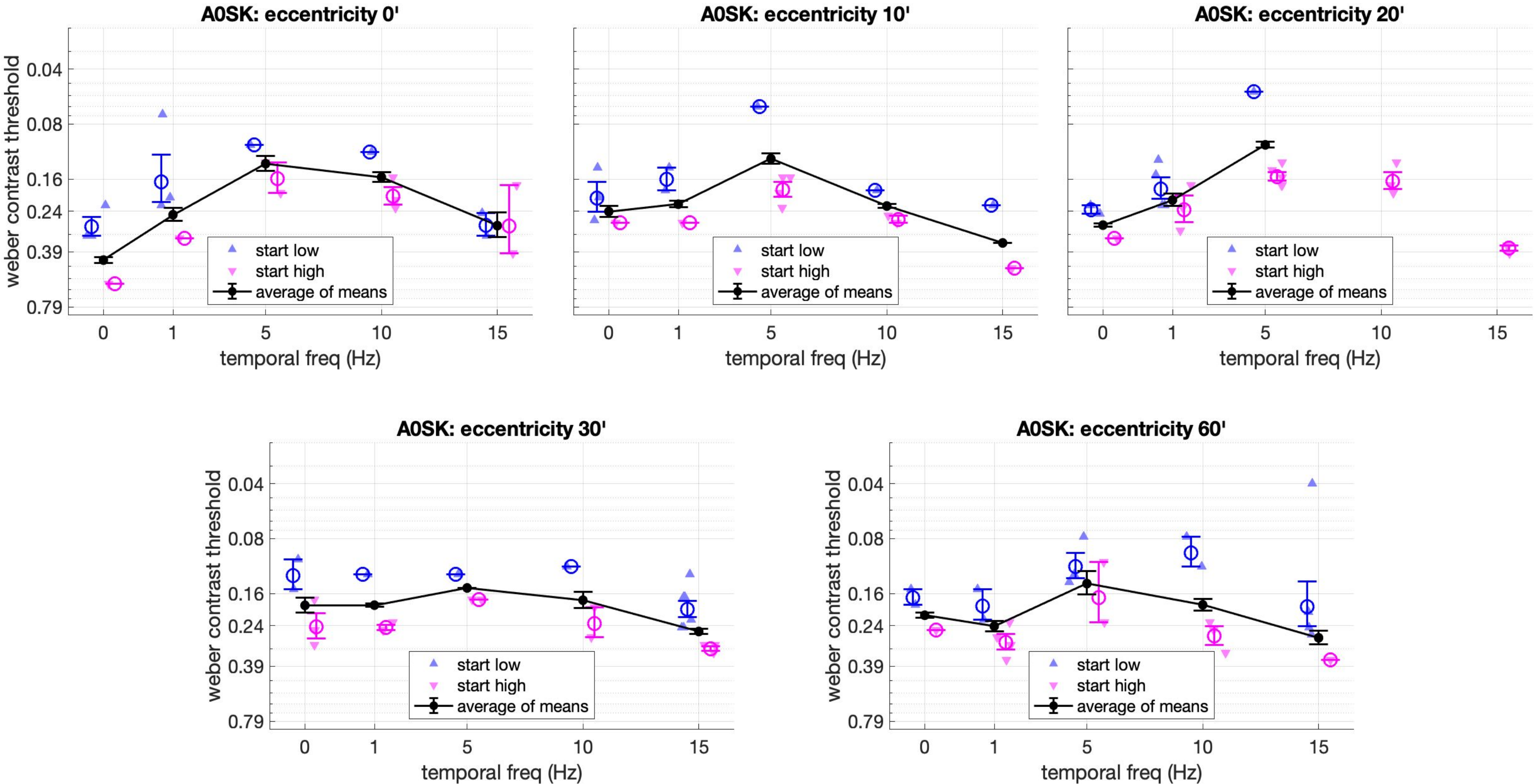
A0SK					
# sessions = 2 Total Time = 60.44 minutes Total Trials = 125 Excluded Trials = 18 Aborted = 3, Bad Fixation = 14, Flagged = 1 Valid Trial Time = 49.25min, 27.62±10.72s per trial					
	0′	10′	20′	30′	60′
0Hz	**4** (3-1)	**4** (3-1)	**3** (2-1)	**5** (2-3)	**3** (2-1)
1Hz	**4** (3-1)	**3** (2-1)	**7** (4-3)	**4** (1-3)	**6** (2-4)
5Hz	**3** (1-2)	**5** (1-4)	**6** (1-5)	**3** (1-2)	**5** (3-2)
10Hz	**4** (1-3)	**3** (1-2)	**3** (0-3)	**3** (1-2)	**5** (2-3)
15Hz	**4** (2-2)	**2** (1-1)	**3** (0-3)	**10** (6-4)	**5** (4-1)

