Spatiotemporal sensitivity across the visual field

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Contents

1 Introduction

The goal of these experiments is to characterize spatiotemporal sensitivity at various eccentricities across the retina. This has not been done thoroughly, particularly at points nearer the fovea, and can be done more accurately with retinal stabilization.

These results would of course be interesting on their own but will more importantly enable us to make more accurate predictions about visual function at different points on the retina.

The design of these experiments is similar to Kelly (1979) in which spatiotemporal sensitivity was measured within the fovea under retinal stabilization.

2 Resources

- **Data** is available on box (`APLab-Projects/SpaceTimeCoupling/ContrastSensitivity_Eccentricity/data` or `https://rochester.box.com/s/reilf143kcbxlj11wpygxbvzf4jg5qa2`)
- **Implementation of Contrast Sensitivity mapping experiments in new eyeris is available on gitlab**: `https://gitlab.com/jintoy/contrastsensitivitymap`
- **Analysis of Contrast Sensitivity mapping data** is available on box:
  - on gitlab: `https://gitlab.com/jintoy/contrastsensitivitymap_analysis`
  - on BOX: `APLab-Projects/SpaceTimeCoupling/ContrastSensitivity_Eccentricity/Code` or `https://rochester.box.com/s/j0fdeth1e03w3zd8mhoodsoveydytone`
- **Subject and experimenter instructions available on box:** `APLab-Projects/SpaceTimeCoupling/ContrastSensitivity_Eccentricity/Documents/ContrastSensitivity_Ecc_Instructions.docx` or `https://rochester.box.com/s/il6fc04jujofc2xru6ewom0j8w4ae7kh`

3 Experiment 1: Mapping foveal temporal sensitivity

Here we will measure contrast sensitivity to a modulated stimulus presented at different eccentricities throughout the fovea.

3.1 Stimulus and Paradigm

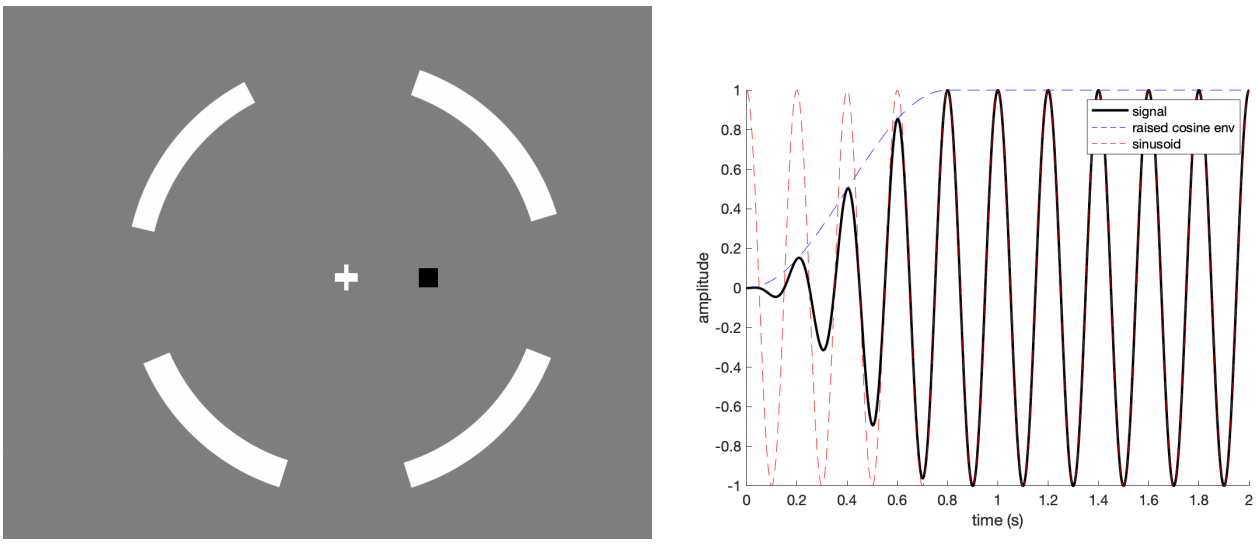

Figure 1: Example stimulus. A small probe (black square) will be temporally modulated and stabilized on the retina. Subjects will adjust the contrast until it is just barely visible while maintaining fixation on the white cross (method of adjustment). The fixation cross and arcs are not stabilized.

1. Method of adjustment: Subjects will adjust the contrast of the probe via button presses until the probe is just barely *detect-able*. The initial contrast may be very low or very high.
    - We will run this version first because we believe it will be faster. If thresholds are similar across different trials, we may continue with this method. If there is high variance across trials, we will run some subjects on version 2 which should be more accurate.
    - **Subject instructions:** If the square is at first invisible, increase its contrast until you can just barely see it. Then go one click down in contrast. If the square is at first visble, decrease its contrast until you can just barely *not* see it, then go one click up in contrast.
2. Psychometric threshold estimation: The probe will be presented for a fixed period of time (2-3 seconds?) and subjects will be asked to report present or absent after a cue. The signal amplitude in each trial will be random (constant stimuli) or selected by an adaptive staircase procedure (maximum likelihood pest?).
    - In this case the stimulus will both ramp up and down

3.2 Methodological details and notes

See Section 6.2 in appendix for the outcome of the earliest test of this experiment and improvements to stabilization.

Piloting started on started December 9, 2020.

Run parameters and notes:

- method of adjustment starting from both low and high contrast
- Eccentricities: [0, 10, 20, 30, 60] arcmin
- Temporal Frequencies: [0, 1, 5, 10, 15, 25] Hz
- Total conditions: 30
- A024 did not run at 25Hz
-
- Experimenter: Ruitao
- Subject: Janis (A024), Sanjana (A0SK)
-
- Size of probe: 10pixels = 10.4arcmin (A024), 6 pixels = 6.18arcmin (A0SK)
- Bug discovered on January 11: we believed the probe size was 4pixels = 4.15arcmin, but setSize() was not working so the probe was actually 10pixels = 10.4arcmin. The smaller probe greatly elevated thresholds though, so maybe we'll go with something in between for future subjects.
- contrast is adjusted in multiplicative steps of 1.1
- Distance to monitor: 0.93m
- Pixel to angle conversion: 1.03arcmin per pixel
- Eyeris Version: 18.11.1
-
- Stabilization:
  - Slow stabilization was enabled (∼30Hz cutoff), sticky parameter = 0.
  - Stabilization was only accurate for gaze within a 100arcmin radius due to an additional slow stabilization parameter (fixationRadius) because the no-track signal is currently unreliable.

