Foveal Crowding: Pilot results

Mapping Acuity and Crowding Effects in the Fovea

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APLAB

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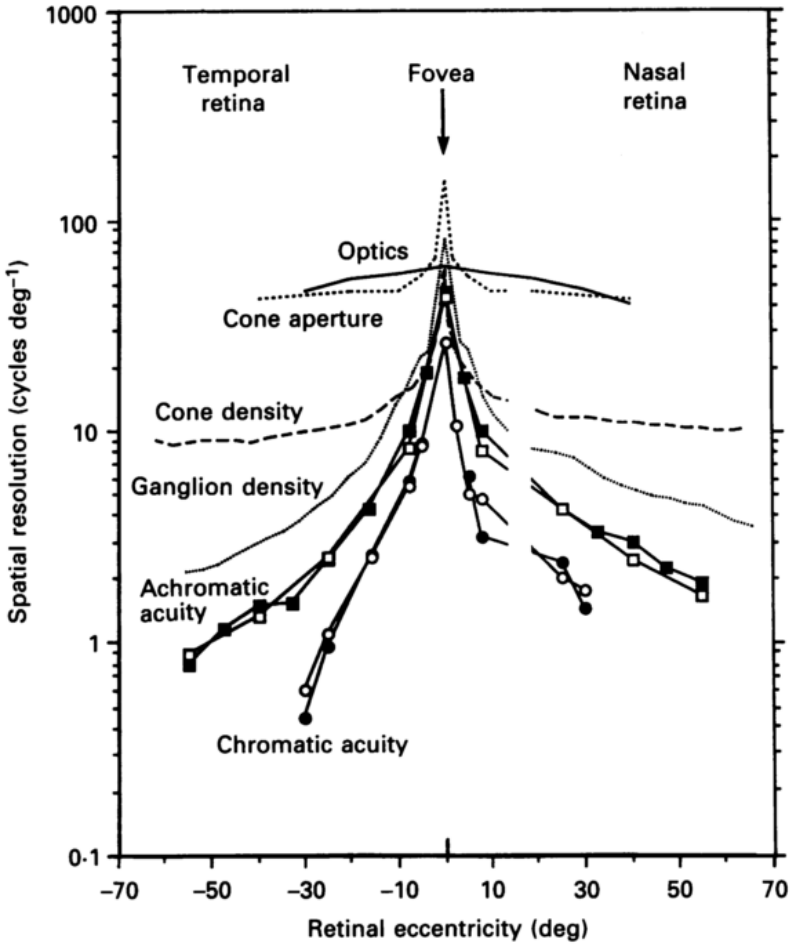
Acuity across the Retina

Acuity is measured as minimum angle of resolution (MAR) or in log units as LogMAR.



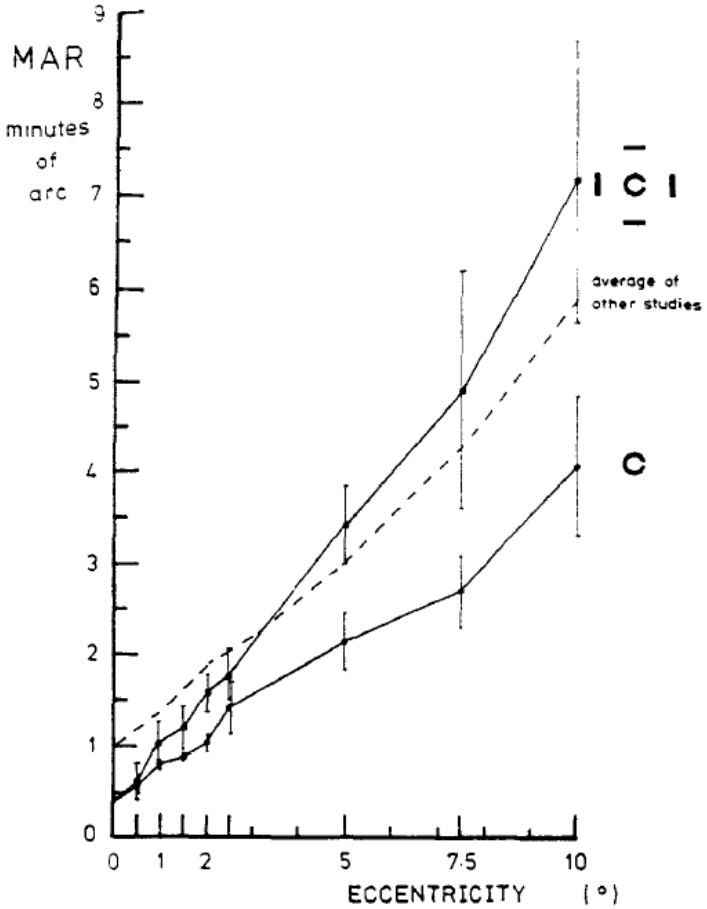


Figure: Anderson et al. (1991) and Jacobs (1979)

Acuity in the Foveola??

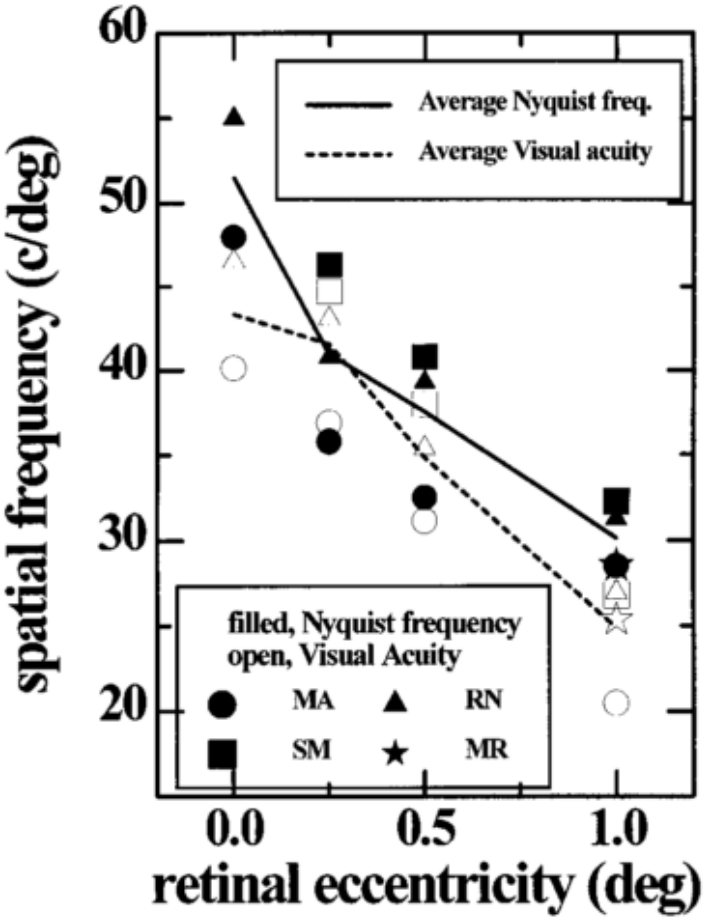


Figure: Marcos & Navarro (1997)

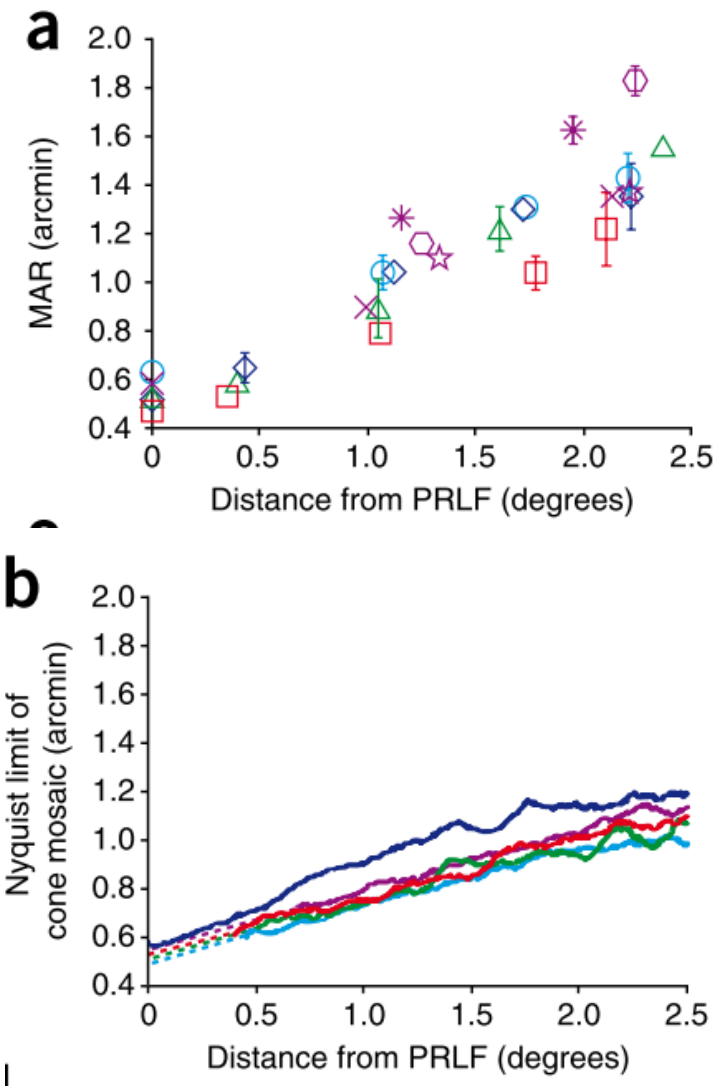


Figure: Rossi & Roorda (2010)

Visual Crowding

- Crowding is the inability to identifiy target objects in clutter
- Flankers that are within the crowding zone of the target impair target identification.

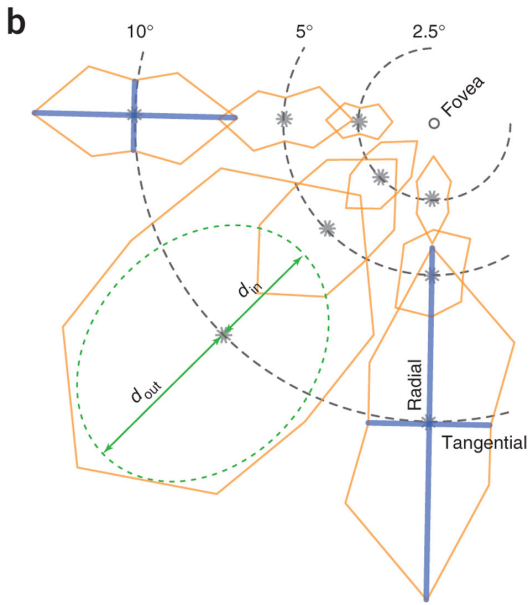


Figure: Nandy & Tjan 2012

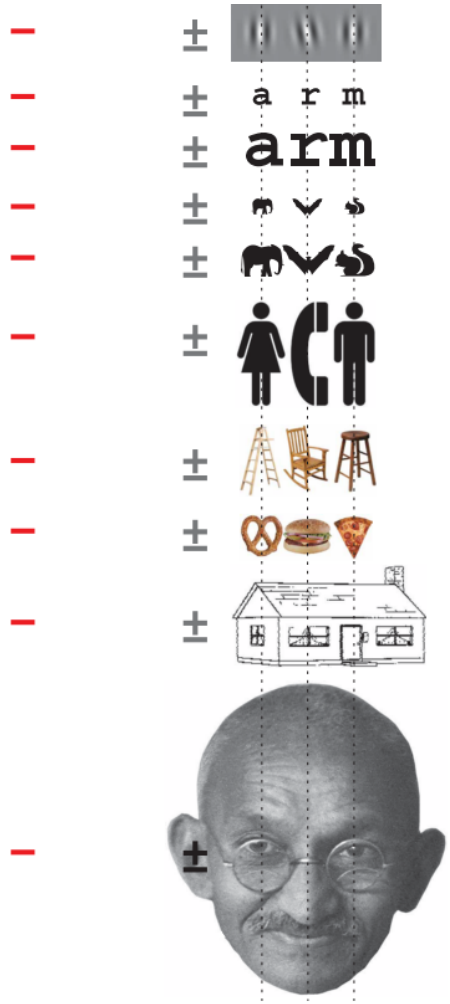


Figure: Pelli & Tillman 2008

How are the effects of crowding measured?

