Drift Gain Experiment

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APLAB

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Introduction

- Patients with macular degeneration have vision loss within the fovea as the central portion of the retina is deteriorating.
- Can extrafoveal vision be improved by changing the amount of image motion on the retina?

Experimental Methods (Figure 1)

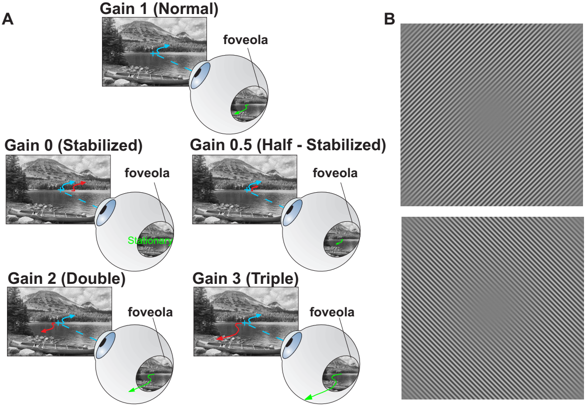


Figure: **A**, Different gain conditions change the motion of the image on the retina. Gains less than 1 reduce retinal motion and gains greater than 1 increase retinal motion. **B**, Stimuli. The task was to determine the orientation of a 16 cpd grating which was presented with a gaze-contingent 1° diameter scotoma at the center of gaze to prevent foveal vision.

Experimental Methods (continued)

Trial Flow:

- recalibration procedure
- 500 ms fixation on cue
- 800 ms ramp time (contrast of stimulus increases linearly)
- 500 ms stimulus contrast plateau period
- 4 second response period

Each recording block consisted of trials in one gain condition. Contrast changed from trial to trial following an adaptive procedure targeting 75% performance in the grating discrimination task. The threshold was determined by fitting a psychometric function to performance in one gain condition, then converted to contrast sensitivity (inverse of Michelson contrast).

Data Collection and Filtering

	Total	Valid Trials					Invalid Trials		
		0	.5	1	2	3	B/NT/ND	S	MS
S1	1360	170	205	189	181	182	271	85	103
		84	125	88	75	83			
S2	1481	127	170	123	145	278	208	234	277
		90	118	81	84	157			
S3	1600	227	251	194	245	241	17	188	284
		132	146	126	141	107			
S4	1320	175	191	125	156	177	338	193	60
		75	131	78	93	101			
S5	1479	203	194	143	155	165	202	104	414
		106	107	90	91	115			
S6	1440	100	127	137	115	207	286	87	535
		54	94	104	92	116			
S7	1840	147	167	141	107	125	614	439	392
		91	74	83	72	74			

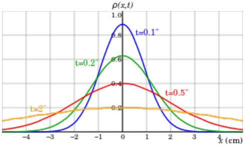
Brownian Motion Model of Drift

The motion of gaze during drift can be described by a random walk characterized by a diffusion coefficient D.

$$q(x, y, t; D) = \frac{1}{4\pi Dt} \exp\left(-\frac{x^2 + y^2}{4Dt}\right)$$

where D can be estimated from motion (either eye motion or retinal image motion).

$$D = \frac{\langle x(t)^2 \rangle + \langle y(t)^2 \rangle}{4t} = \frac{\langle r^2 \rangle}{4t}$$



Eye Motion and Retinal Image Motion

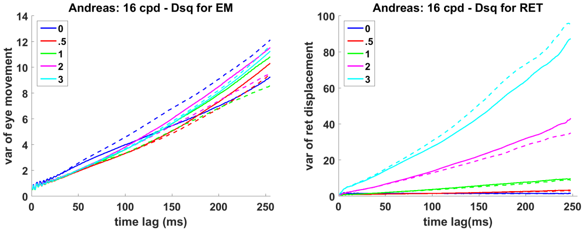


Figure: Examples of $\langle r_e^2 \rangle$ and $\langle r_r^2 \rangle$ for one subject plotted for different gain conditions.

Behavioral Results (Figure 2)

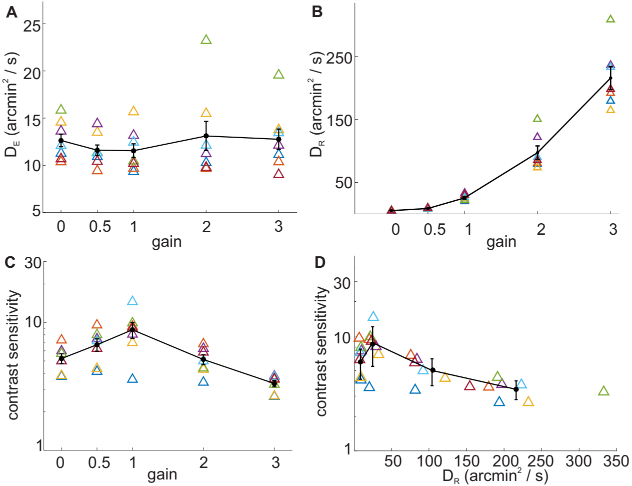


Figure 2 Caption

A-B, Diffusion coefficients of eye movements and retinal image motion across gain conditions. **C,** Contrast sensitivity varied across gain conditions, with highest sensitivity under normal viewing conditions. **D,** Contrast sensitivity versus retinal diffusion coefficient. Each color represents an individual subject. Black lines with error bars show mean and SEM at each gain condition.

Performance Predicted by D_R

Are subjects already behaving in a way to maximize performance? Can we theoretically determine the optimal behavior for this task?