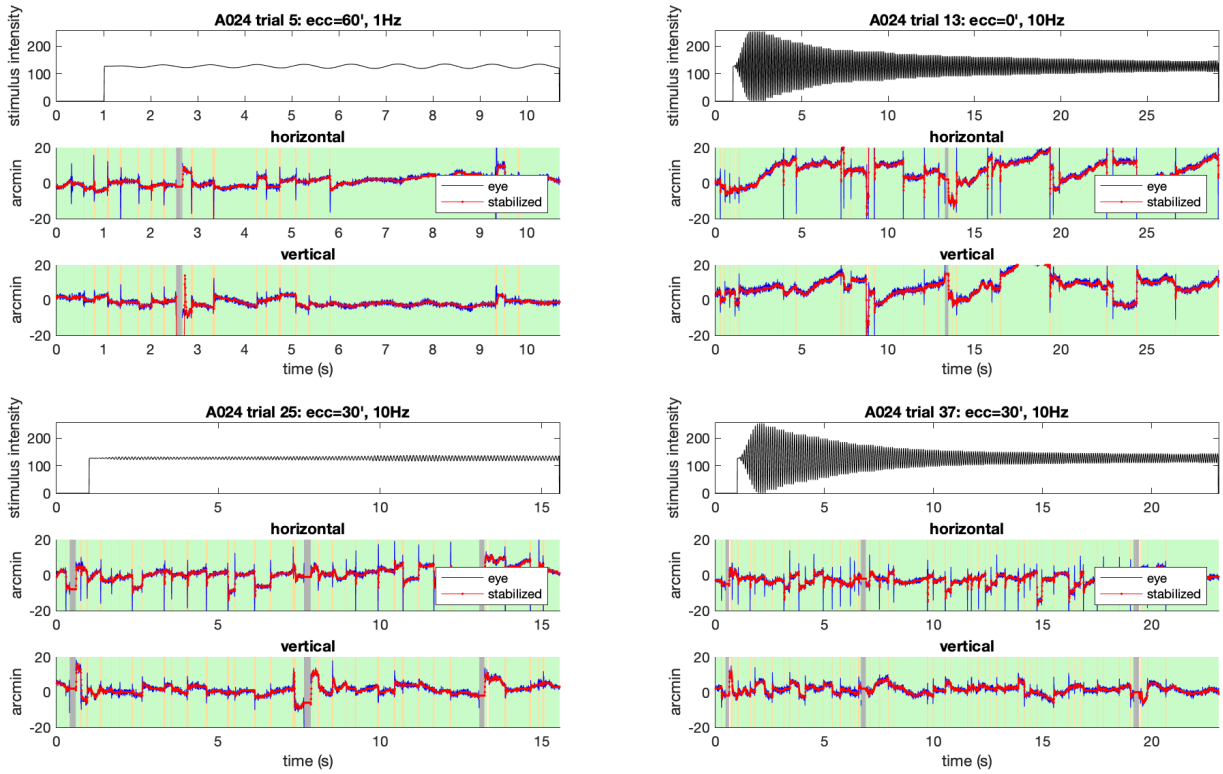

Figure 2: Four example trials. Top panel shows pixel intensity of the stimulus over time. Bottom two panels show horizontal and vertical eye and stabilized traces. Gray boxes indicate blink or no-tracks. Tracking quality degraded near the end of the session (bottom right panel). See more examples on Box `APLab-Projects/SpaceTimeCoupling/ContrastSensitivity_Eccentricity/Figures/A024/TrialSummary_sanitychecks`.

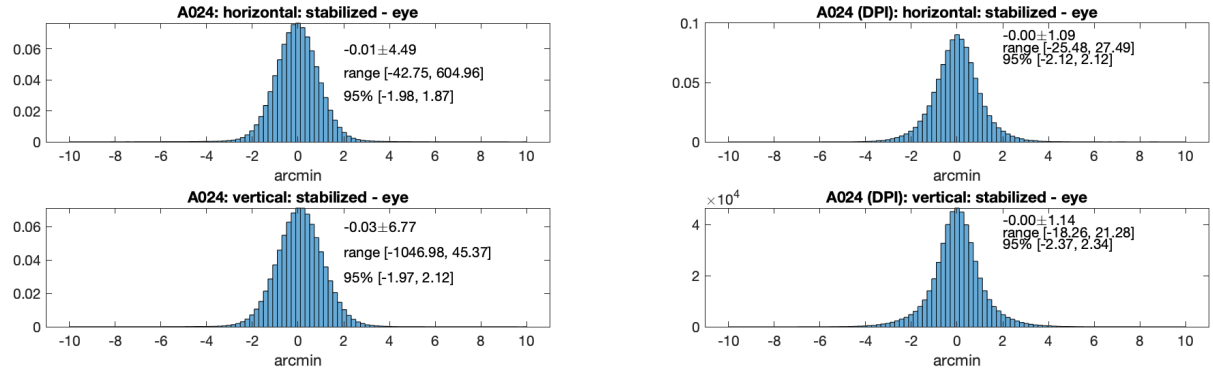

Figure 3: Distributions of positional error from stabilization (stabilized trace - eye trace) from DDPI-MK2 (LEFT) and DPI (RIGHT), both from Janis. A one-frame delay is imposed on the stabilized trace. No smoothing was applied to the eye trace. Graph includes data during drift segments. The DPI data is from the corrugation discrimination experiment, left and right eye data are combined.

3.3 Results

3.3.1 Number of Trials

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)

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.

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 2: 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.

3.3.2 Contrast thresholds

Separate thresholds are estimated for both increasing and decreasing method of adjustment (i.e. low and high initial contrasts). Threshold mean and standard deviation is estimated for each trial type (m_l, s_l and m_h, s_h for low and high initial contrasts respectively). Then, the final contrast threshold is:

$$m = (m_l + m_h)/2$$
$$s = \frac{\sqrt{s_l^2 + s_h^2}}{2}$$

The standard error plotted below is $s/\sqrt{n}$ where n is the number of trials in that condition regardless of initial contrast.