Approach 1: Quantify impact of flanker(s) on task performance using fixed target and flanker sizes and varying flanker distance or position. (Bouma, 1970; Nandy & Tjan, 2012)

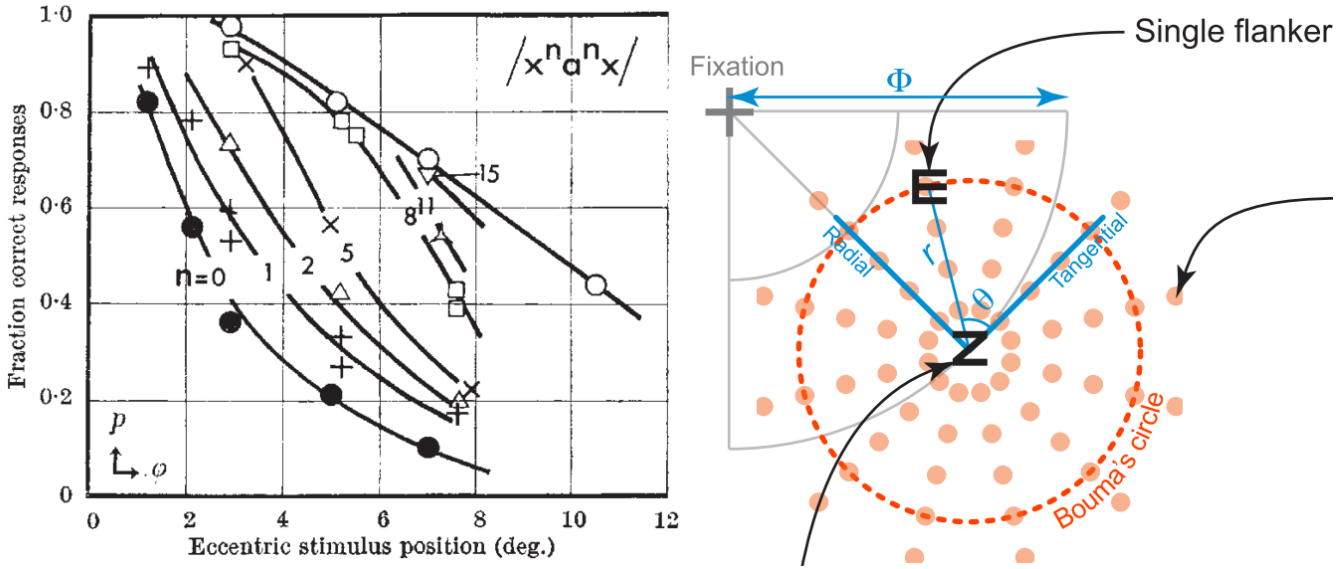


Figure: Bouma (1970) and Nandy & Tjan (2012)

How are the effects of crowding measured?

Approach 2: Quantify impact of flanker(s) with threshold estimations for varying target and flanker sizes, flanker distances, eccentricities,... (Pelli et al, 2004; Chung et al, 2001; Levi et al., 2002)

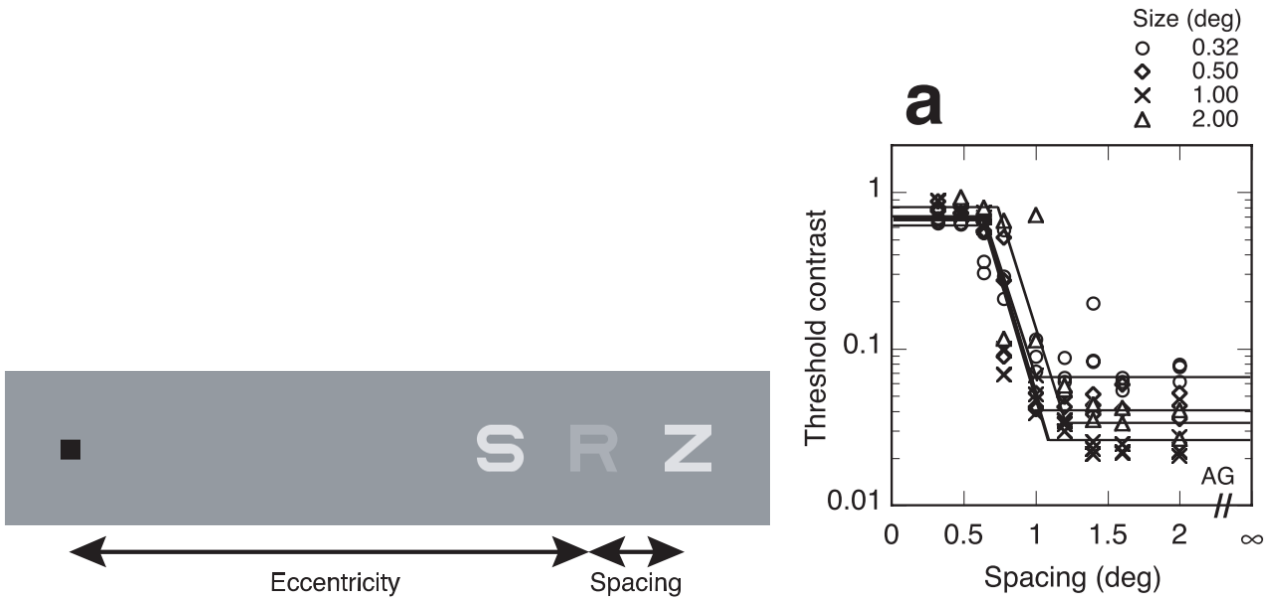


Figure: Pelli et al. (2007)

How are the effects of crowding measured?

Approach 3: Quantify impact of flanker(s) by measuring flanked and unflanked acuity where the flanker distance is a multiple of the target size (Levi, Song, & Pelli, 2007; Jeon et al, 2010; Norgett & Siderov, 2014).

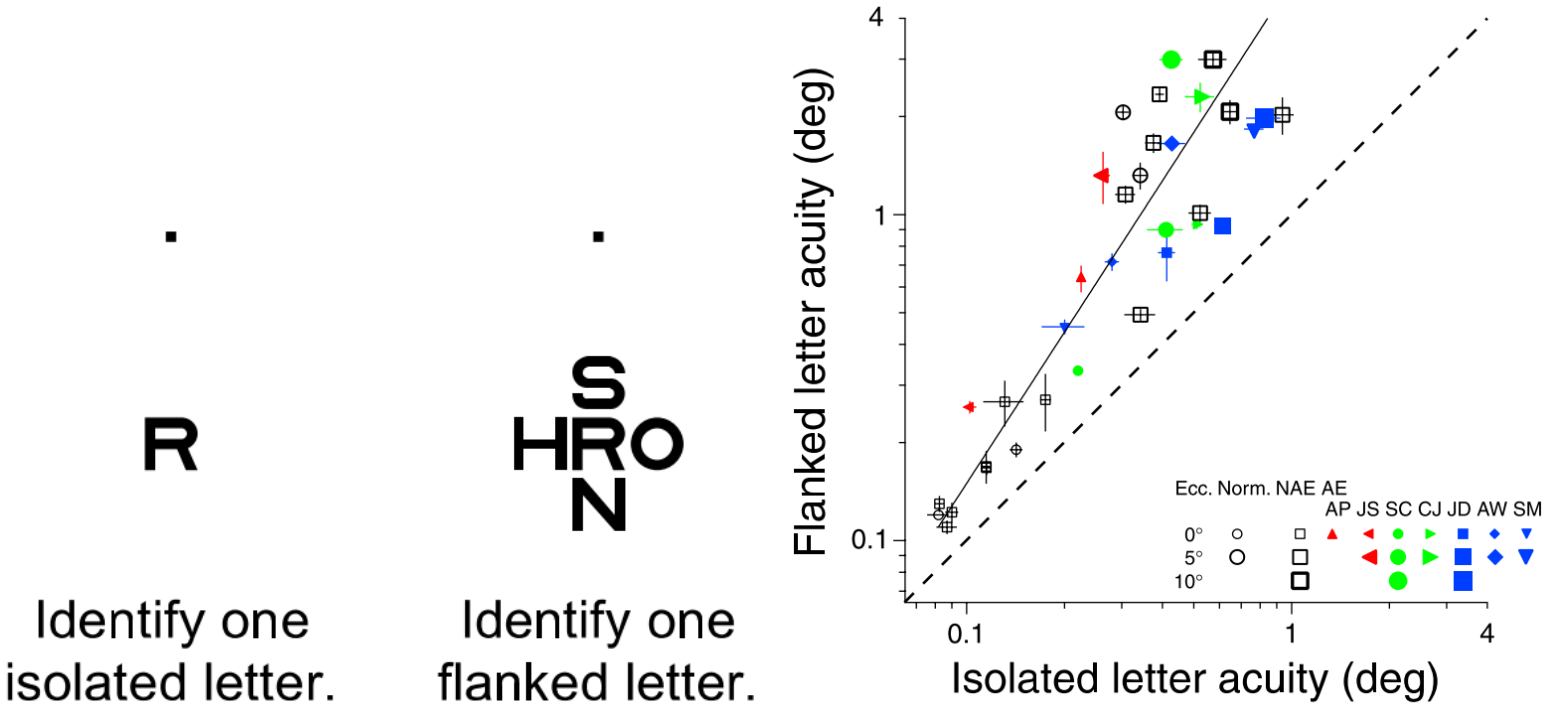


Figure: Levi, Song, & Pelli (2007)

What about foveal crowding?

"[acuity] is unaffected by crowding if done foveally, where critical spacing is only a few minutes of arc" (Pelli & Tillman, 2008)

"there is a question about whether genuine crowding actually occurs in the fovea" (Levi, 2008)

What about foveal crowding?

