Oculomotor Contributions to Foveal Visual Acuity

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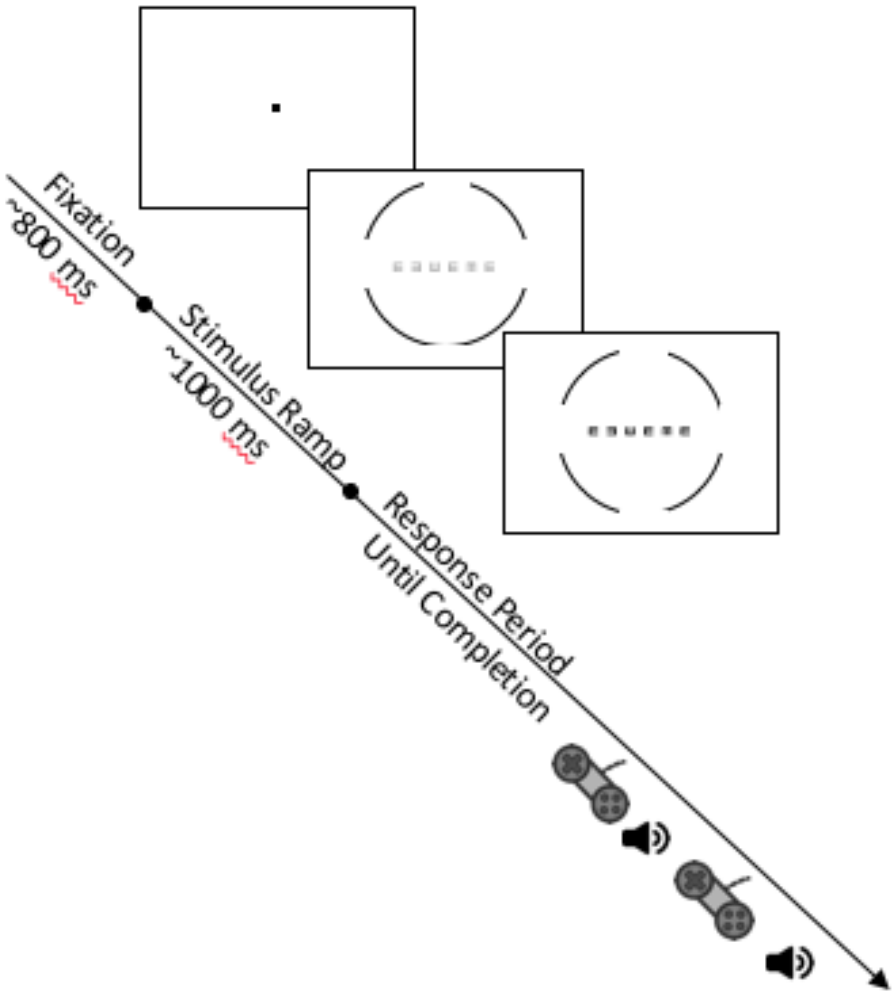
Introduction

- Temporal modulations to retinal input caused by fixational eye movements are crucial to perception of fine detail (Rucci et al., 2007)
- Microsaccades are used to bring gaze to new location of interest (Ko, Poletti & Rucci, 2010) and compensate for nonhomegeneous vision in foveola (Poletti, Listorti & Rucci, 2013)
- Highest resolution in the eye in foveola (1 degree diameter)
- Clinical visual acuity tests, Snellen or EDTRS charts, measure the spatial resolution of the visual system

Overview

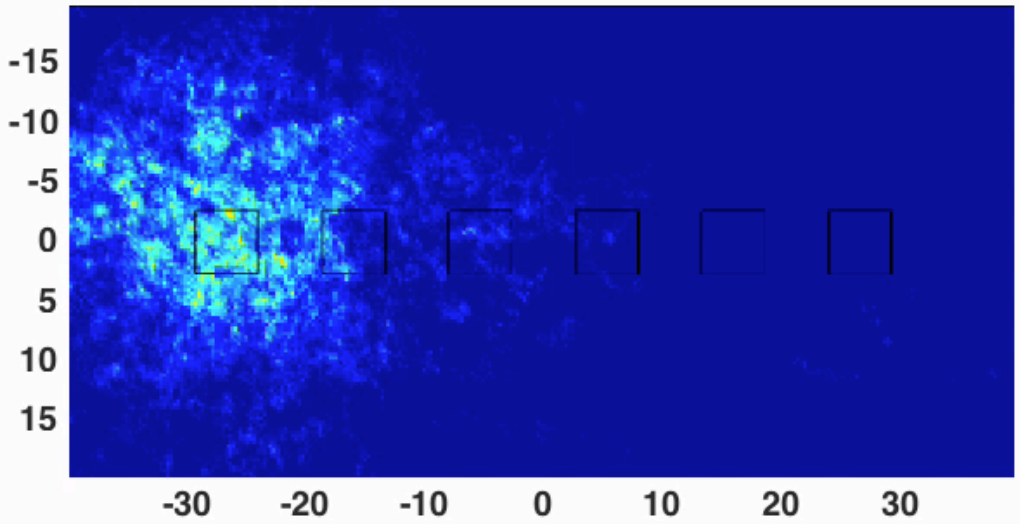
- Experiment 1: Characterization of Normal Oculomotor Behavior and the Relationship between behavior and performance in the task
- Experiment 2: Effects of Retinal Stabilization
  - 2a: effect on contrast sensitivity, visual acuity across foveola
  - 2b: effect on visual acuity and the loss of spatial resolution