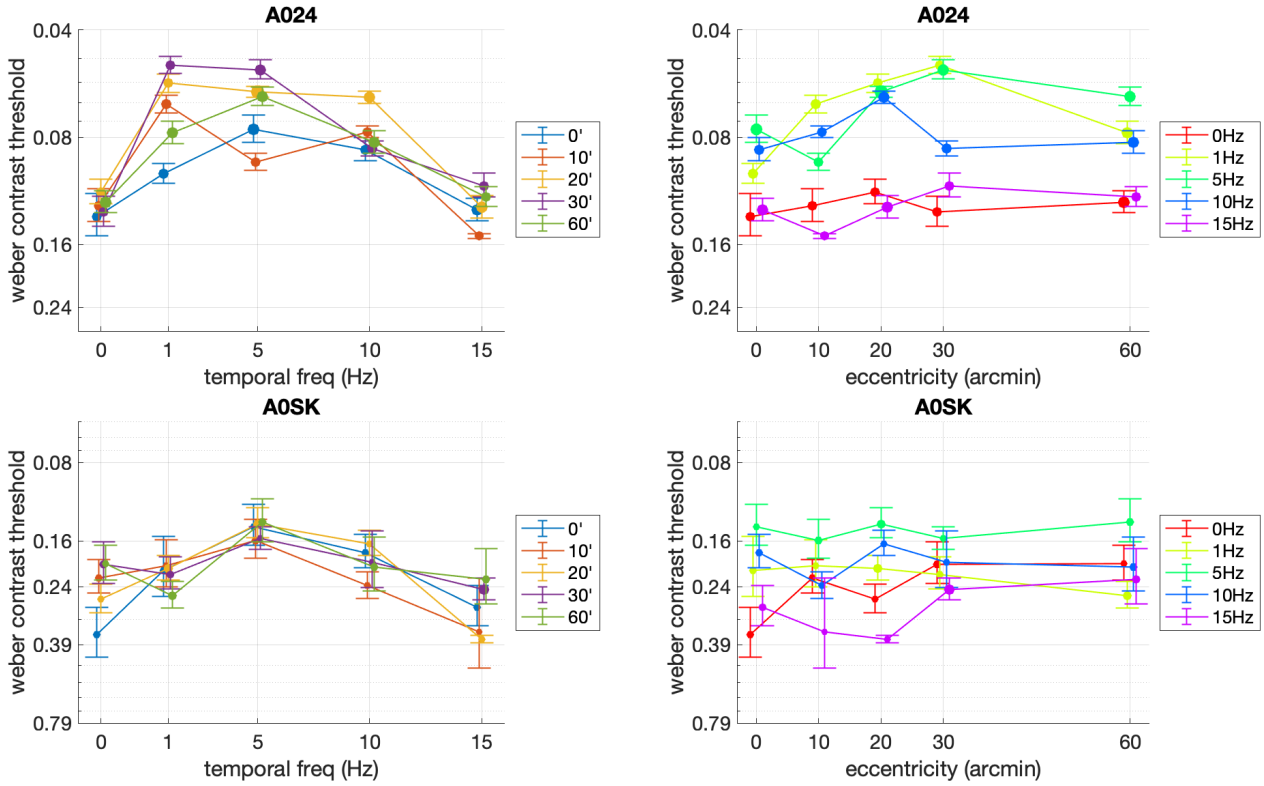

Figure 4: Mean contrast thresholds measured by method of adjustment. Error bars are standard errors across trials. (LEFT) Contrast thresholds as a function of temporal frequency. Color indicates eccentricity of probe. (RIGHT) Contrast thresholds as a function of eccentricity. Color indicates temporal frequency.