- technical difficulties in presenting stimulus at different foveal eccentricities
- crowding and masking may be confused within the fovea because of optical blur
- more general masking effects, not necessarily crowding (for: Levi et al., 2002; Hariharan et al., 2005; against: Danilova & Bondarko, 2006)
- physics, not physiology (Hess et al., 2000; Liu & Arditi, 2000; Liu 2001; Chung & Tjan, 2007)

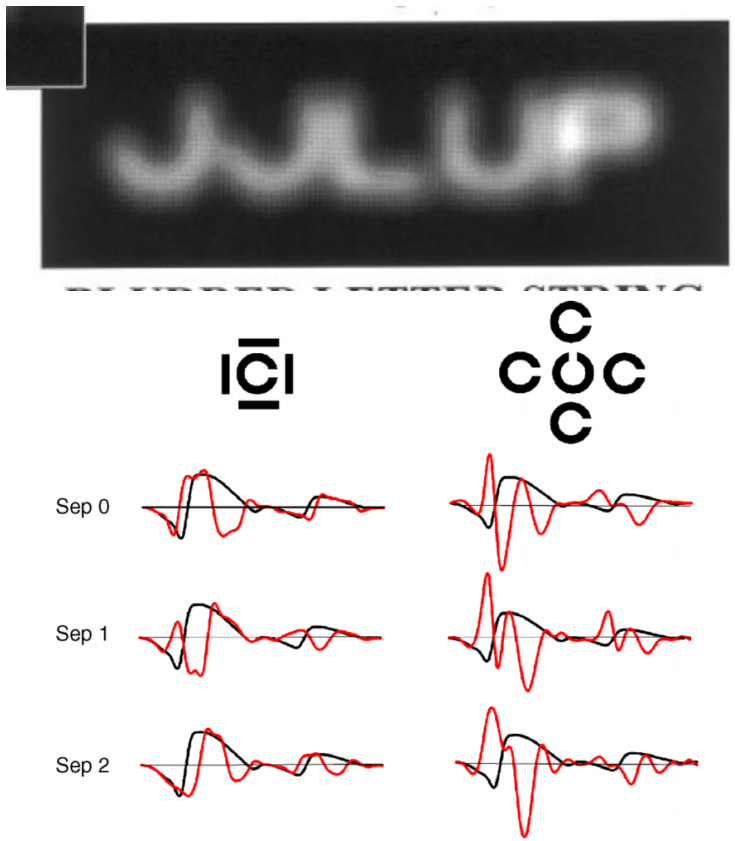


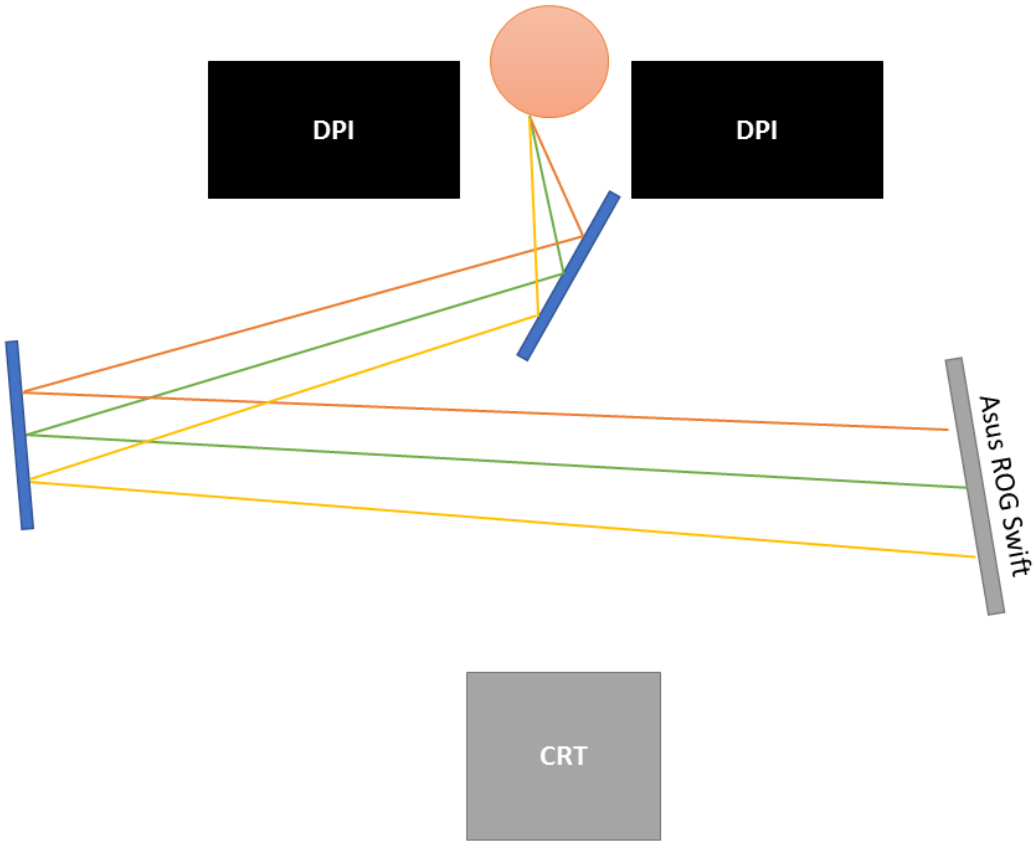
Figure: Liu (2000); Danilova & Bondarko (2006)

Objectives

- Map acuity within the foveaola
  - asymmetries in nasal vs temporal foveal vision?
  - individual variability?
- Measure the effects of crowding within the foveola

(very rough) schematic diagram of display setup

We need high spatial and temporal resolution to measure acuity under stabilized conditions.



- eye to display = 4.1m
- pixel angle = 0.236 arcmin and 200Hz refresh rate

Experiment Design: Overview

We want to measure visual acuity in uncrowded and crowded conditions.

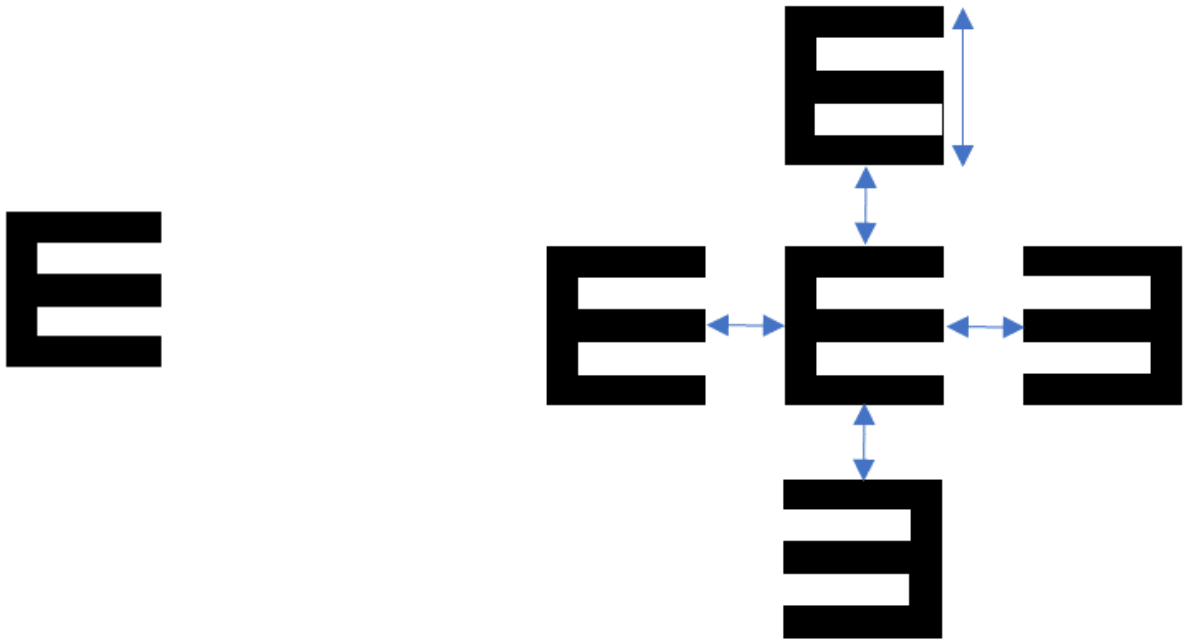
- Eccentricities tested: 0, 5, 15, 25, and 60 arcmin[1]
- 10 conditions (uncrowded/crowded x eccentricity) tested in individual blocks of about 100 trials in pseudorandom order
- Task: Report orientation of tumbling-E optotype (left or right, 2-AFC)
- PEST algorithm changed size of optotypes to target 75% performance in discrimination task
- Stimuli were fully stabilized to maintain fixed eccentricity from the center of gaze

Recalibration every trial.

1.5 second fixation every 15 trials.

[1] only temporal eccentricities tested in pilot

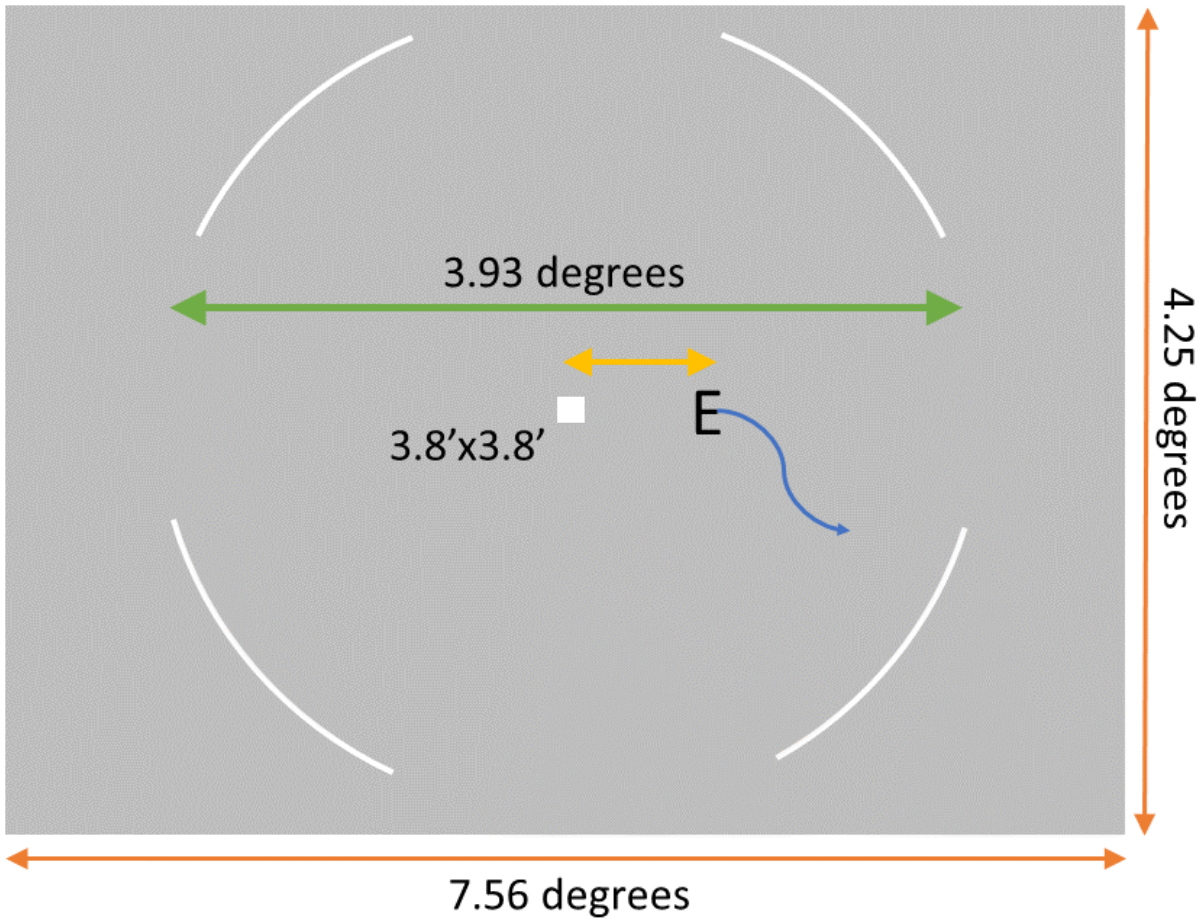
Experiment Design: Stimuli



Examples of uncrowded and crowded stimuli.