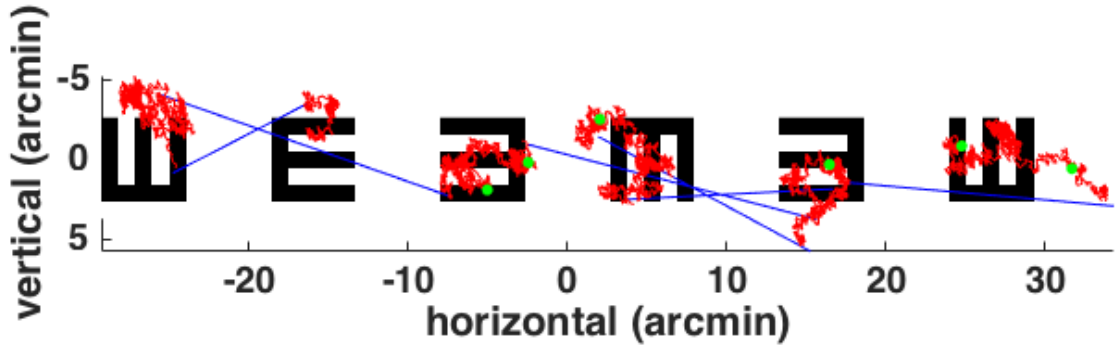
Methods: Experiment 1

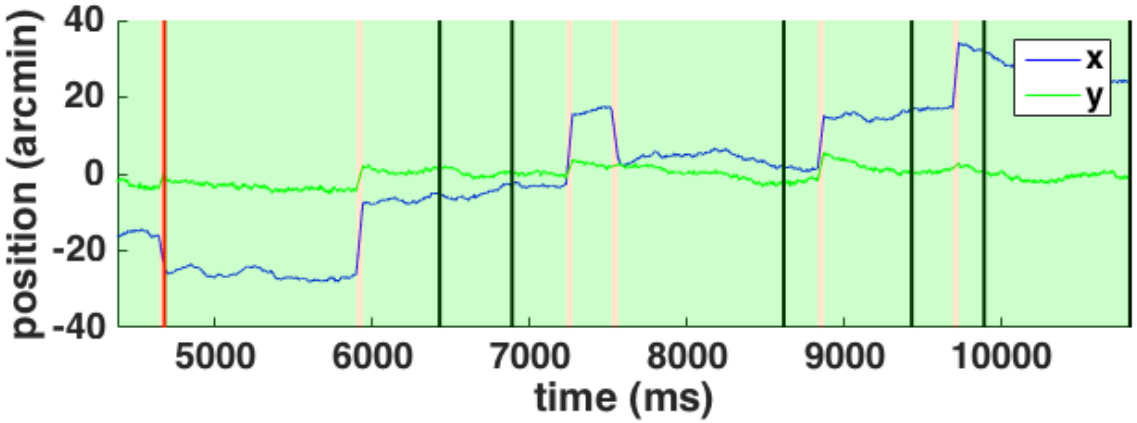


Oculomotor Behavior

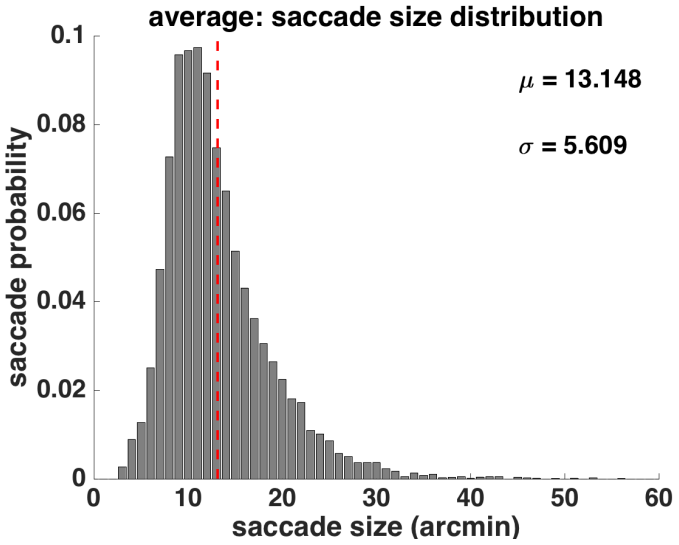
Probability of gaze location over time during task