A024: Individual Trial plots

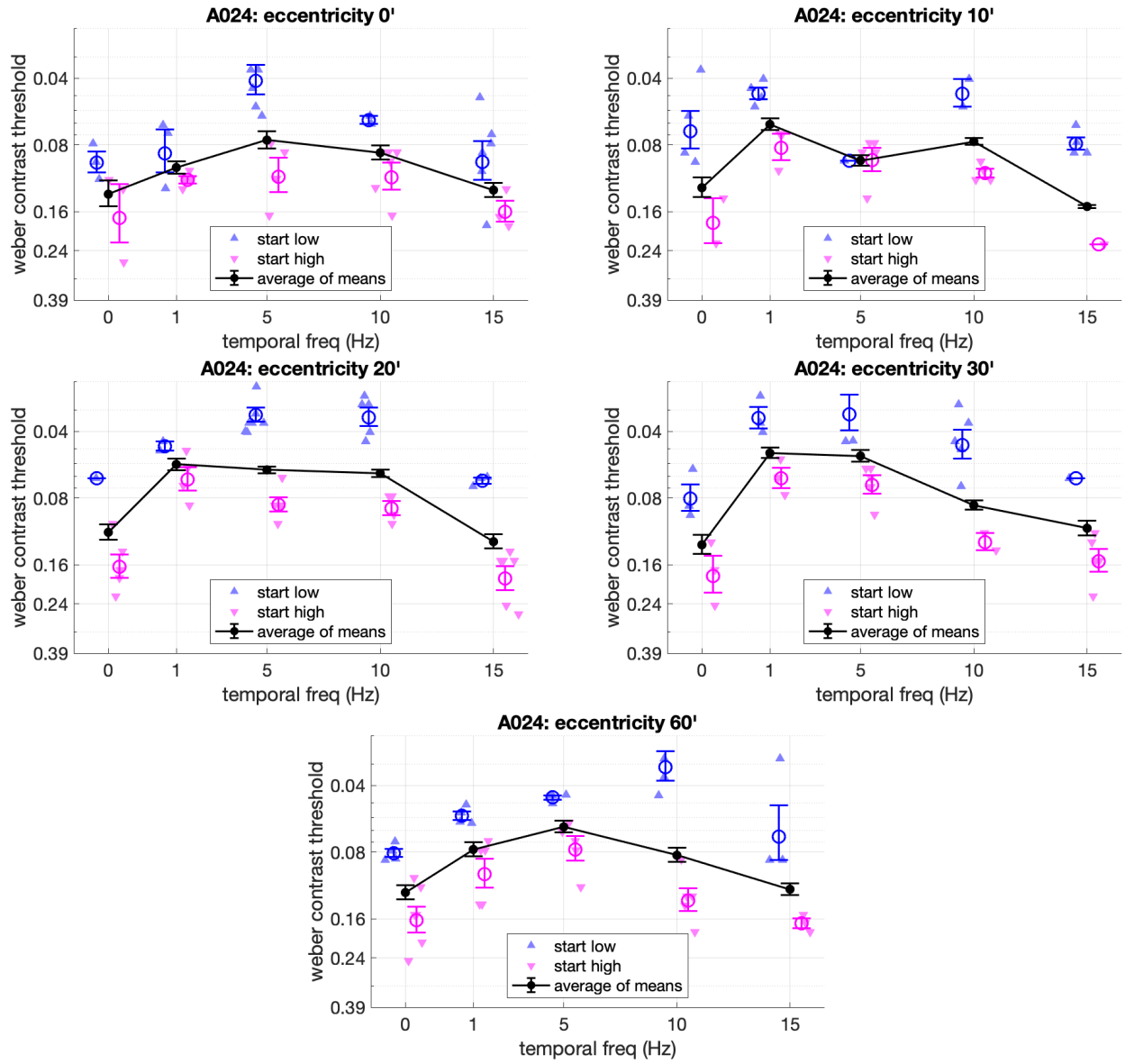

Figure 5: Contrast thresholds as a function of temporal frequency with individual trial data (colored markers). Blue upward triangles are trials that started with low contrast. Pink downward triangles are trials that started with high contrast. Open blue and pink circles are the mean and SEM of trials that started with low and high contrast respectively. The black data points are the mean and standard error of the average between low and high initial contrasts. Some data are plotted offset from fixed eccentricities for clarity.

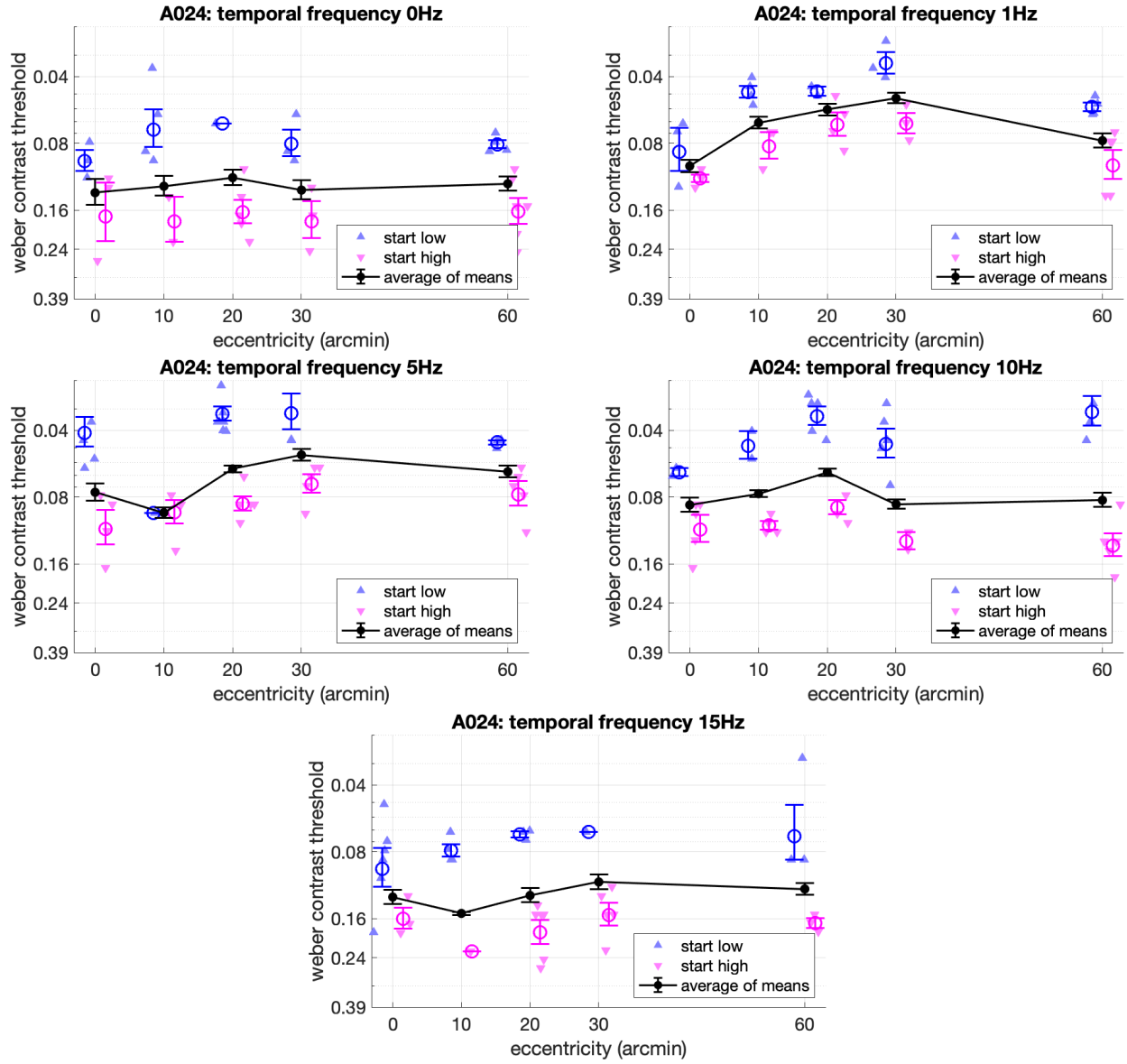

Figure 6: Contrast thresholds as a function of eccentricity with individual trial data (colored markers). Blue upward triangles are trials that started with low contrast. Pink downward triangles are trials that started with high contrast. Individual trial data are plotted offset from fixed eccentricities for clarity. Open blue and pink circles are the mean and SEM of trials that started with low and high contrast respectively. The black data points are the mean and standard error of the average between low and high initial contrasts. Some data are plotted offset from fixed eccentricities for clarity.