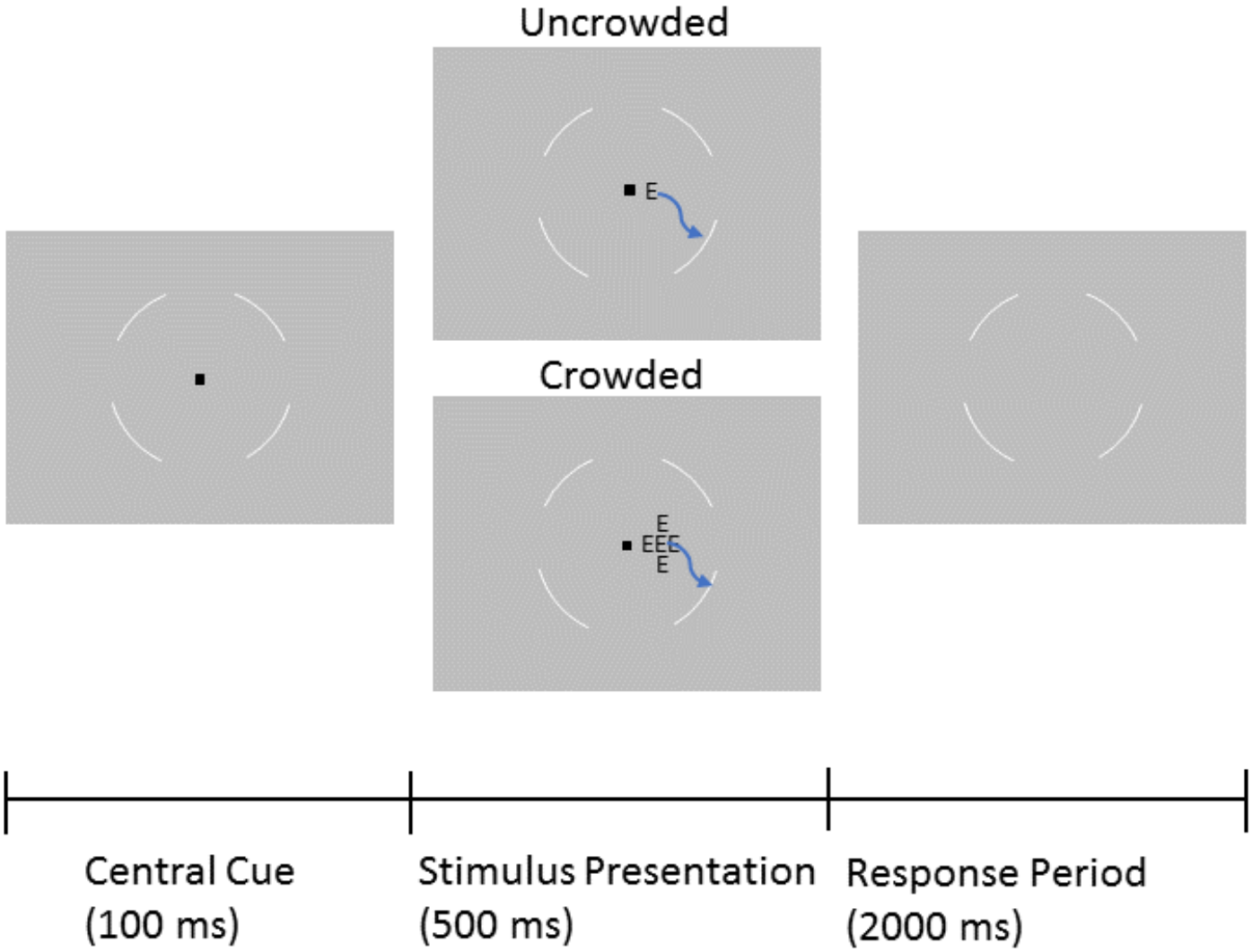
- All tumbling-Es were horizontally facing (left or right).
- Edge-to-edge distance between target and flankers is half the size of the target.

Experiment Design: Display Dimensions



Note that central fixation point is shown only for eccentricities $> 5'$.

Experiment Design: Trial Flow



Data Collection: Overview

- $N = 2$
- ideally we would only include drift trials but we may include MS trials if yields are low
- Today we will mostly look at data from the naive subject (drift only trials)

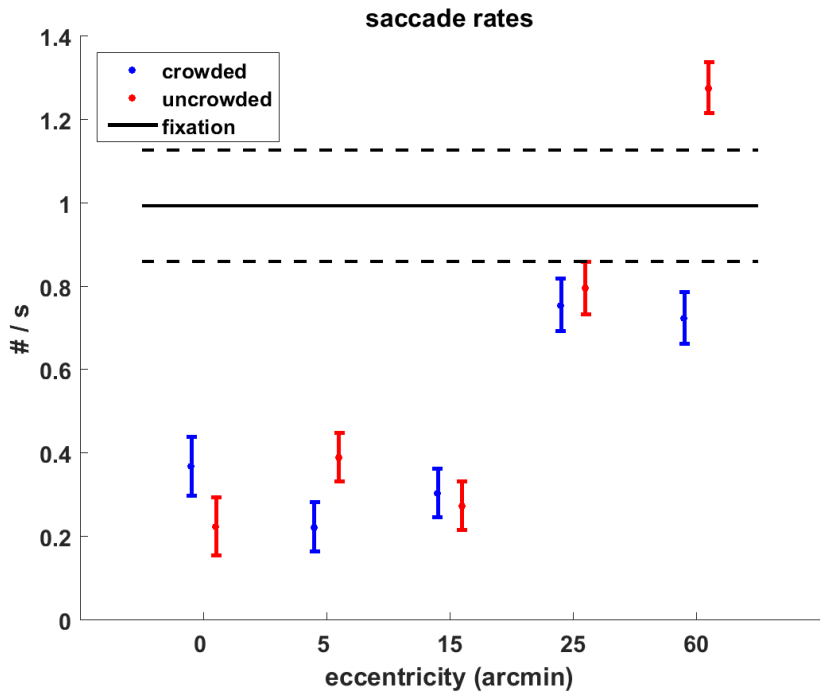
Data Collection: Naive Subject

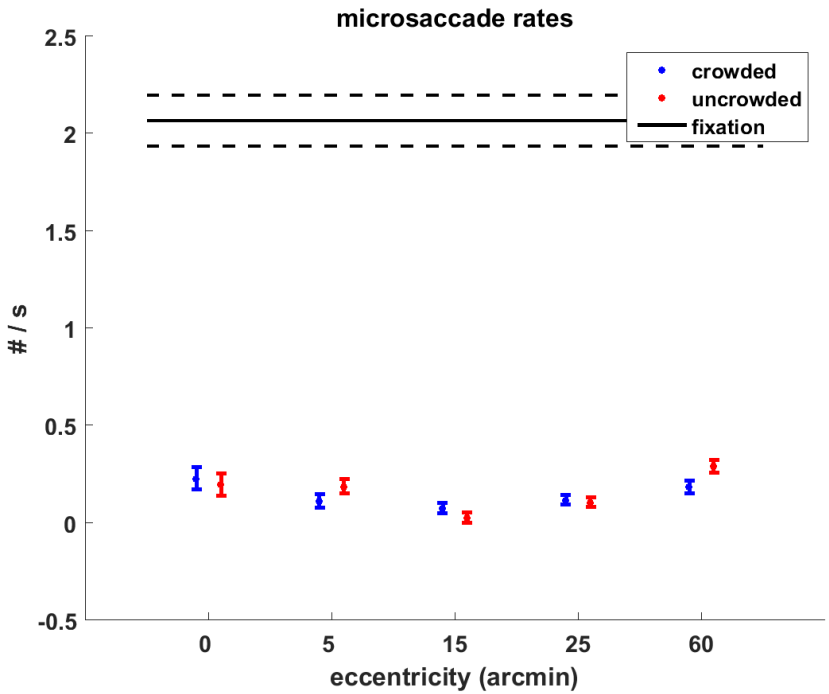
Full data completed for one naive subject (temporal eccentricities only).
(3 training sessions, 6 data collection sessions)

	Total	Valid	MS	S	NT/B	Yield
All	2004	1223	132	646	3	67.61%
Uncrowded	1018	634	72	310	2	69.35%
Crowded	986	589	60	336	1	65.82%
Fixation	125	0	30	45	50	24.00%

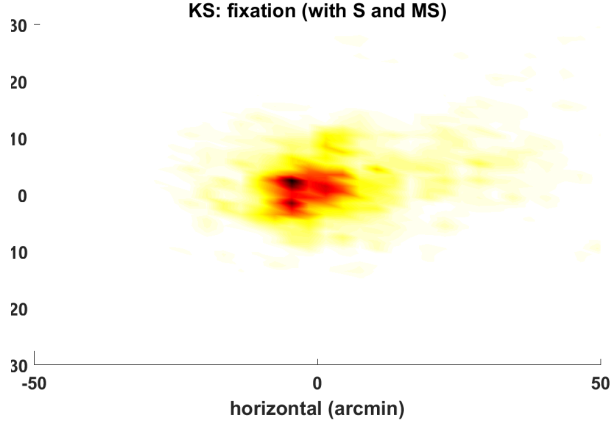
	Uncrowded						**Crowded**					
Ecc.	Total	Valid	MS	S	NT/B	Yield	Total	Valid	MS	S	NT/B	Yield
0	143	96	15	31	1	111: 77.62%	155	107	24	24	0	131: 84.52%
5	160	125	13	22	0	138: 86.25%	254	162	25	66	1	187: 73.62%
15	184	143	8	33	0	151: 82.07%	159	126	2	31	0	128: 80.50%
25	253	129	12	112	0	141: 55.73%	170	96	5	69	0	101: 59.41%
60	278	141	24	112	1	165: 59.35%	248	98	4	146	0	102: 41.13%