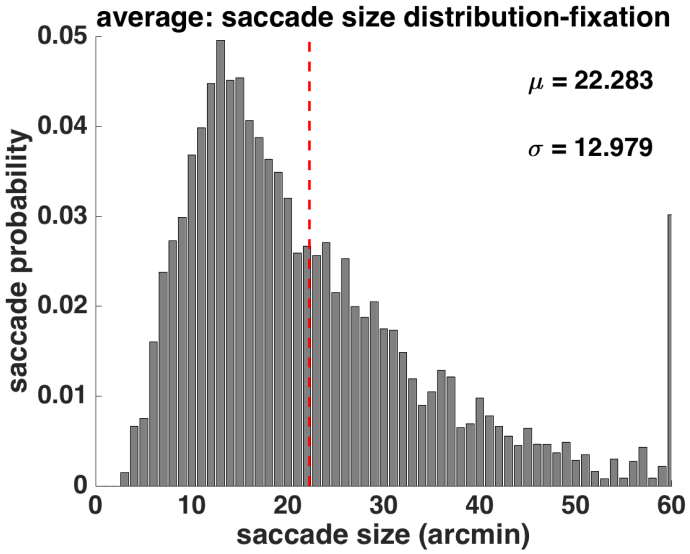


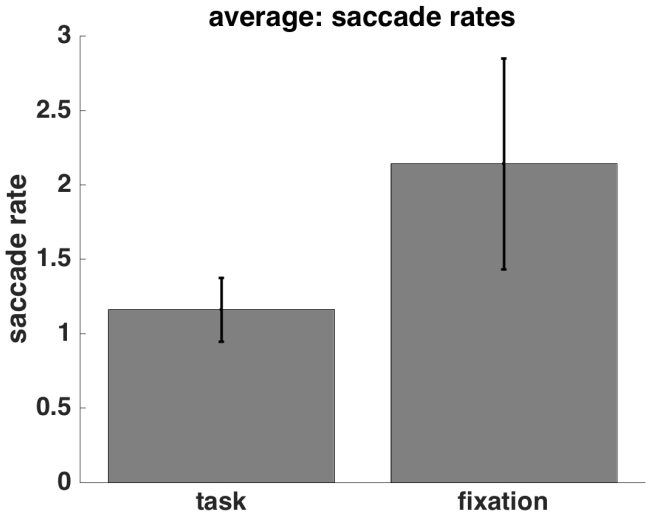




Oculomotor Behavior

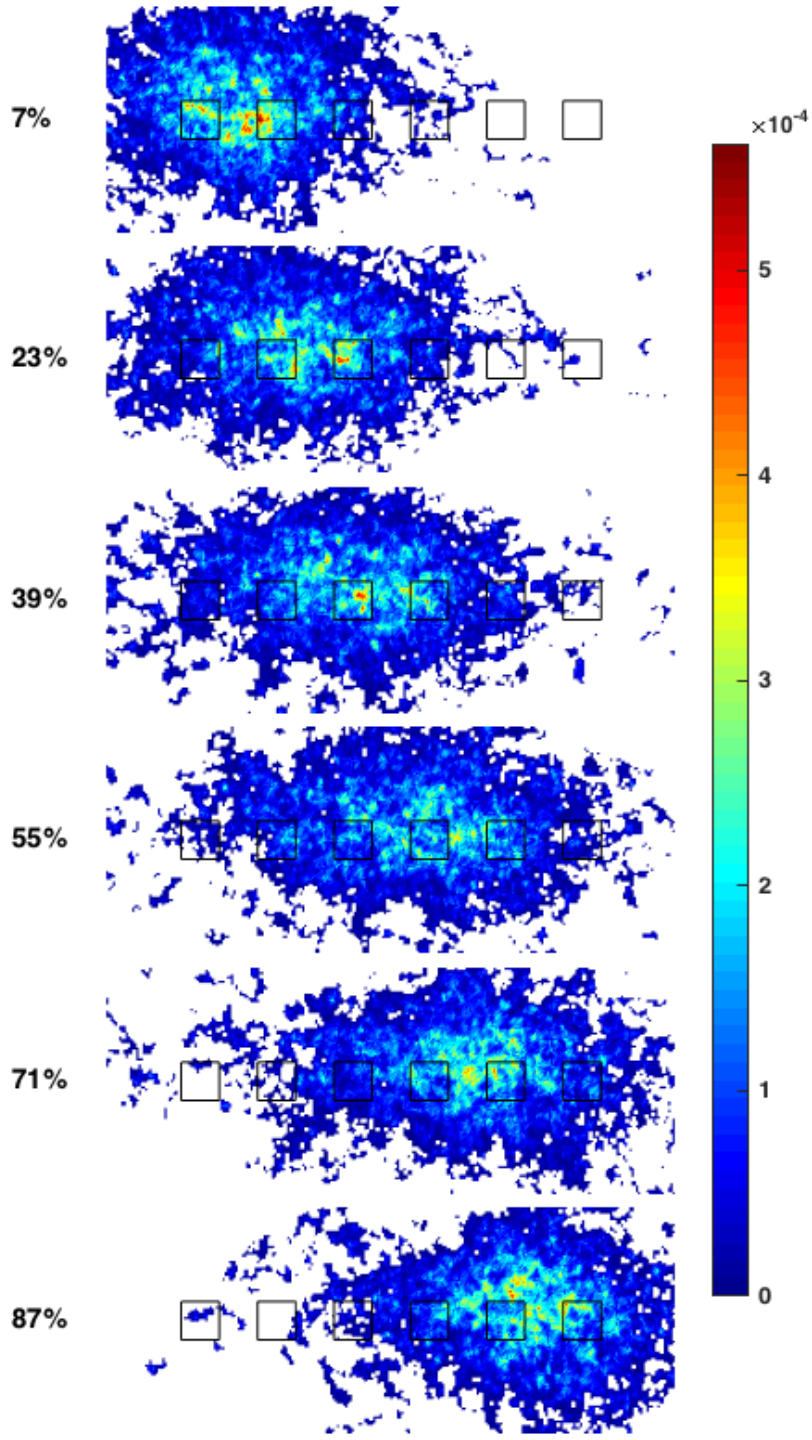






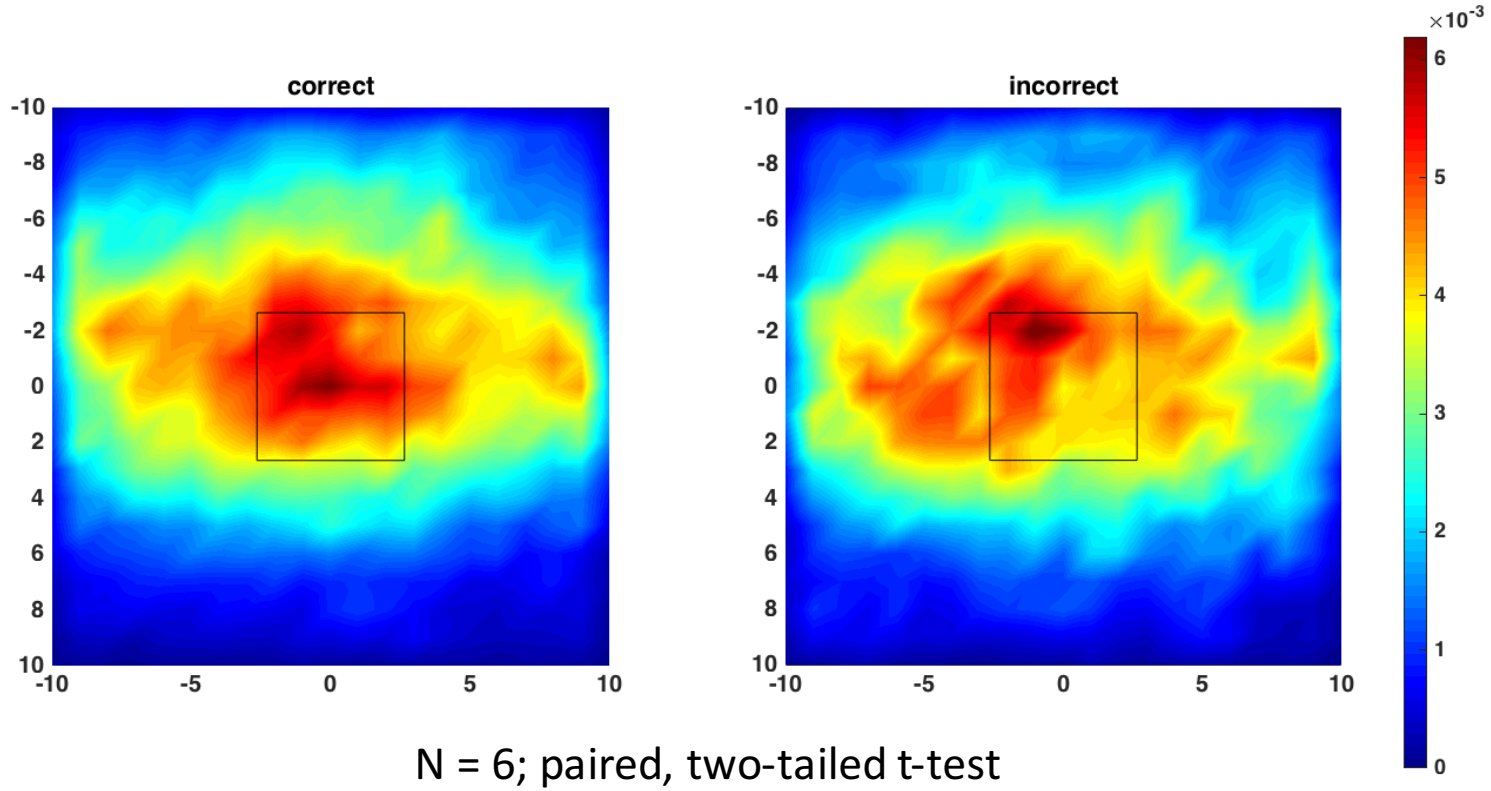
N = 6; paired, two-tailed t-test

*Saccade amplitude and saccade rate are significantly different between task and fixation (P = .004 and P = 0.0257 respectively)