A0SK: Individual Trial plots

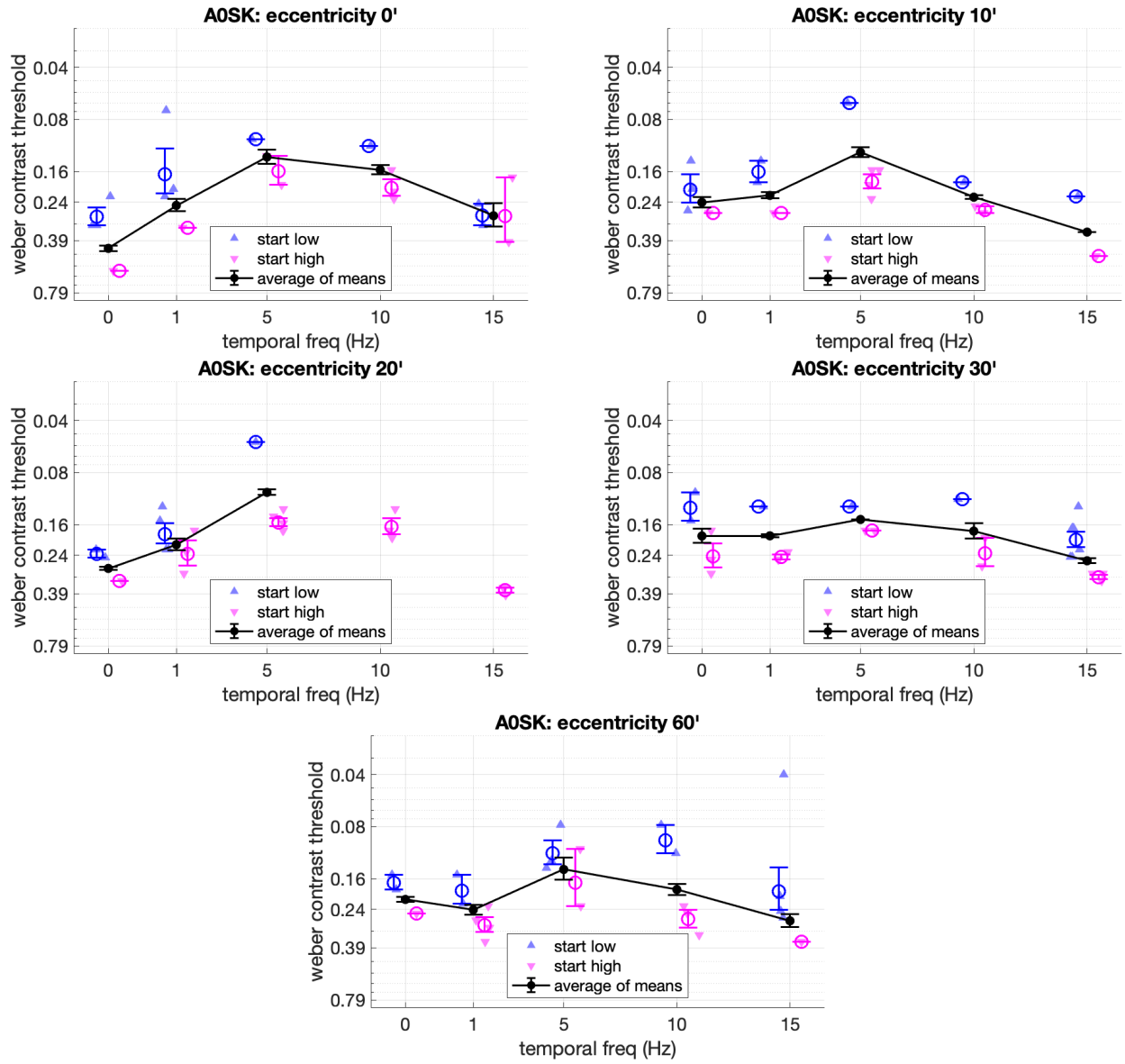

Figure 7: Contrast thresholds as a function of temporal frequency with individual trial data (colored markers). Blue upward triangles are trials that started with low contrast. Pink downward triangles are trials that started with high contrast. Open blue and pink circles are the mean and SEM of trials that started with low and high contrast respectively. The black data points are the mean and standard error of the average between low and high initial contrasts. Some data are plotted offset from fixed eccentricities for clarity.