Table 1: Number of valid trials collected in each condition (bold). Numbers in parantheses are the number of trials with low and high initial contrasts respectively. Aborted = trial ended early online. Bad Fixation = gaze left 100arcmin radius. Flagged = trial flagged after visual inspection of data.

A024: Contrast thresholds by eccentricity

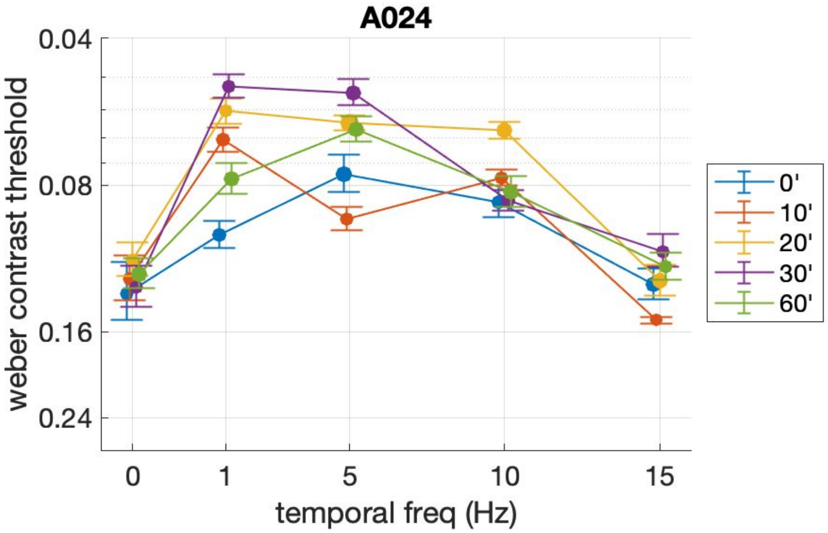


A0SK: Contrast thresholds by eccentricity

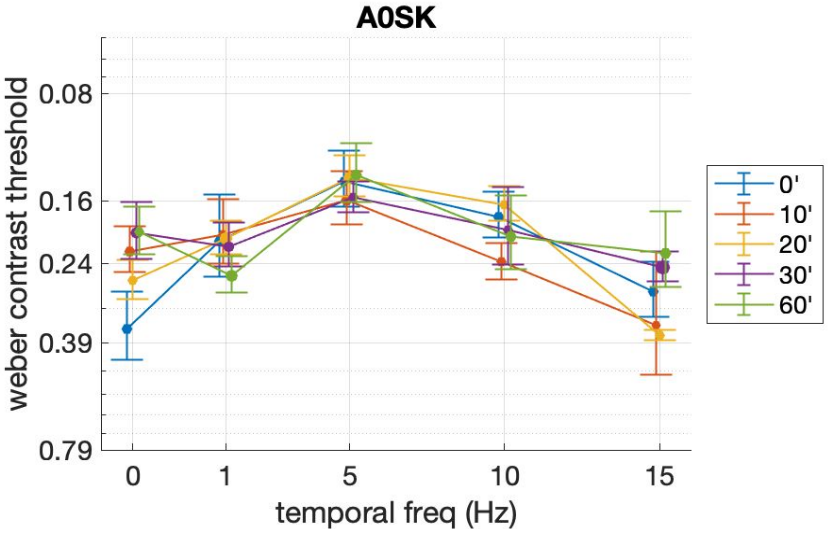