Imprecise Fixations Decrease Performance

Average probability of fixation relative to target in the period 1000-300 ms before a correct or incorrect response



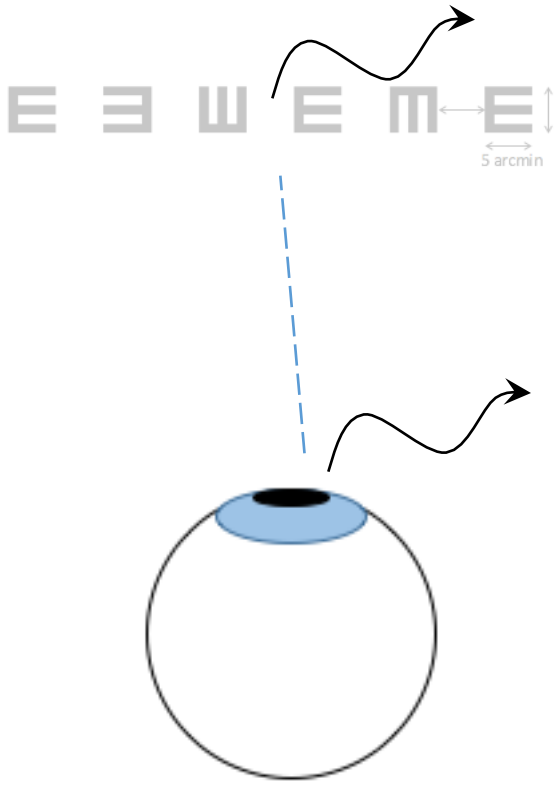
N = 6; paired, two-tailed t-test
Percent time on target (P = 0.06)