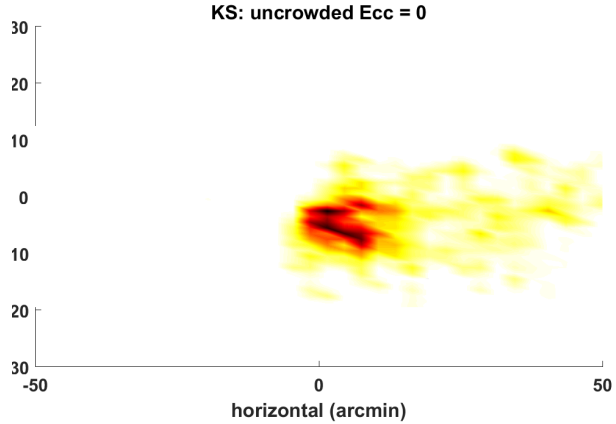
Saccade and Microsaccade rates

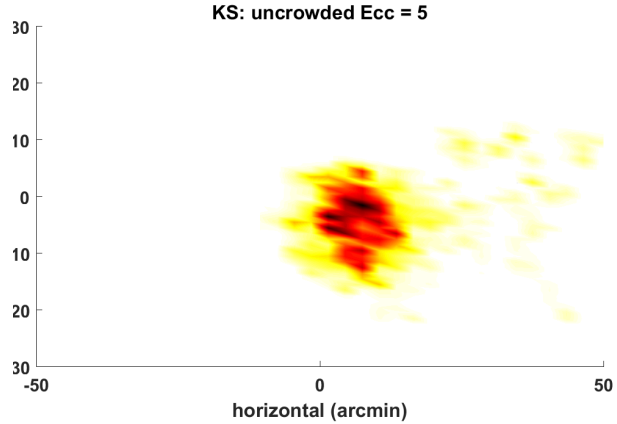


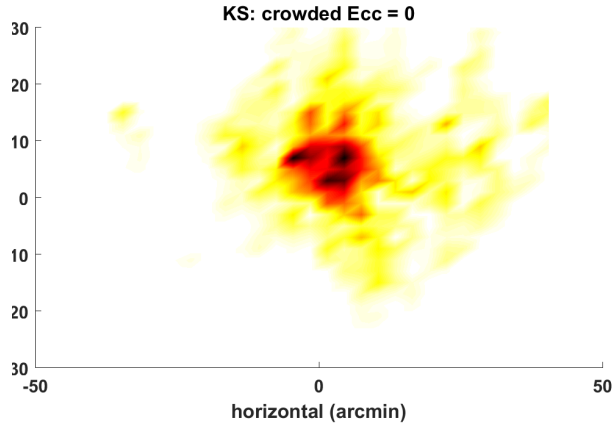


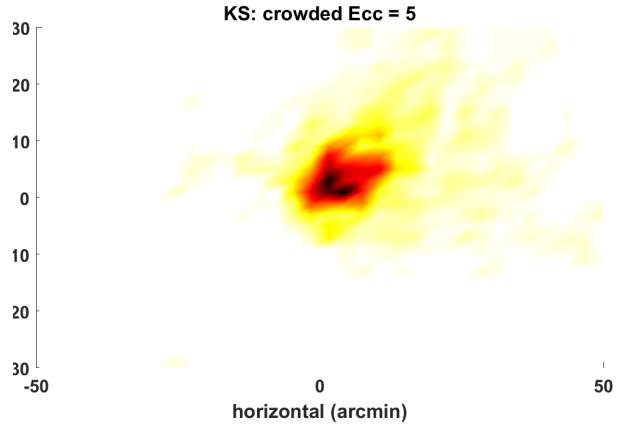
PDF of gaze positions - part 1



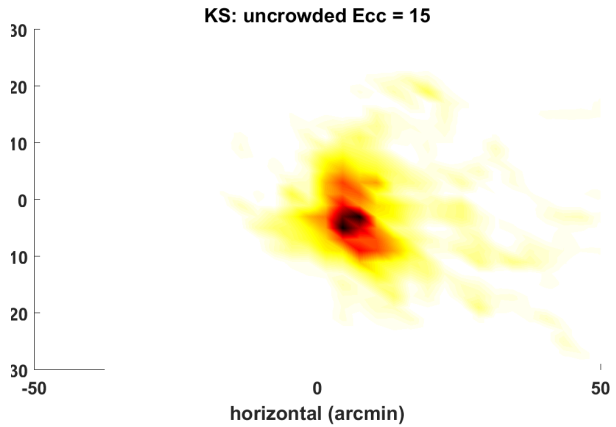


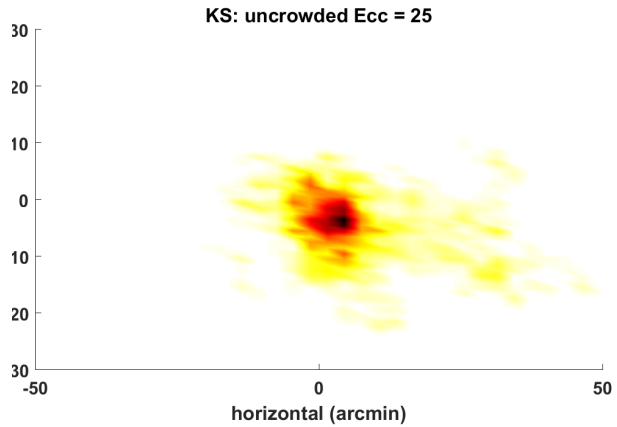


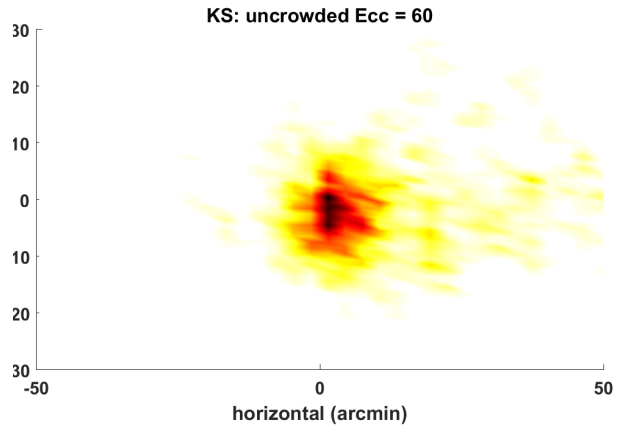


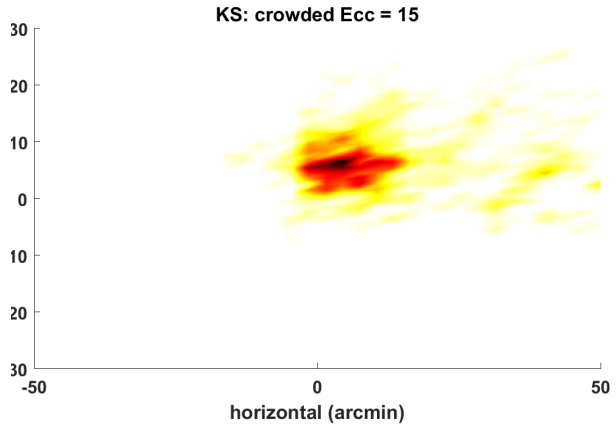


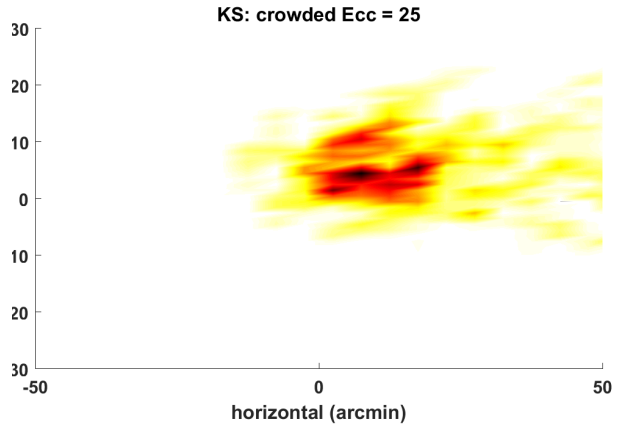
PDF of gaze positions - part 2

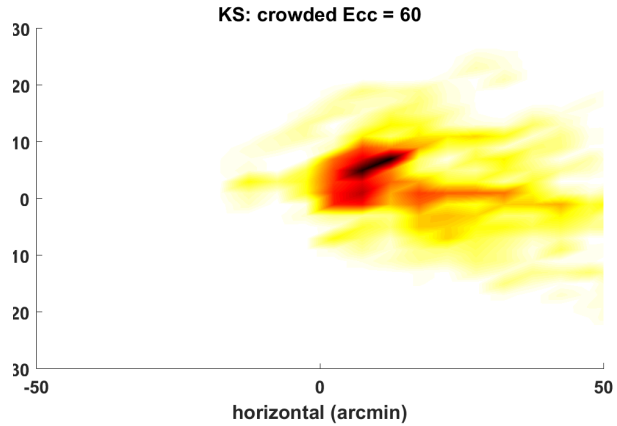












Psychometric Function fitting

$$P(x) = \gamma + S(x) \cdot (1 - (\lambda + \gamma)) \qquad \text{psychometric function}$$

$x =$ stimulus size (MAR)

$\gamma = 0.5$ (guess rate)

$\lambda = 0$ (lapse rate)

- Cumulative normal distribution

$$S(x) = \frac{1}{2}\left[1 + \text{erf}\left(\frac{x - \mu}{\sigma\sqrt{2}}\right)\right]$$

- Cumulative Weibull distribution[2]

$$S(x) = \begin{cases} 1 - e^{-(x/\alpha)^{\beta}}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

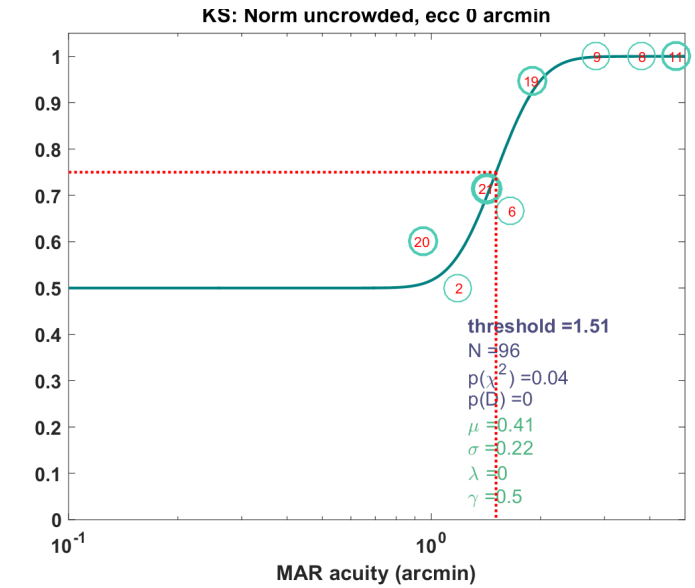
[2] Used to measure acuity thresholds by Williams & Coletta (1987), Lalor et al. (2016), Marcos & Navarro (1997), Jeon et al. (2010) and others.