Temporal contrast thresholds

Probe size = 10 arcmin



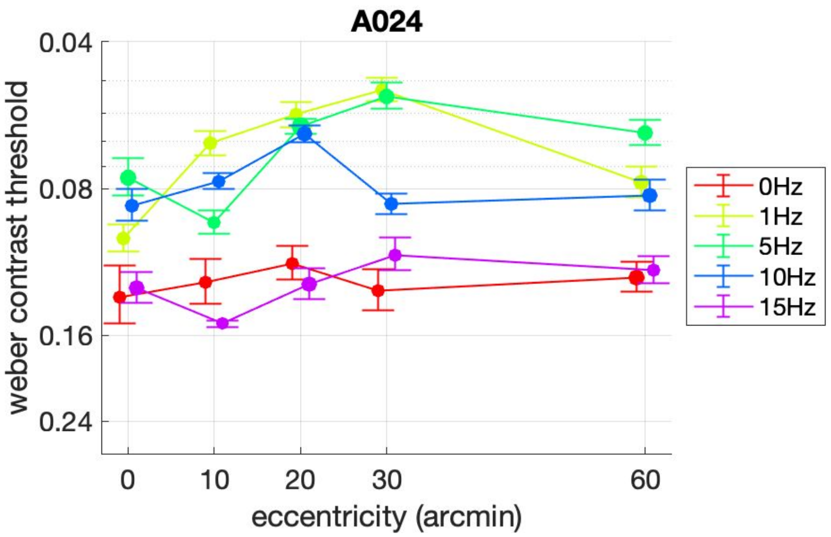
Probe size = 6 arcmin



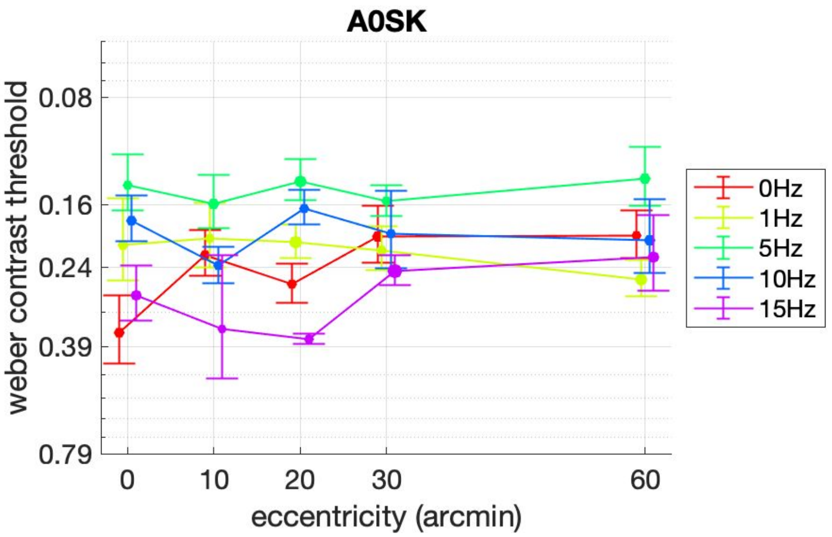
Foveal sensitivity is highest when stimuli are modulated in the range 1-5Hz.

Temporal contrast thresholds

Probe size = 10 arcmin



Probe size = 6 arcmin



There may be an effect of foveal eccentricity on sensitivity: fovea is most sensitive to 1-5 Hz oscillations around 30 arcmin eccentricity.