Discussion of Results from Experiment 1

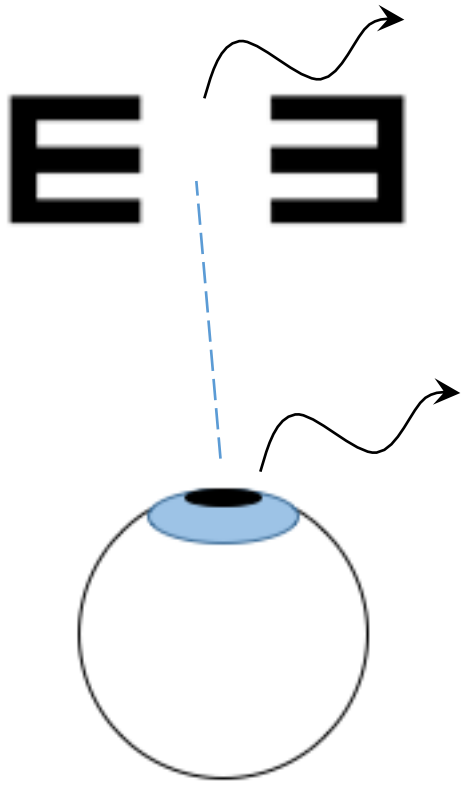
- Even though the stimulus could fit entirely in the foveola, gaze moves from left to right over the course of the task to bring the target into a preferred location of the retina
- Microsaccade amplitude has been tuned for the task: average 13’ is consistent with the 10’ spacing between optotype centers
- Microsaccades are likely used to foveate the targets one at a time
- Decreased performance is associated with imprecise fixations on the target