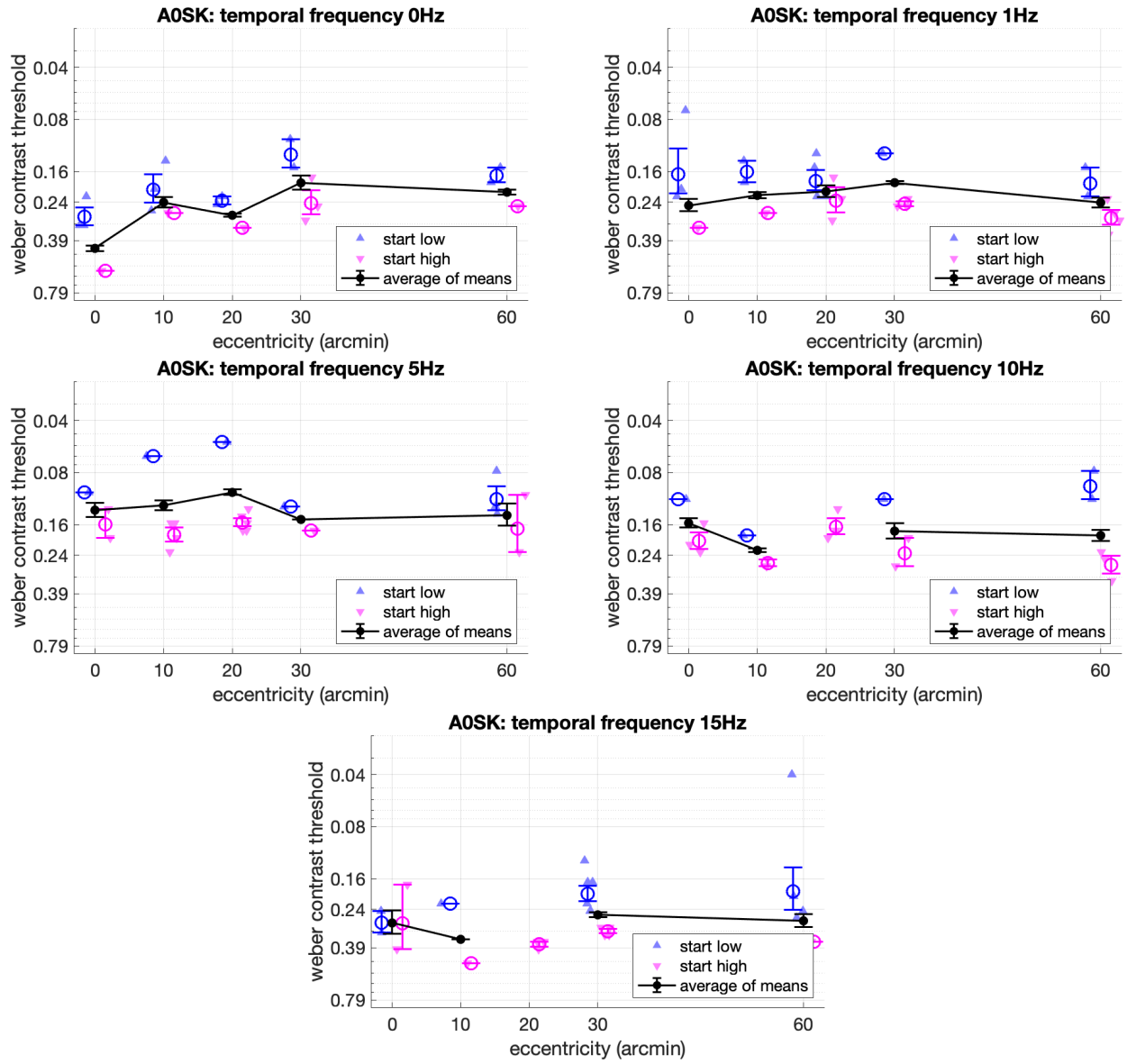

Figure 8: Contrast thresholds as a function of eccentricity with individual trial data (colored markers). Blue upward triangles are trials that started with low contrast. Pink downward triangles are trials that started with high contrast. Individual trial data are plotted offset from fixed eccentricities for clarity. Open blue and pink circles are the mean and SEM of trials that started with low and high contrast respectively. The black data points are the mean and standard error of the average between low and high initial contrasts. Some data are plotted offset from fixed eccentricities for clarity.

3.3.3 Oculomotor Characteristics

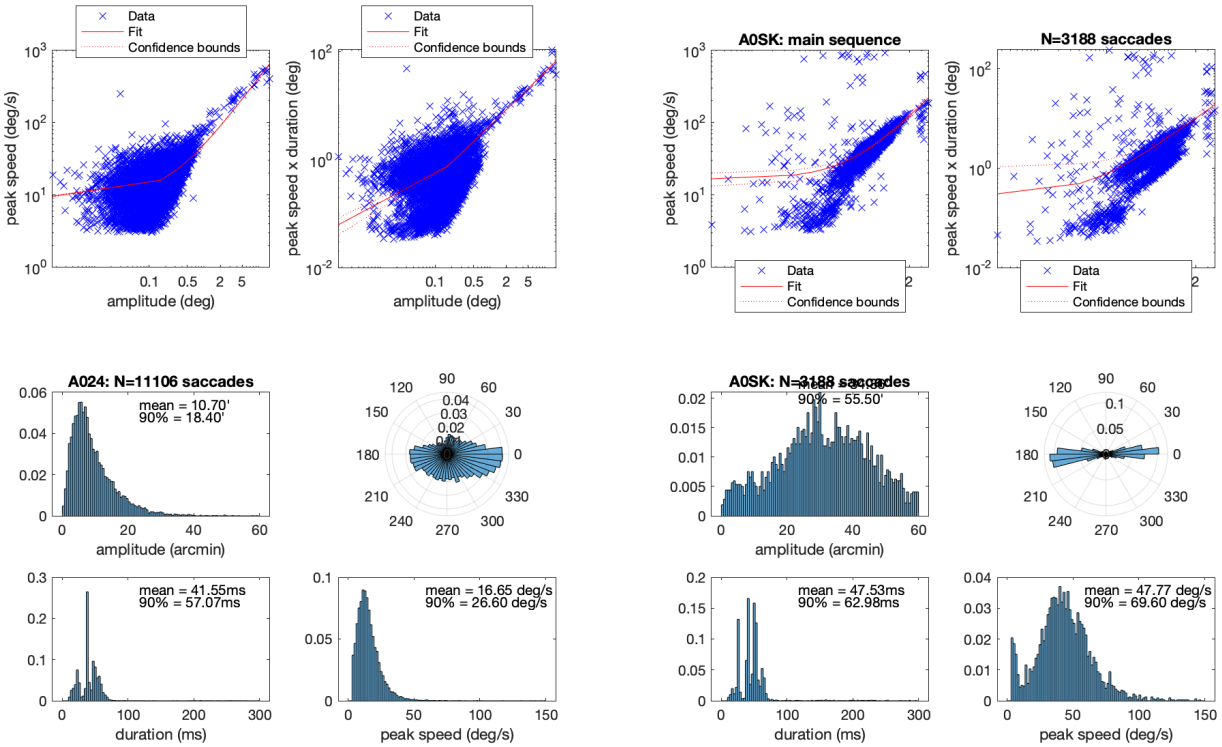

Figure 9: Saccade main sequence and distributions of saccade amplitude, direction, duration, and peak speed. Note that I have included some movements that could be classified as square wave jerks - those eye movements that have the velocity profile of a saccade but do not change position of gaze. Why the peak in duration? Something off in the saccade detection procedure?