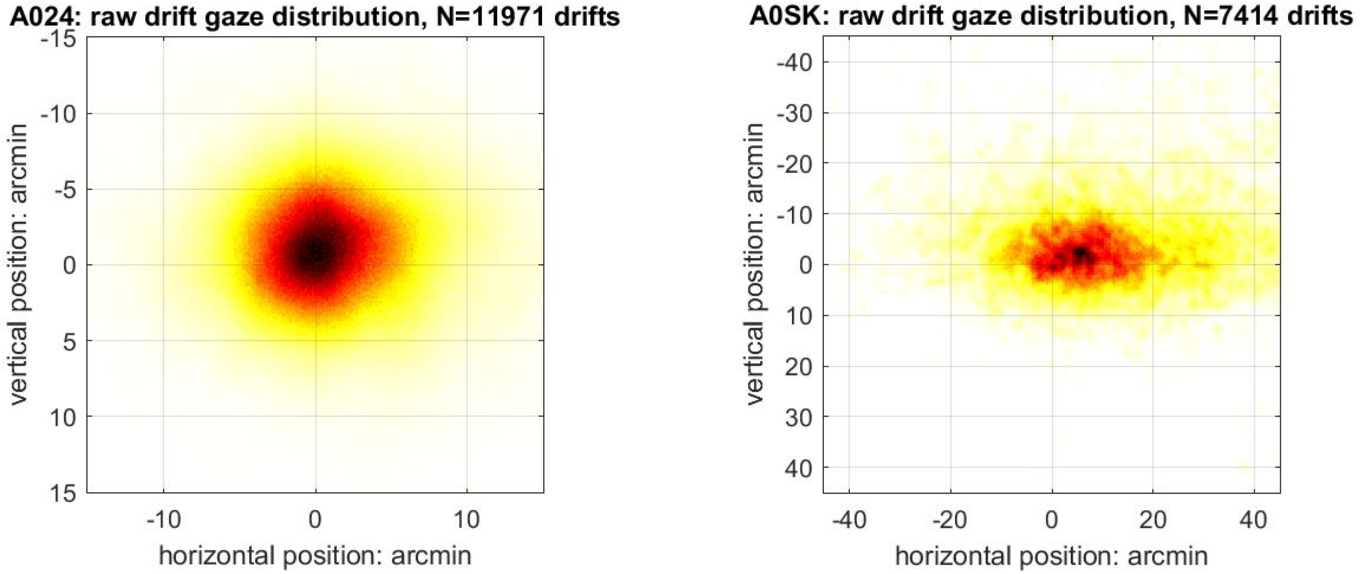
Summary

- Foveal contrast sensitivity is highest when stimuli are modulated in the range 1-5Hz.
- Temporal modulations may be more helpful in more eccentric fovea.
-
- How can we improve instructions to better measure “steady-state” sensitivity?

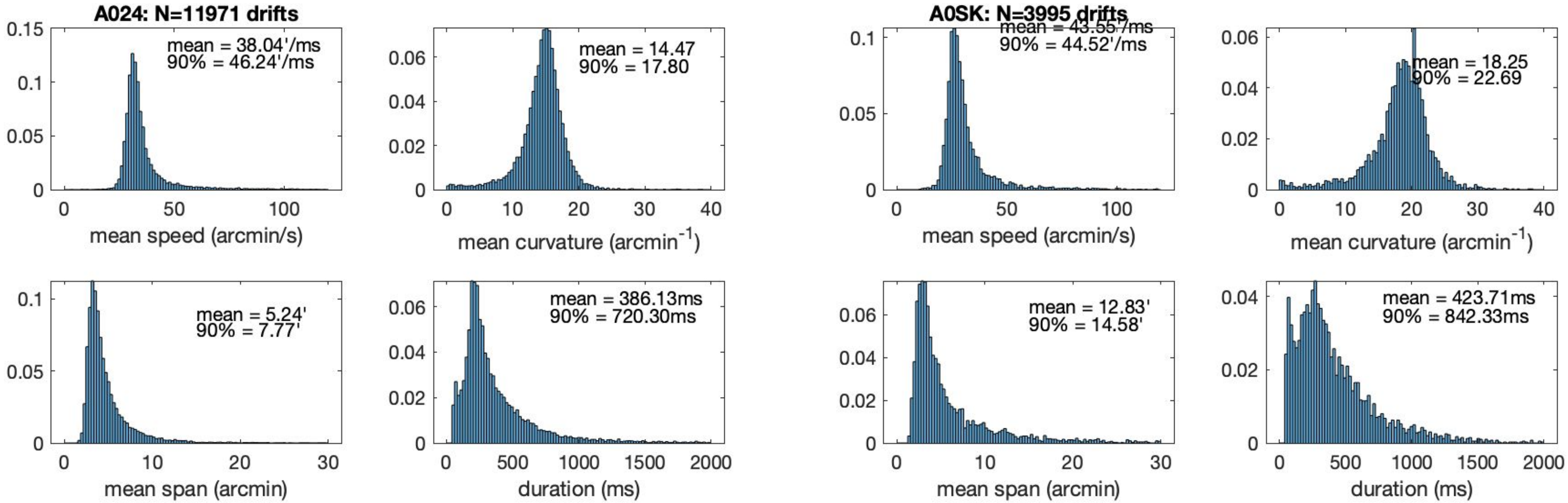
Next Steps:

- Confirm pattern of sensitivity with more accurate threshold estimation
- Extend paradigm to spatio-temporal stimulus at larger eccentricities