Methods: Experiment 2

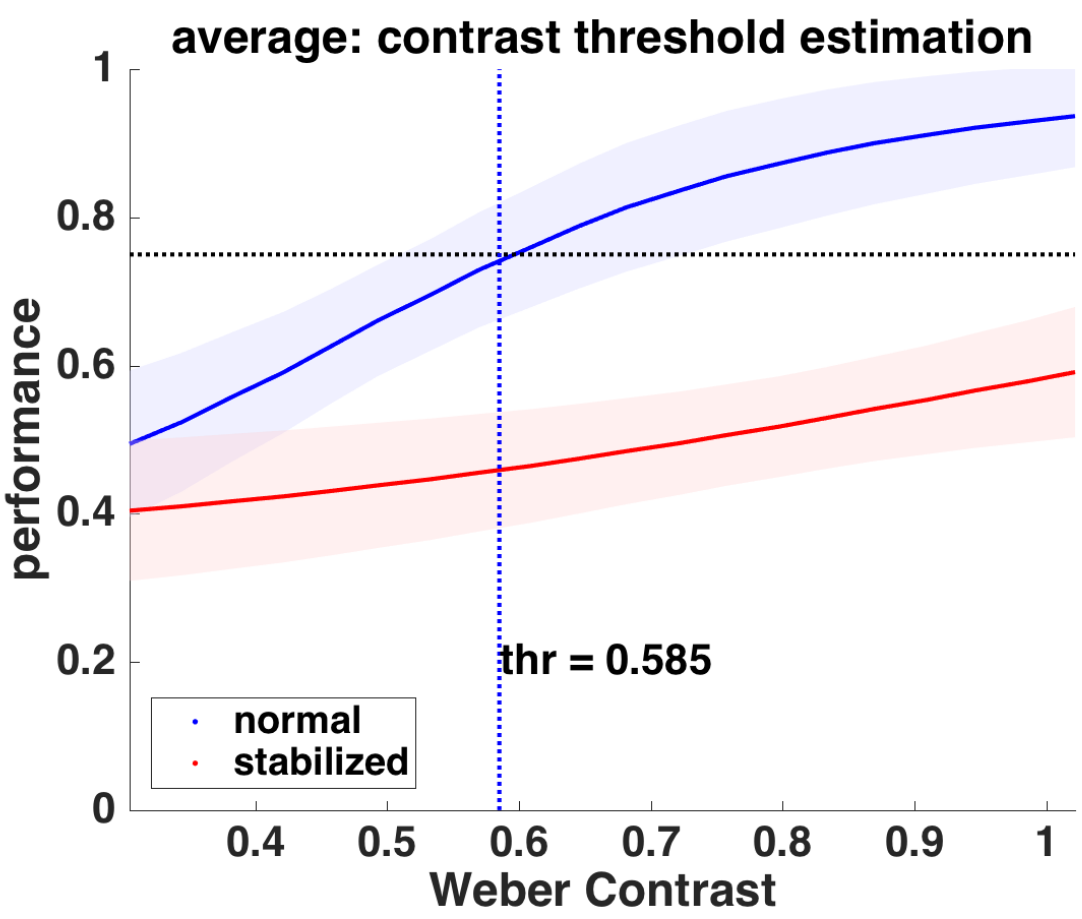
- 2a: stabilized, varying contrast

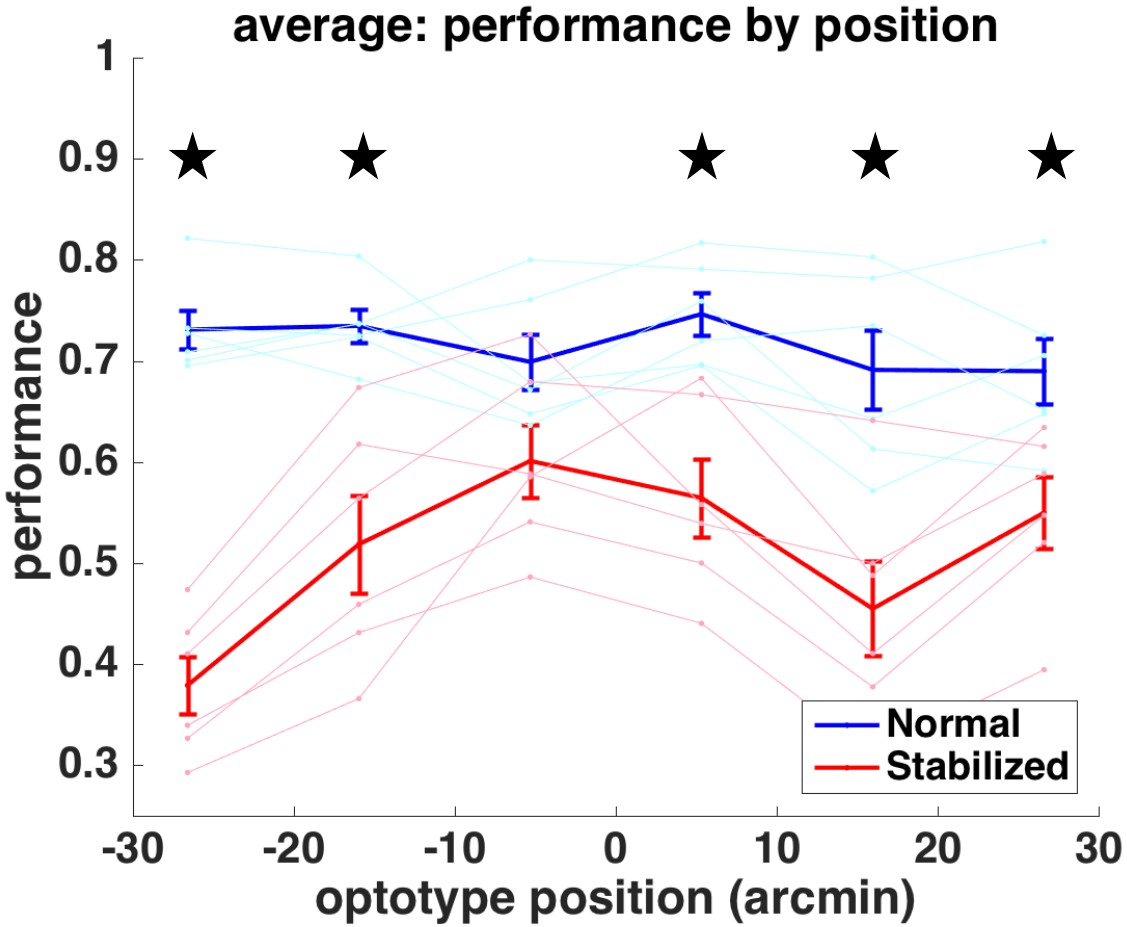


- 2b: stabilized, varying size



Effect on Contrast Sensitivity



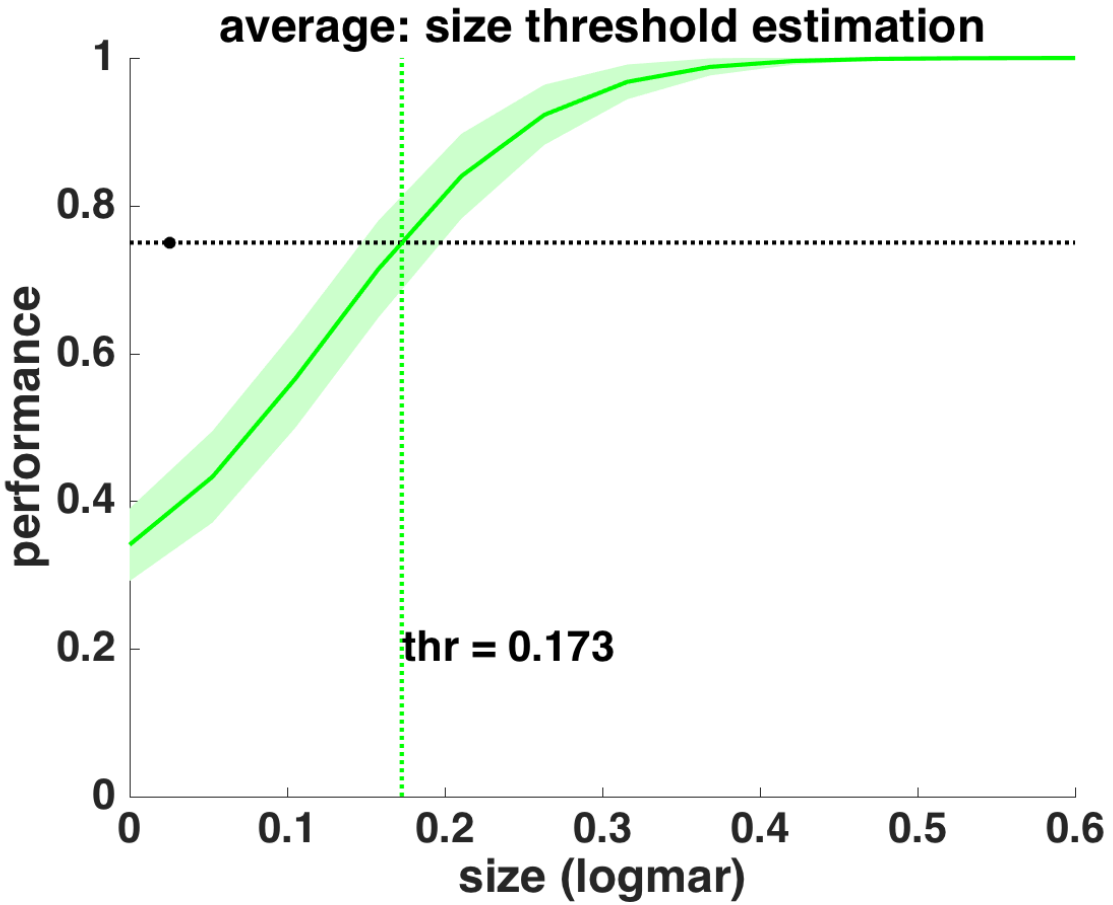


Nasal

Temporal

Loss of Visual Acuity

How big do the optotypes need to be to reach 75% performance again?



Discussion: Experiment 2

- Experiment 2a (contrast sensitivity)
  - No participants were able to reach 75% performance in stabilized conditions due to the limitations of the monitor settings
  - Regardless of optotype position, performance in the task fell from normal viewing conditions
    - Performance fell more at extremities than center, corroborating the idea that vision in the foveola is nonhomogeneous
    - Performance drop in central optotypes could be due to fading or small displacement (about 3') from preferred locus
  - Asymmetry of performance in stabilized conditions
    - Possible contributors
      - Perceptual span expands to the right