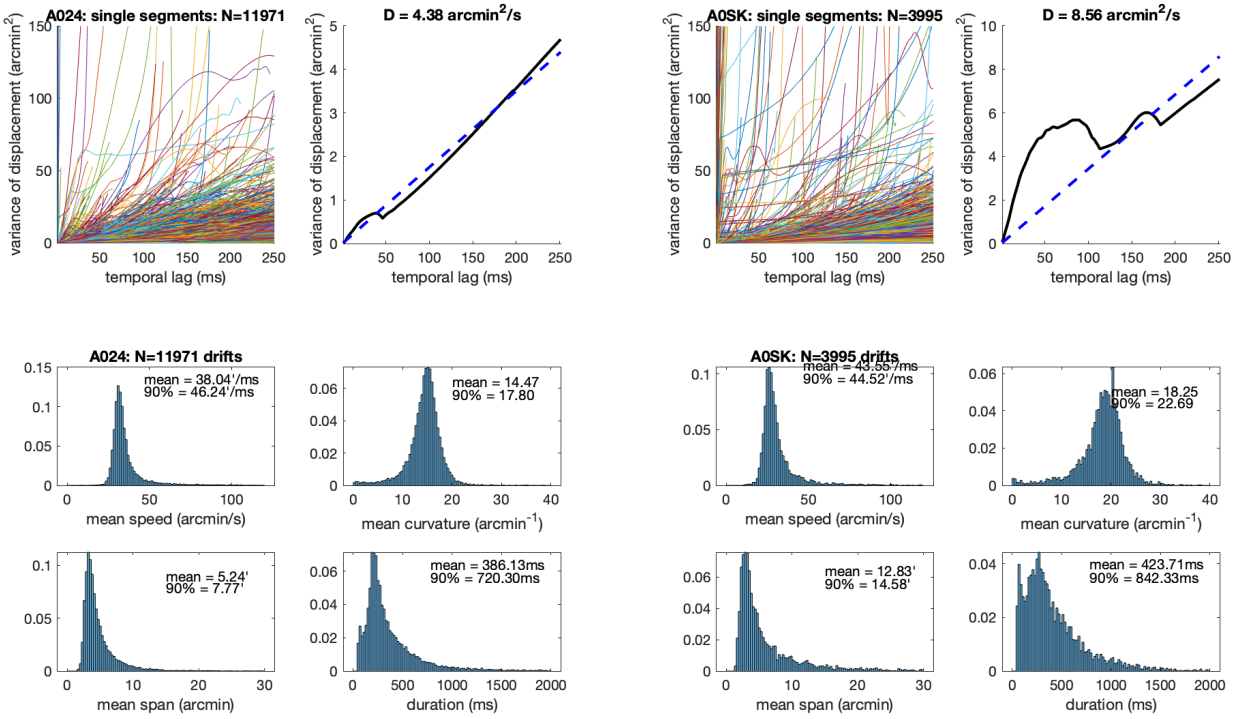

Figure 10: Drift characteristics: variance of displacement as a function of time and distributions of drift speed, curvature, span, and duration.

4 Experiment 2: Mapping spatiotemporal sensitivity across the visual field

Here we will measure spatiotemporal contrast sensitivity presented at different eccentricities throughout the visual field. Essentially, we want to recreate the spatiotemporal sensitivity surface measured by Kelly (1979) at different retinal eccentricities.

4.1 Experimental Methods

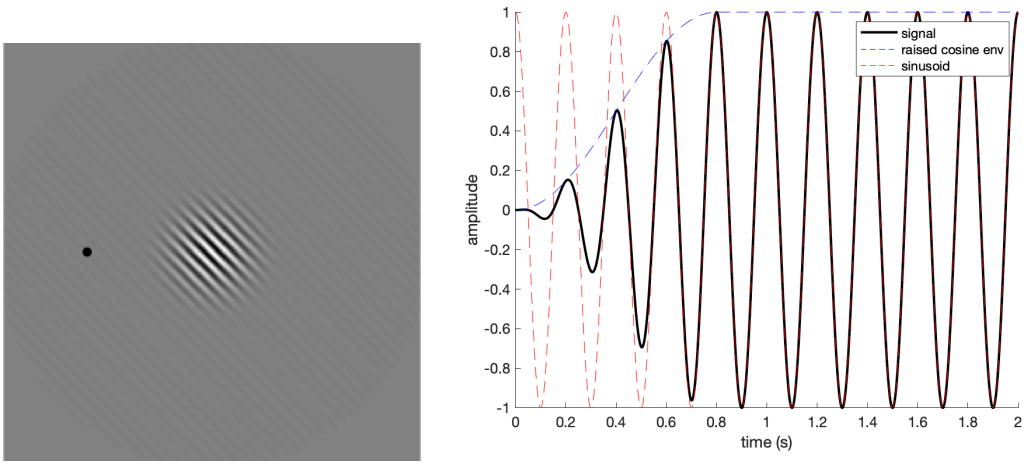

Figure 11: Example stimulus. Gabor patch at a fixed retinal eccentricity. The amplitude of the gabor will be modulated in time as in Experiment 3.

The paradigm is similar to that of Experiment 3. We will start with method of adjust to measure thresholds but switch to estimating full psychometric curves if more accuracy is needed.

Parameters

- Eccentricities: [0, 3 or 5, 10] degrees
- Spatial Frequencies: [1, 4, 10, 16] cpd
- Temporal Frequencies: [0, 1, 5, 10, 15] Hz
- Total conditions: 60
-
- Size of gabor patch? Hold constant across conditions.

5 References

References

Kelly, D. (1979). Motion and vision. ii. stabilized spatio-temporal threshold surface. *Josa*, 69(10):1340–1349.

6 Appendix

6.1 Linearization of monitor luminance

As of November 2, 2020, the monitor in ddpi-mk2 is the 240Hz Asus ROG Swift 258. This has been previously linearized,but should be retested at a finer scale - especially so that we can measure sensitivity to low spatial frequencies.

See linearization report on the wiki: `https://wiki.bcs.rochester.edu/ApLab/Equipment-GamingMonitors?action=AttachFile&do=view&target=data_ASUS258_FACE_2018_07_26.pdf`

6.2 Experiment 1: Test on ddpi-mk2 - preliminary results and sanity checks(Novem 20, 2020)

This data set was collected to test the full pipeline. Janis was the subject with Ruitao and Emin tracking. Note that these results are not valid due to large errors in stabilization explained below.

Run parameters and notes:

- Eccentricities: [0, 10, 20, 30] arcmin
- Temporal Frequencies: [0, 1, 5, 10, 15] Hz
- Total conditions: 20
-
- Total good trials: 19
-
- Size of probe: 4pixels = 4.15arcmin
- Distance to monitor: 0.93m
- Pixel to angle conversion: 1.03arcmin per pixel
-
- Stabilization included the large 85Hz oscillation ($\sim$ 3arcmin)

- the cosine ramp was incorrect
- method of adjustment starting from both low and high contrast