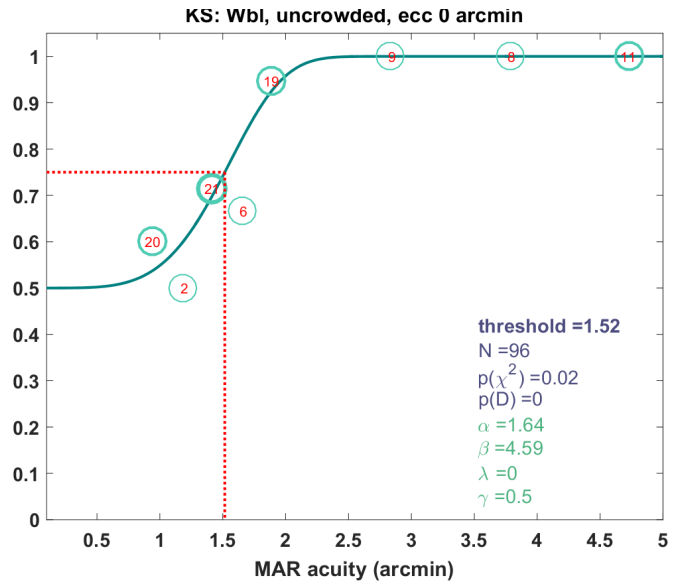
Eccentricity = 0 arcmin

Normal

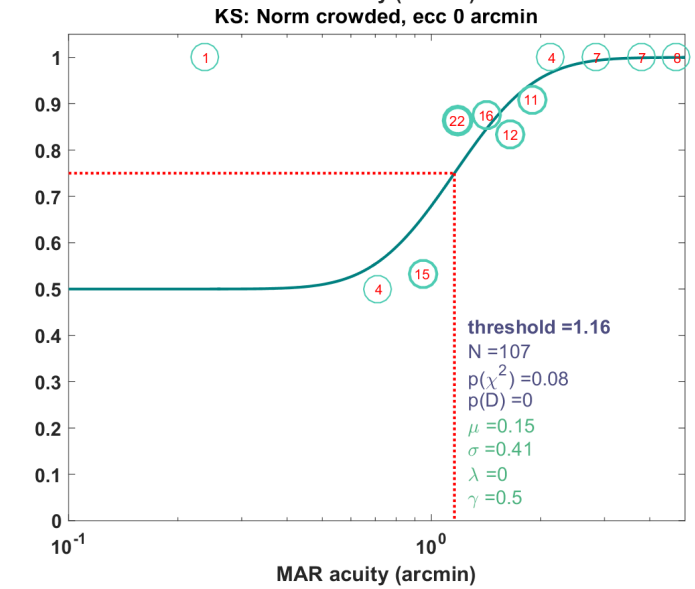
Weibull

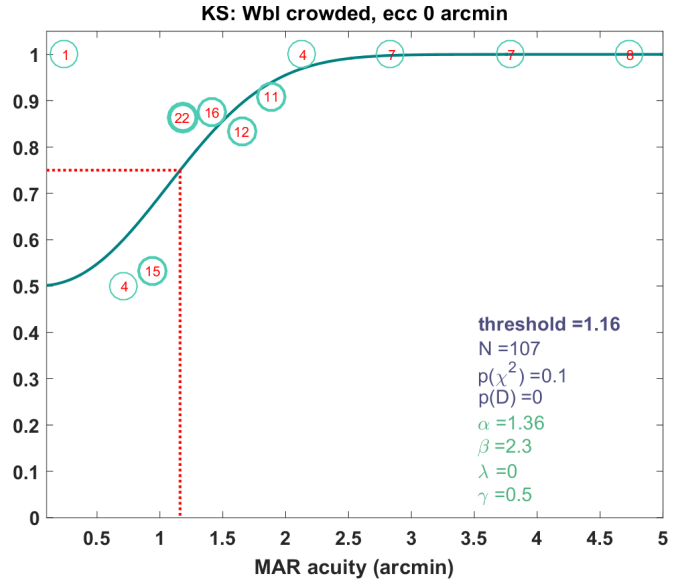
Uncrowded





Crowded



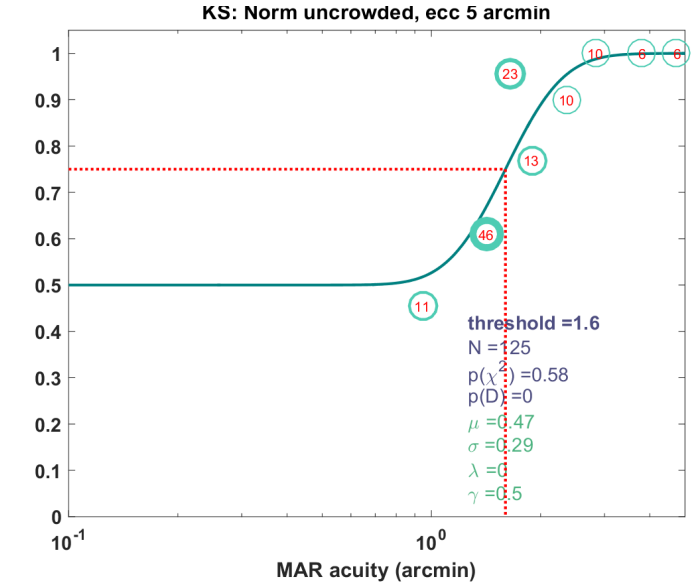


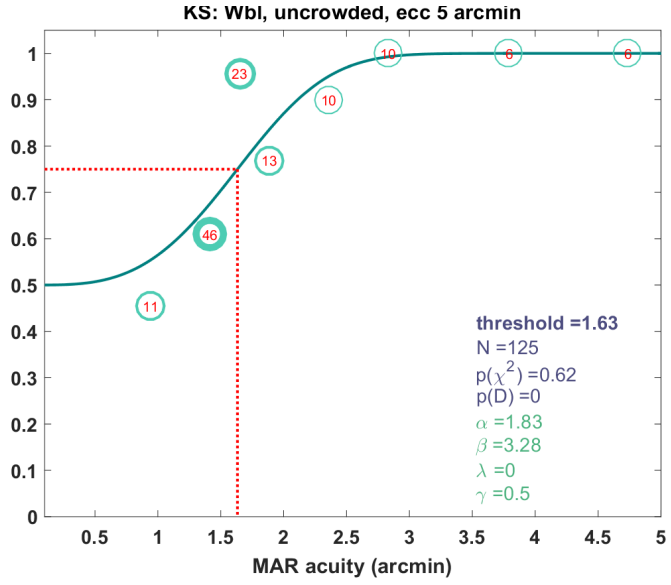
Eccentricity = 5 arcmin

Normal

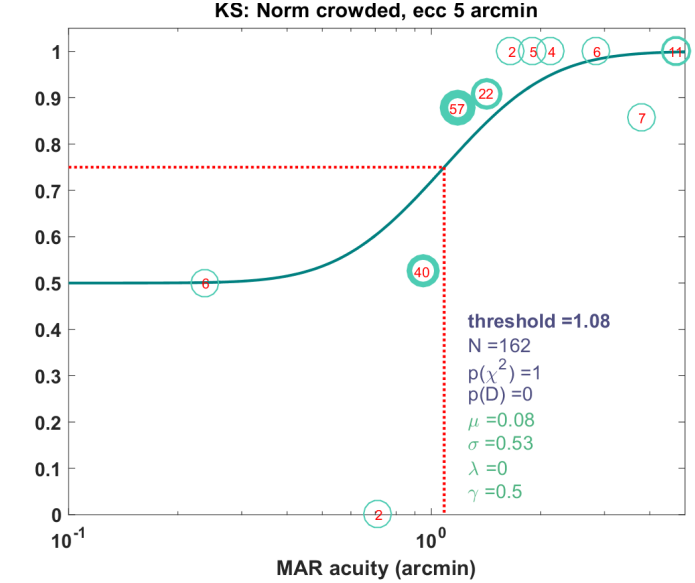
Weibull

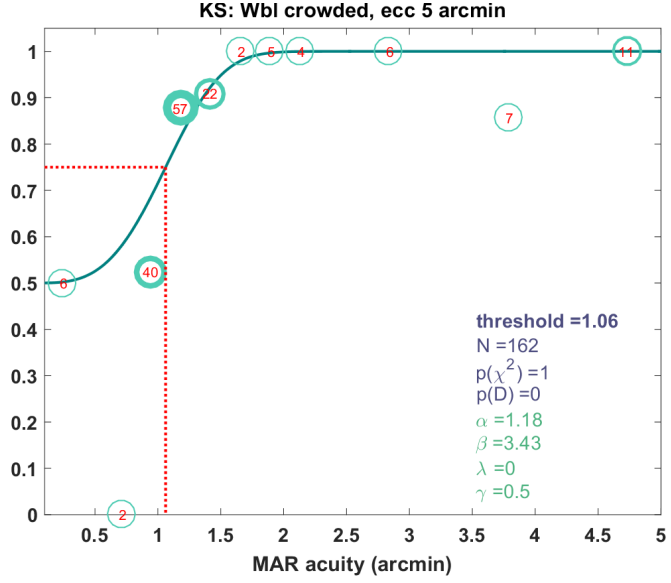
Uncrowded





Crowded



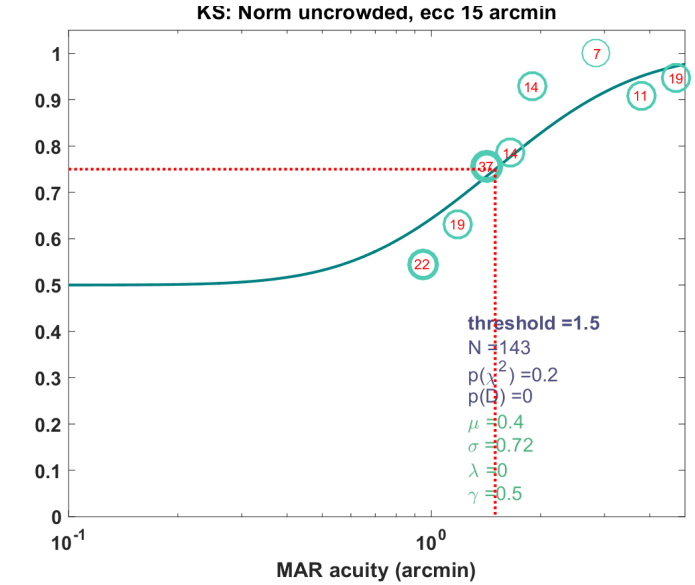


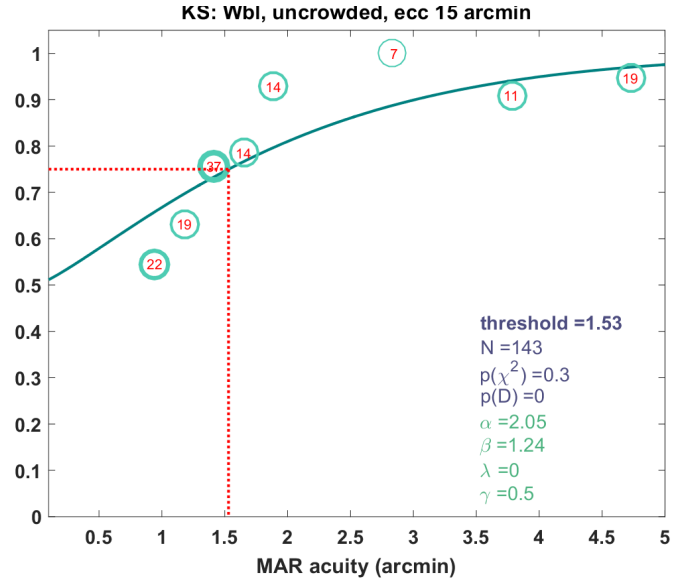
Eccentricity = 15 arcmin

Normal

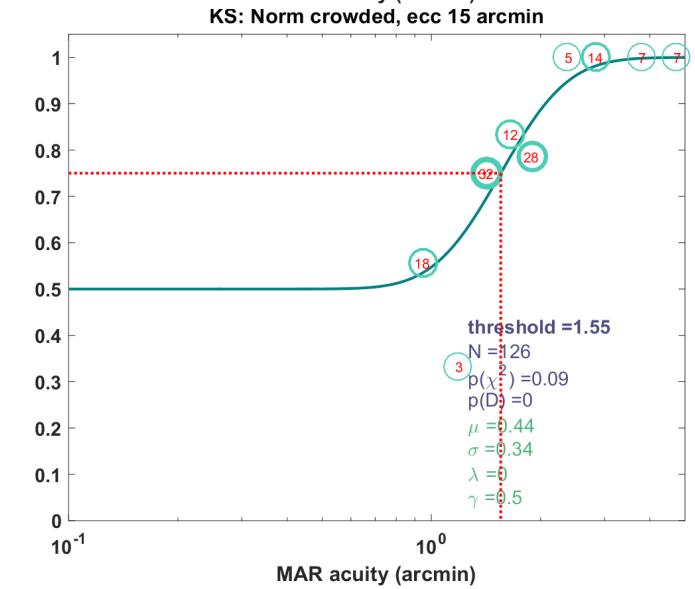
Weibull

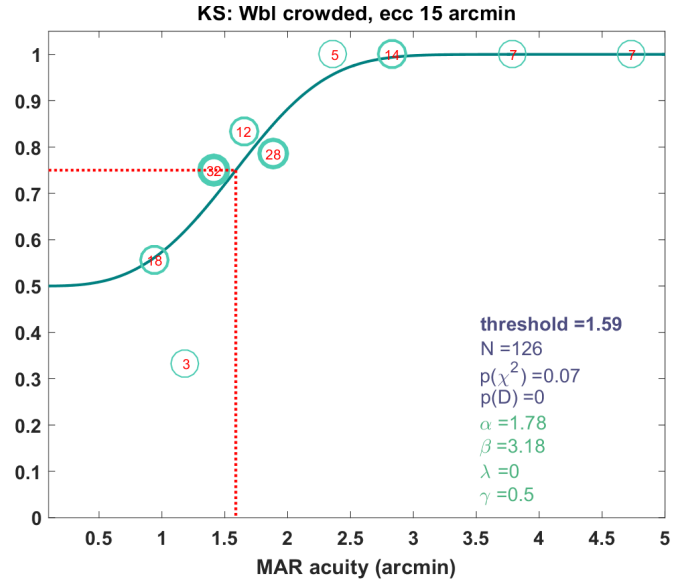
Uncrowded





Crowded



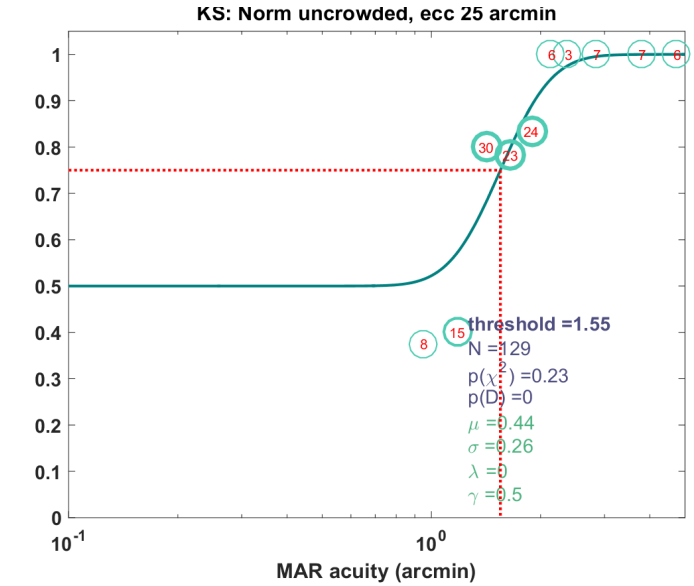


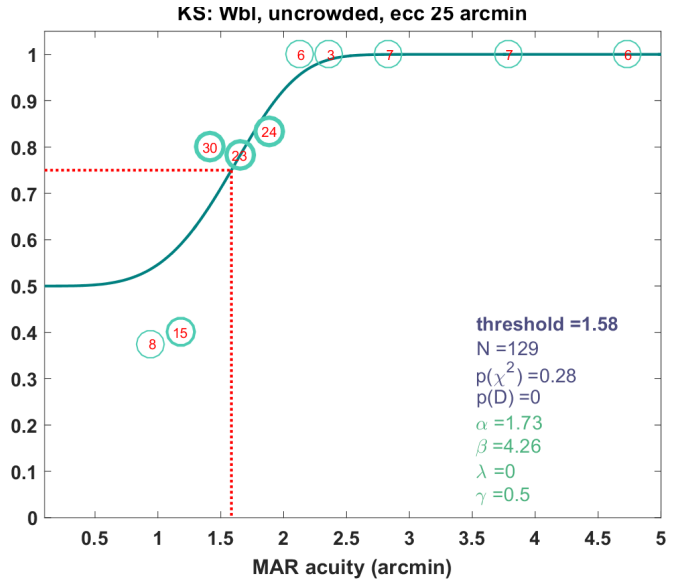
Eccentricity = 25 arcmin

Normal

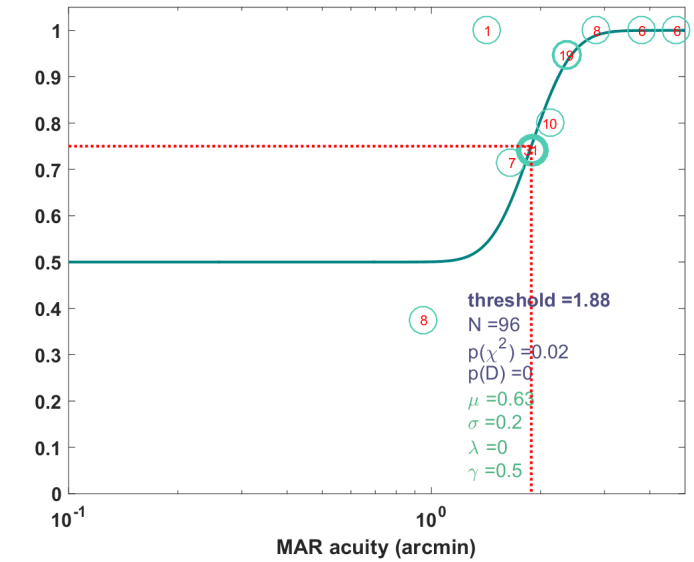
Weibull

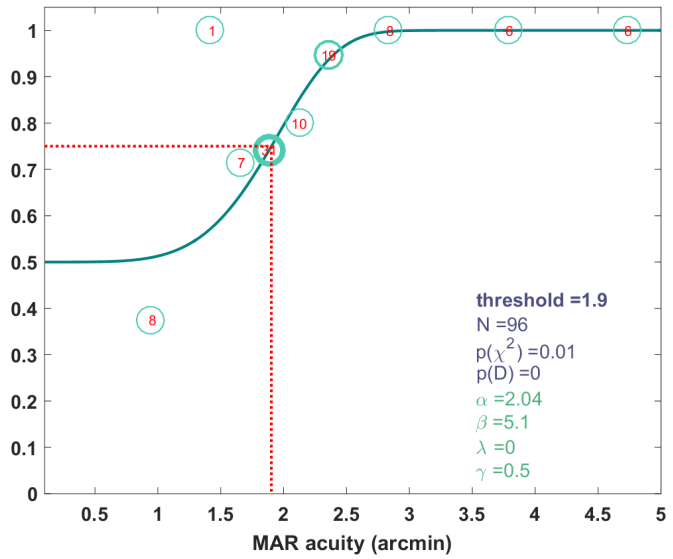
Uncrowded





Crowded



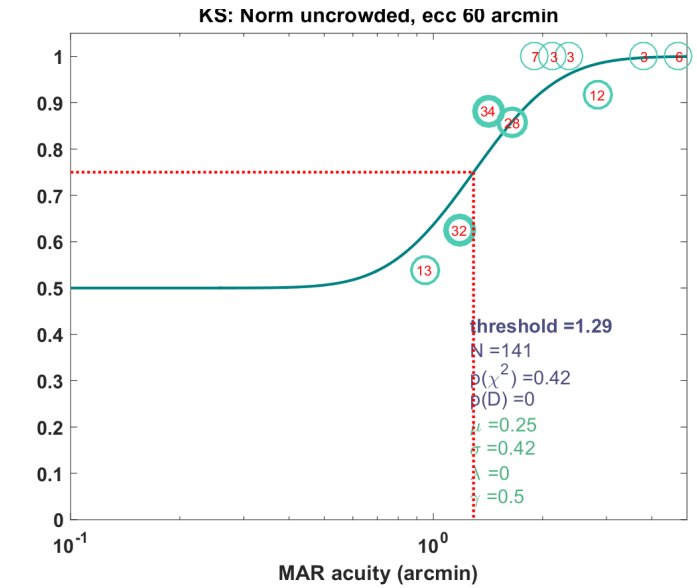


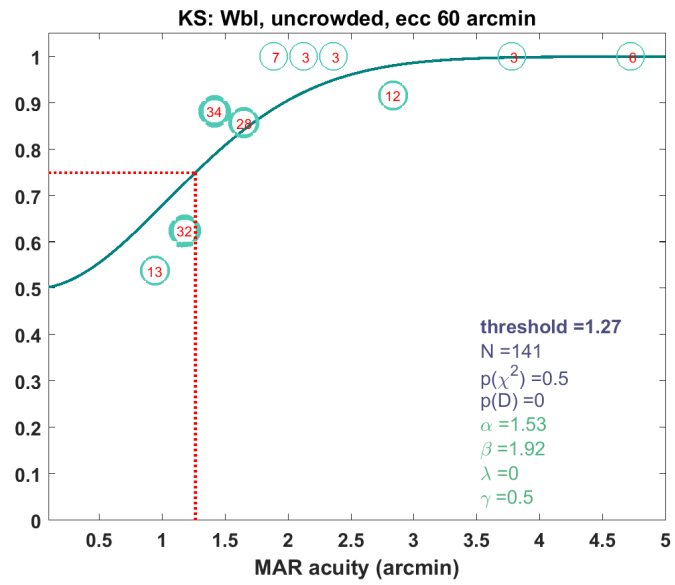
Eccentricity = 60 arcmin

Normal

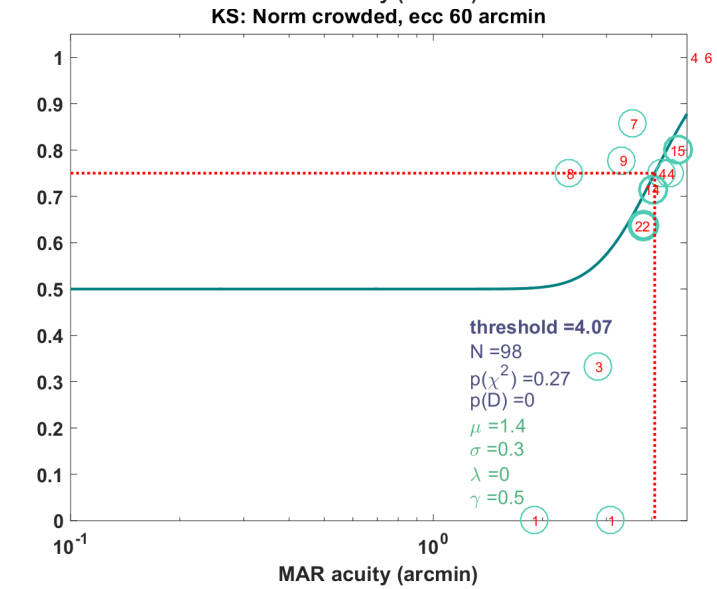
Weibull

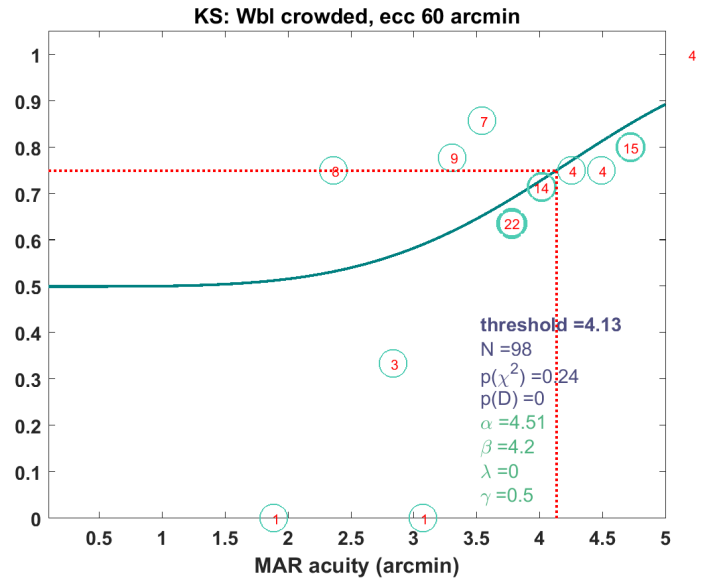
Uncrowded



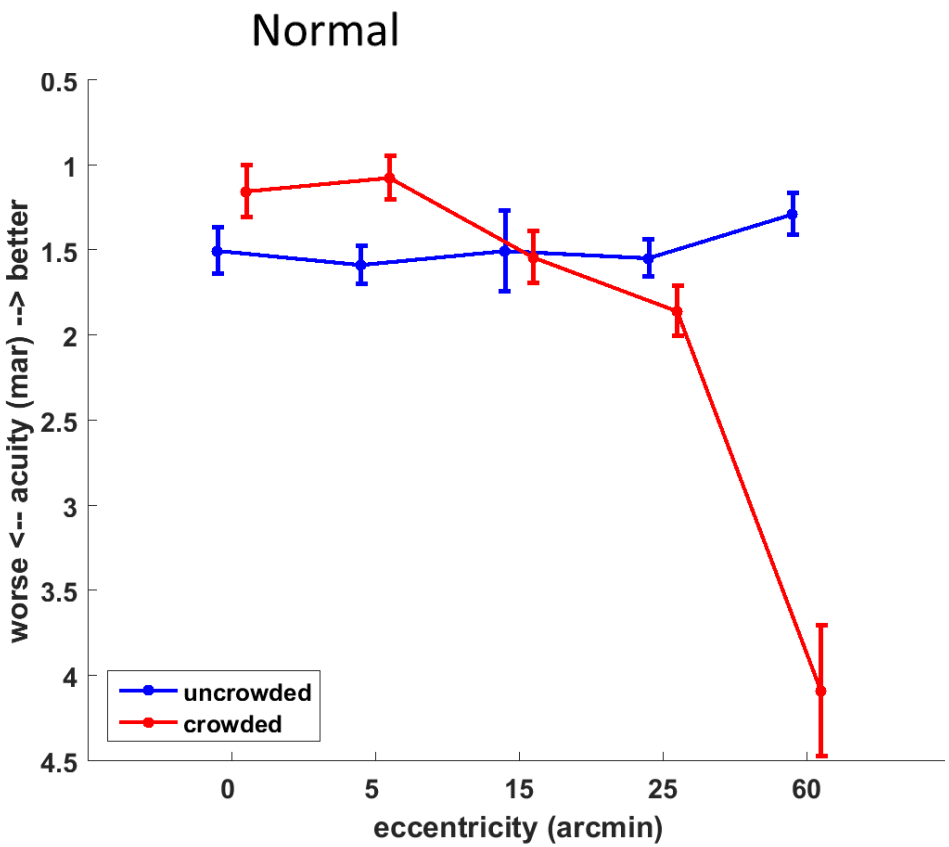


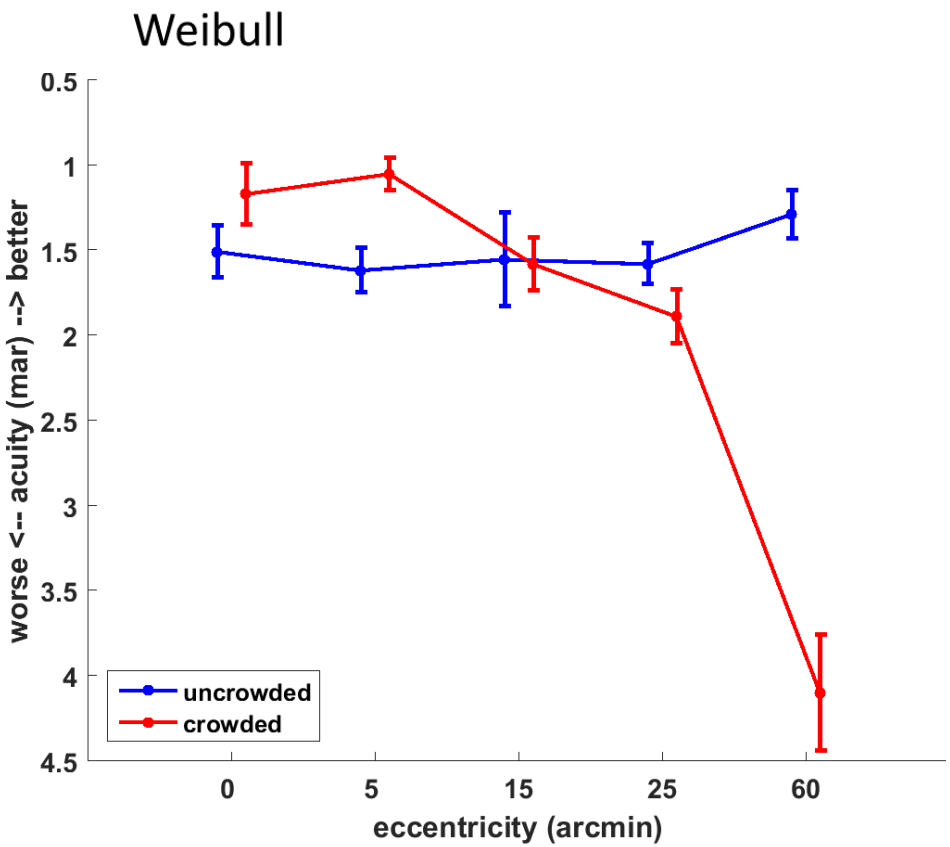
Crowded





MAR Acuity by Eccentricity (Naive subject)