      - Increased exposure time
      - Asymmetrical effect of crowding in foveola
    - Cone densities within foveola have not been thoroughly explored
      - In periphery, cone density is generally higher nasally than temporally (Curcio et al., 1990)
      - Data from Song et al., 2011 suggest similar cone density profiles for nasal and temporal within foveola in younger subjects, but greater densities nasally vs. temporally in older subjects

Discussion: Experiment 2

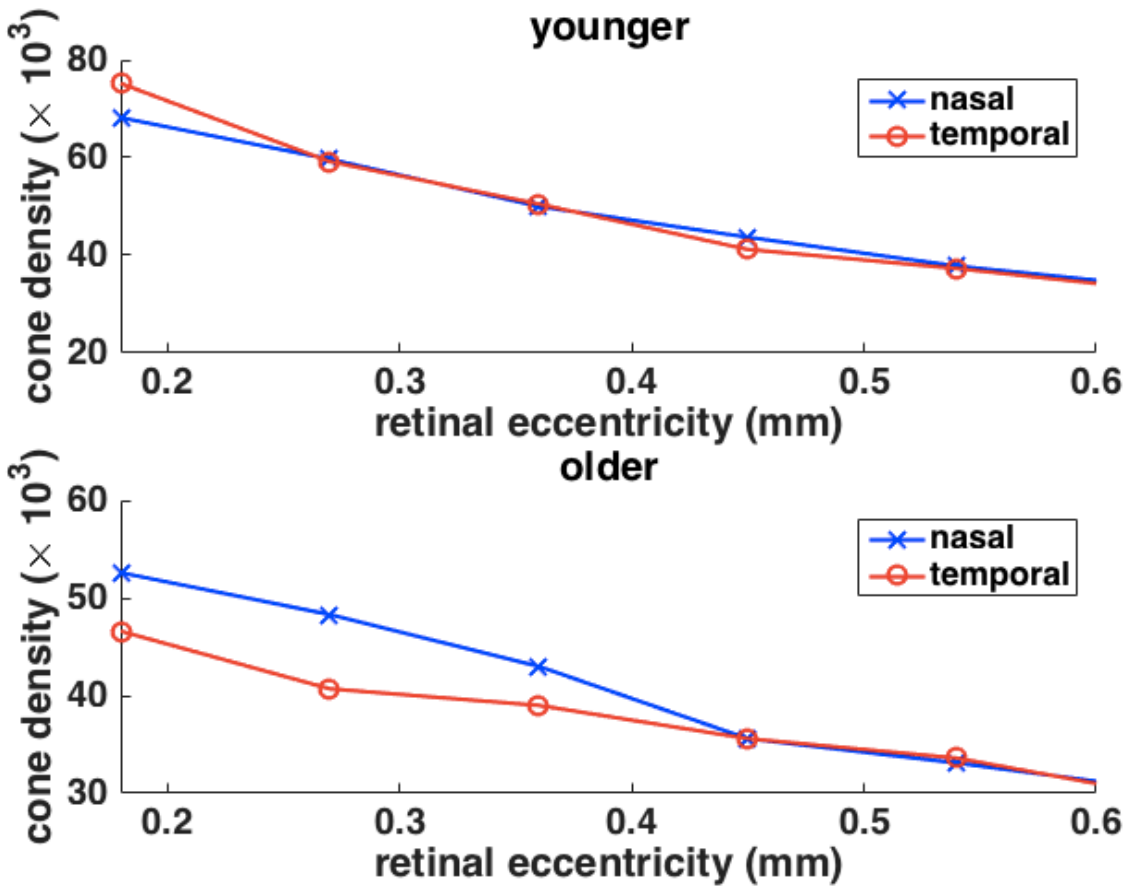
- Experiment 2b:
  - On average there is a loss of 0.15 logmar (or 1.4 arcmin or 2 lines on a Snellen chart)
  - Difficulty of task changes as a function of both optotype size and amount of crowding, thus we are underestimating the effect
    - Contrary to modern design standards, which use a fixed number of optotypes on each line (Bailey & Lovie, 1976; Bailey & Lovie-Kitchin, 2013) or use distractors when optotypes are presented one at a time (Beck et al., 2003)