What is the temporal power of retinal image motion generated by D_R at 16 cpd ($k_x^2 + k_y^2 = 16^2$)?

$$Q(k_x, k_y, f; D_R) = \mathcal{F}\{q(x, y, t; D_R)\} = \frac{2D_R(k_x^2 + k_y^2)}{4\pi^2 D_R^2 (k_x^2 + k_y^2)^2 + f^2)}$$

Human temporal sensitivity is band-pass around $f = 10$ Hz [1].

[1] Watson, 1981; parameters fit to Roufs & Blommaert, 1981

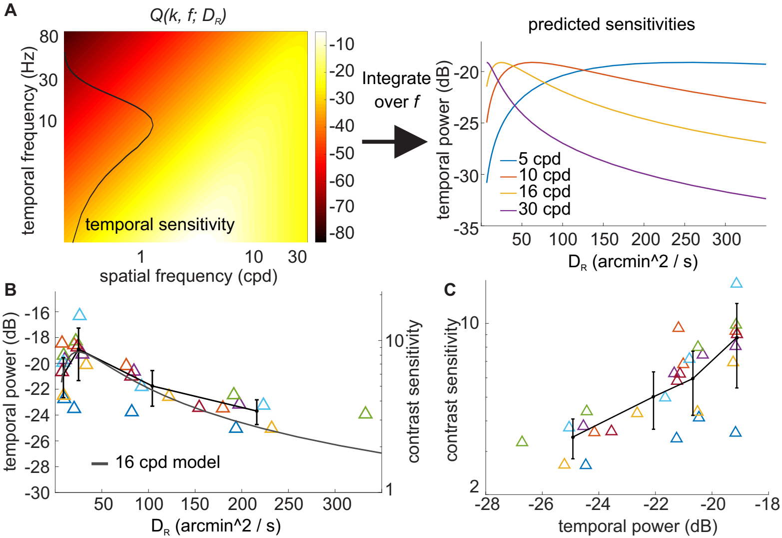

A
$Q(k, f; D_R)$
temporal frequency (Hz)
80
30
10
temporal sensitivity
1
10
30
spatial frequency (cpd)
-10
-20
-30
-40
-50
-60
-70
-80
Integrate
over f
predicted sensitivities
temporal power (dB)
-20
-25
-30
-35
5 cpd
10 cpd
16 cpd
30 cpd
50
100
150
200
250
300
D_R (arcmin^2 / s)
B
temporal power (dB)
-16
-18
-20
-22
-24
-26
-28
-30
16 cpd model
50
100
150
200
250
300
D_R (arcmin^2 / s)
contrast sensitivity
10
1
C
contrast sensitivity
10
2
-28
-26
-24
-22
-20
-18
temporal power (dB)

Figure 3 Caption

A, Model of performance based on Brownian motion drifts and human temporal sensitivity. Q, the power spectral density of Brownian motion, is averaged over temporal frequencies to generate a prediction of sensitivities. **B,** The prediction for 16 cpd is overlaid on the contrast sensitivity vs retinal diffusion shown in Figure 2D. **C,** Relationship between contrast sensitivity and prediction based on each subject's retinal diffusion coefficient.

Computing Temporal Power from Retinal Motion

$$P(k_x, k_y, f) = \mathcal{F}_{x,y,t}\left\{e^{-2\pi i(k_x x_r(t)+k_y y_r(t))}\right\}$$

where $x_r(t) = \alpha \cdot (x_e(t) - x_i(t))$ is the motion of the image on the retina, $x_e(t)$ is the motion of the eye movements, $x_i(t)$ is the motion of the image on the monitor, and α is a retinal amplification factor.

Temporal Power from Retinal Motion (Figure 4)

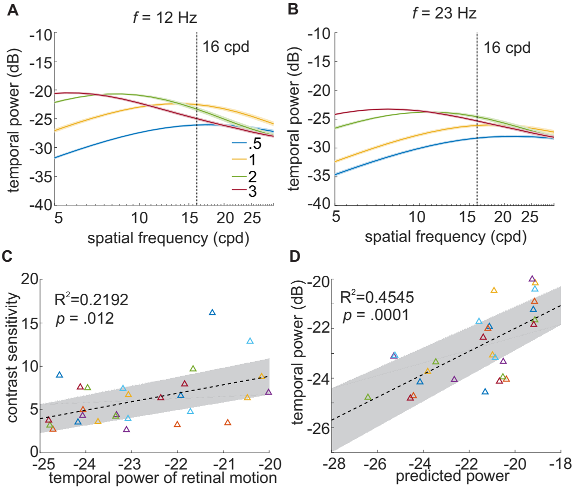


Figure 4 Caption

A-B, Slices of $P(k, f)$ for $f = 12$ and $f = 23$ at each gain condition. Different gains contribute power at different temporal frequencies. **C,** Contrast sensitivity vs $P(k, f)$ for each subject and gain condition. **D,** $P(k, f)$ vs $Q(k, f)$ for each subject and gain condition. Dotted lines and shaded region show regression of these points and the 95% confidence interval.

Summary

- Subject's normal behavior is already optimal for the task.
- Changing the amount of retinal image motion (from normal viewing conditions) shifts power out of the range temporal frequencies to which humans are most sensitive causing decreased performance.
- We predict that the performance of a person with non-optimal behavior could be improved by applying a gain to the retinal image motion.

Extra Figures

Motion Orthogonal or Parallel to Grating Stimulus