MAR Acuity by Eccentricity: Threshold Values

Drift and MS

	Cumulative Normal distribution			
	Uncrowded		Crowded	
Ecc	Thresh	Boot mn±sd	Thresh	Boot mn±sd
0	1.33	1.33±0.15	1.22	1.22±0.12
5	1.59	1.58±0.11	1.09	1.09±0.12
15	1.49	1.49±0.21	1.55	1.55±0.14
25	1.55	1.55±0.11	1.87	1.85±0.16
60	1.26	1.27±0.11	4.00	3.99±0.35

	Cumulative Weibull distribution			
	Uncrowded		Crowded	
Ecc	Thresh	Boot mn±sd	Thresh	Boot mn±sd
0	1.37	1.37±0.15	1.24	1.23±0.15
5	1.63	1.61±0.14	1.06	1.07±0.16
15	1.52	1.52±0.26	1.59	1.58±0.14
25	1.59	1.58±0.11	1.89	1.87±0.16
60	1.23	1.25±0.14	4.07	4.04±0.36

*1000 bootstrap iterations

Drift Only

	Cumulative Normal distribution			
	Uncrowded		Crowded	
Ecc	Thresh	Boot mn±sd	Thresh	Boot mn±sd
0	1.51	1.50±0.14	1.16	1.15±0.15
5	1.60	1.59±0.11	1.08	1.07±0.13
15	1.50	1.50±0.24	1.55	1.54±0.15
25	1.55	1.55±0.11	1.88	1.86±0.15
60	1.29	1.29±0.12	4.07	4.09±0.38

	Cumulative Weibull distribution			
	Uncrowded		Crowded	
Ecc	Thresh	Boot mn±sd	Thresh	Boot mn±sd
0	1.52	1.51±0.15	1.16	1.17±0.18
5	1.63	1.62±0.13	1.06	1.05±0.10
15	1.53	1.55±0.28	1.59	1.58±0.16
25	1.58	1.58±0.12	1.90	1.89±0.16
60	1.27	1.29±0.14	4.13	4.10±0.34

Data from Experienced Subject

- Eccentricities: 0, 5, and 60arcmin
- Analyzed drift and MS trials

Data Collection: Experienced Subject