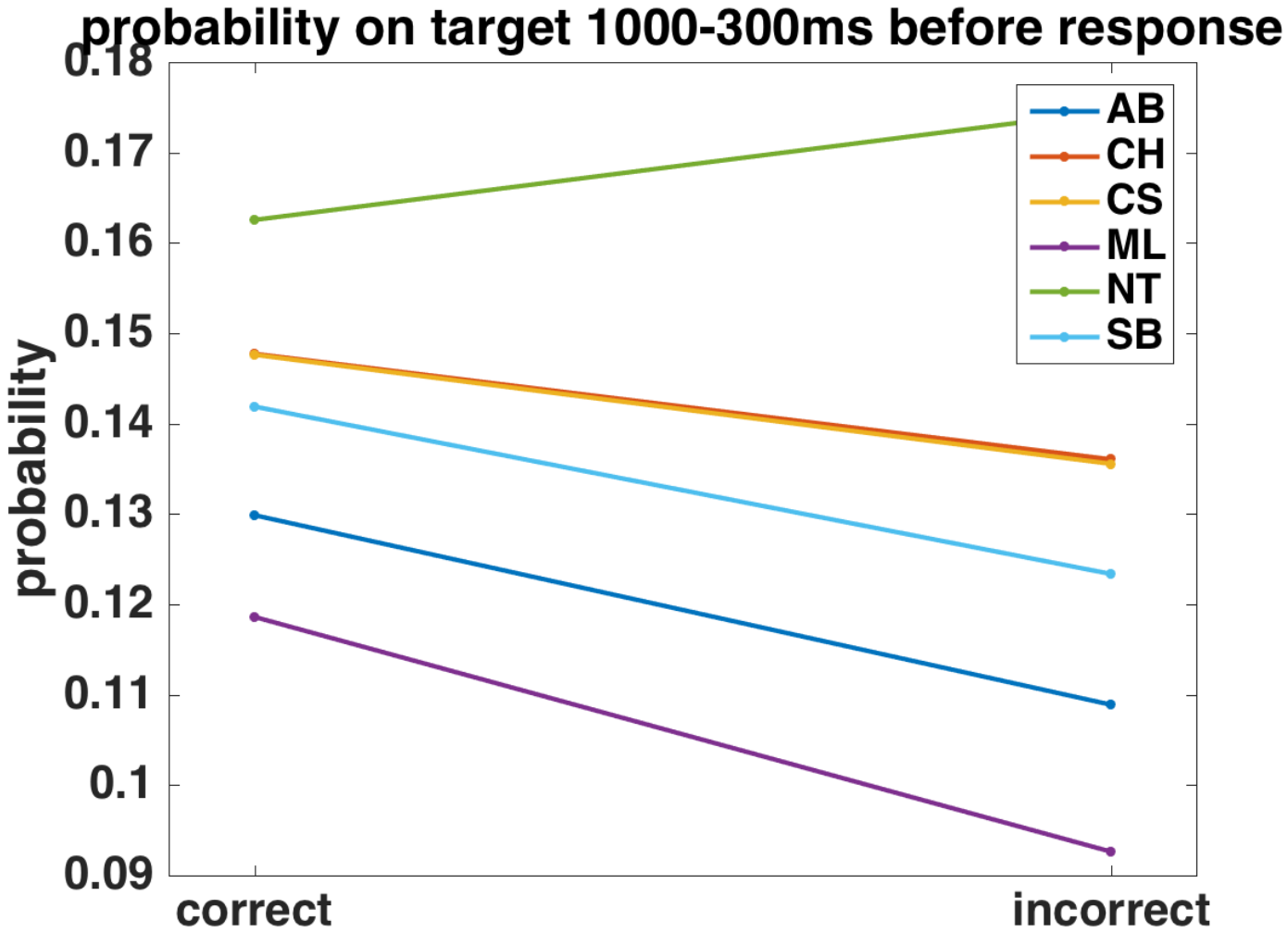
Summary

- Eye movements are required for the visual system to achieve maximum visual acuity
- Imprecise fixations on the order of several minutes of arc are detrimental to performance in visual acuity tests
- Effects of crowding and eccentricity within foveala are not well understood

Supplementary Figures

Song et al., 2011




probability on target 1000-300ms before response
probability
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
correct
incorrect
AB
CH
CS
ML
NT
SB