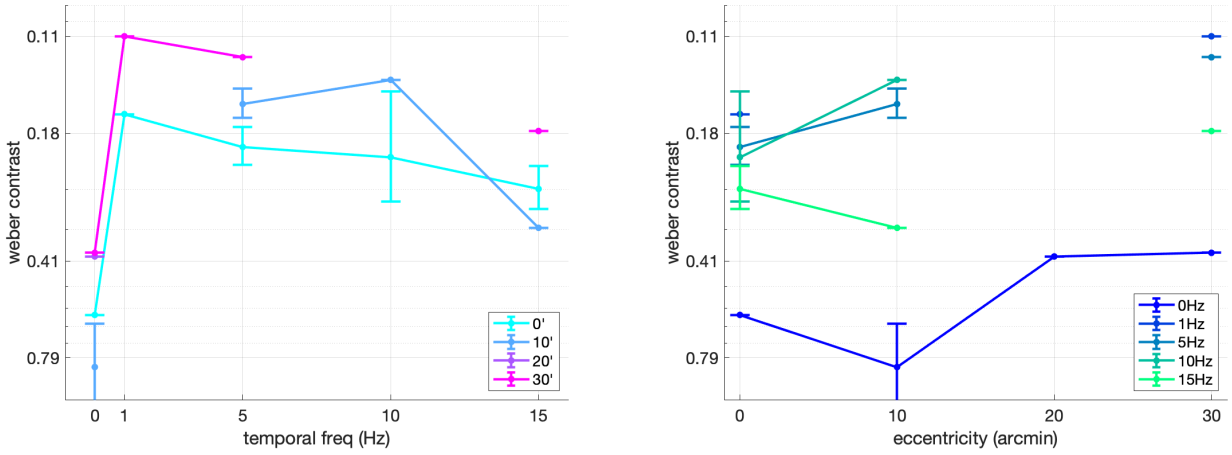

Figure 12: Contrast sensitivity measured at 4 foveal eccentricities for 5 temporal modulations. The y-axis is weber contrast (amplitude of of luminance modulation divided by background luminance). LEFT: CS as a function of temporal frequency for different foveal eccentricities. RIGHT: CS as a function of eccentricity for different temporal frequencies.)Note that there are only 1-2 trials per data point. Stabilization quality was poor for this data set. See next figure for details.

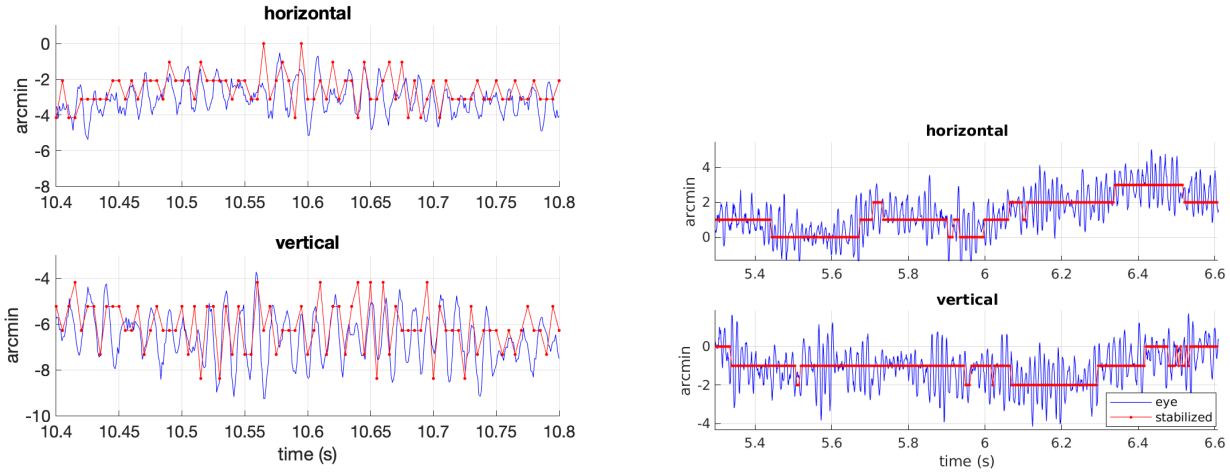

Figure 13: Due to the 85Hz in the eye trace (source currently unknown), the stabilized trace moves quite a bit on the display and jumped by as much by 3 pixels in a single frame (left). This prompted the quick implementation of the low-pass filter and sticky stabilization (right). Note that the eye trace (blue) is sampled at approximately 1016Hz, and the stabilized trace at 200Hz. We have not yet collected data with the slow stabilization as of Dec 4, 2020.

7 Project Log

7.1 To Do Tasks

1. When shaders become available in eyeris, implement gabor patch / annulus stimulus options - **JI**
2. When new eyeris becomes available on ddpi-mk1, move experiment there - **JI + RL**

7.2 Completed Tasks

- **Early December 2020**:
  - Change recalibration markers to plus and cross so that there's less masking of the square stimuli - **JI**
  - Only use two button presses - increase or decrease contrast by small amount
- **late November 2020**:
  - When eyeris is rendering at 200Hz on the monitor, begin pilot data collection - **JI + RL**
  - confirm that all relevant data is saved in each trial - **JI**
  - implement raised-cosine contrast ramp - **JI**
  - implement joypad functions - **JI**
  - move parameters into configuration file - **JI**
  - Implement slow stabilization for ddpi-mk2 in new eyeris
- **November 2, 2020:** find parameters for linearization of ASUS ROG 258 monitor - JI: updated appendix 6.1 for ddpi-mk2 display

7.3 Foveal Temporal Sensitivity: Pilot run notes

- **(Dec 9, 2020)** Data was collected in two runs (5.5 minutes and 15 minutes):
  - Trials: 36 good of 41 total
  - The first run included 10 trials (9 good), after which Janis incrased the size of the arcs and reduced the size of the fixation marker.
  - The second run included the remaining trials. Tracking was good for the first 10-12 minutes.
  - Compared to last time, there were only two buttons to adjust contrast by a small step size.
  - Ruitao said that the ddpi would occasionally track a spurious reflection near the 1st (but it was not the 2nd) that affected mostly the later trials in run 2.
- **(Dec 10, 2020)** Data collected in 3 runs
  - Only minor changes to experimental paradigm: An abort button was added so that subjects could skip a trial if tracking or stabilization was bad, the monitor settings changed slightly (contrast on the monitor went from 16 to 0). Initialize contrast levels were either 60 or 1 (instead of 127 and 5 respectively).

  - Tracking in run 3 degraded slightly, otherwise the experiment went smoothly.

- **(Dec 11, 2020)** Data collected in 4 runs
  - Only minor changes to experimental paradigm: conditions biased to fill in gaps in previous data collection
  - Note that we had to open NVIDIA in order to actually apply the color changes.
  - we did see a shift in the graphics - did not largely affect the experiment otherwise
  - Data collected in 4 runs. Between run 1 and 2, Ruei inflated the isolaters on the optical table. Between runs 2 and 3, Ruei moved the left stage farther away to see if moving the second dichro away improved image quality.

- **(Dec 16, 2020)** First run with A0SK
  - New subject was given instruction sheet to read and RL answered clarifying questions.
  - Subject did XXX minutes of practice trials without eye tracking to learn the task.
  - RL reports that the photocell was not stable.
  - A single run of about 5 minutes with retinal stabilization was taken.
  - The 25Hz condition was added starting with this session.