Partial data collected for one experienced subject.
(3 data collection sessions)

	Total	Valid	MS	S	NT/B	Yield
All	1062	513	353	188	8	81.54%
Uncrowded	528	241	234	50	3	89.96%
Crowded	534	272	119	138	5	73.22%
Fixation	86	1	76	8	1	89.53%

	Uncrowded						Crowded					
Ecc.	Total	Valid	MS	S	NT/B	Yield	Total	Valid	MS	S	NT/B	Yield
0	214	93	116	4	1	209: 97.66%	135	94	38	3	0	132: 97.78%
5	118	48	59	10	1	107: 90.68%	127	85	25	17	0	110: 86.61%
15	41	20	16	5	0	36: 87.80%	35	11	13	10	1	24: 68.57%
25	30	9	11	9	1	20: 66.67%	21	3	3	14	1	6: 28.57%
60	125	71	32	22	0	103: 82.40%	216	79	40	94	3	119: 55.09%

MAR Acuity by Eccentricity: Threshold Values

Drift and MS

	Cumulative Normal distribution			
	Uncrowded		Crowded	
Ecc	Thresh	Boot mn±sd	Thresh	Boot mn±sd
0	1.11	1.10±0.12	1.22	1.21±0.08
5	1.05	1.04±0.15	1.19	1.19±0.09
15	1.32	1.31±0.11	1.42	1.40±0.09
25	0.98	1.14±0.16	NaN	1.73±0.08
60	1.22	1.20±0.22	2.13	2.11±0.22

	Cumulative Weibull distribution			
	Uncrowded		Crowded	
Ecc	Thresh	Boot mn±sd	Thresh	Boot mn±sd
0	1.13	1.12±0.11	1.23	1.23±0.08
5	1.06	1.06±0.15	1.20	1.20±0.09
15	1.33	1.33±0.11	1.43	1.42±0.10
25	0.97	1.16±0.16	NaN	1.74±0.08
60	1.24	1.23±0.23	2.16	2.13±0.24

*1000 bootstrap iterations

MAR Acuity by Eccentricity (Experienced subject)