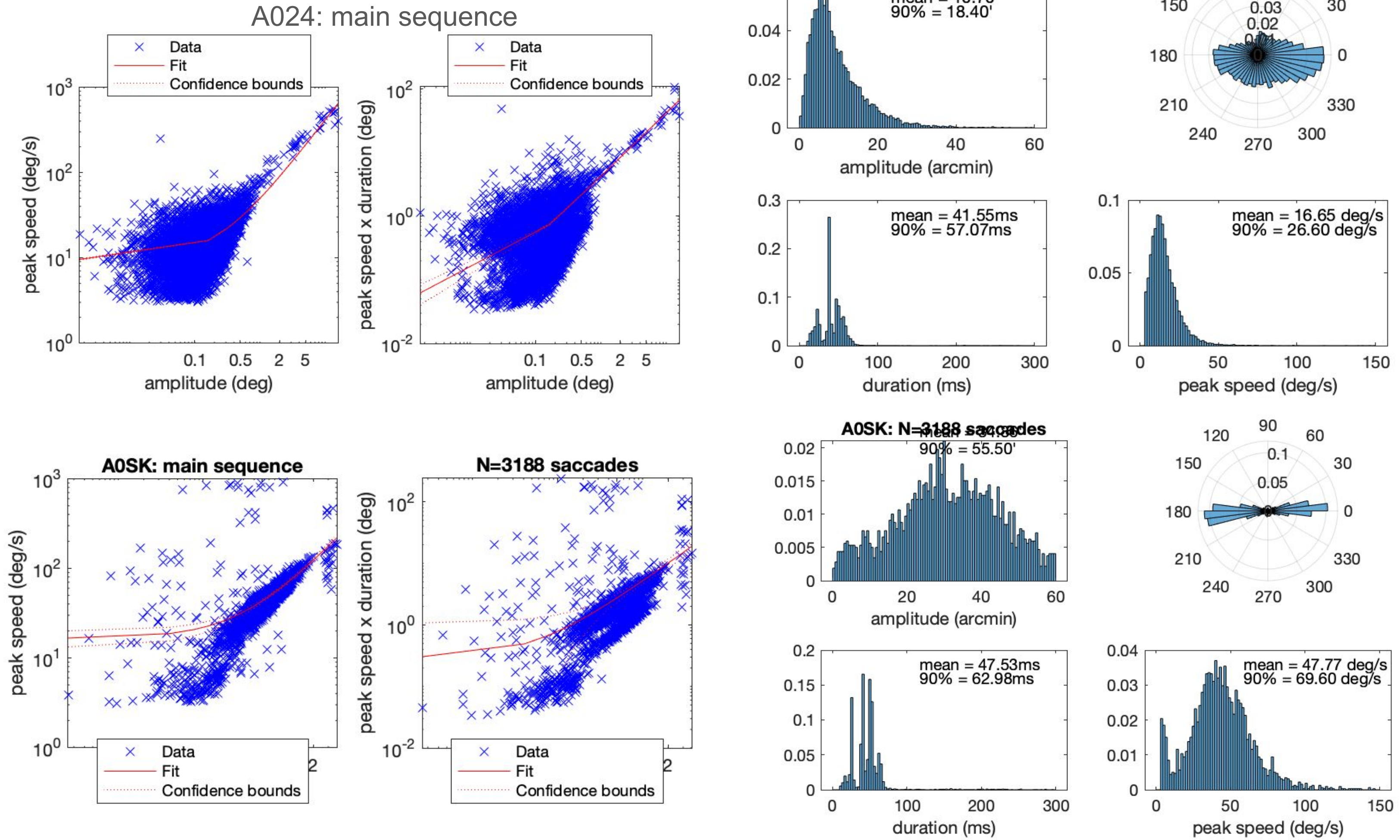
Eye movement characteristics



Drift characteristics



Saccades



A024: main sequence
Data
Fit
Confidence bounds
peak speed (deg/s)
amplitude (deg)
peak speed x duration (deg)
A024: N=11106 saccades
mean = 10.70'
90% = 18.40'
amplitude (arcmin)
mean = 41.55ms
90% = 57.07ms
duration (ms)
mean = 16.65 deg/s
90% = 26.60 deg/s
peak speed (deg/s)
A0SK: main sequence
N=3188 saccades
A0SK: N=3188 saccades
90% = 55.50'
amplitude (arcmin)
mean = 47.53ms
90% = 62.98ms
duration (ms)
mean = 47.77 deg/s
90% = 69.60 deg/s
peak speed (deg/s)