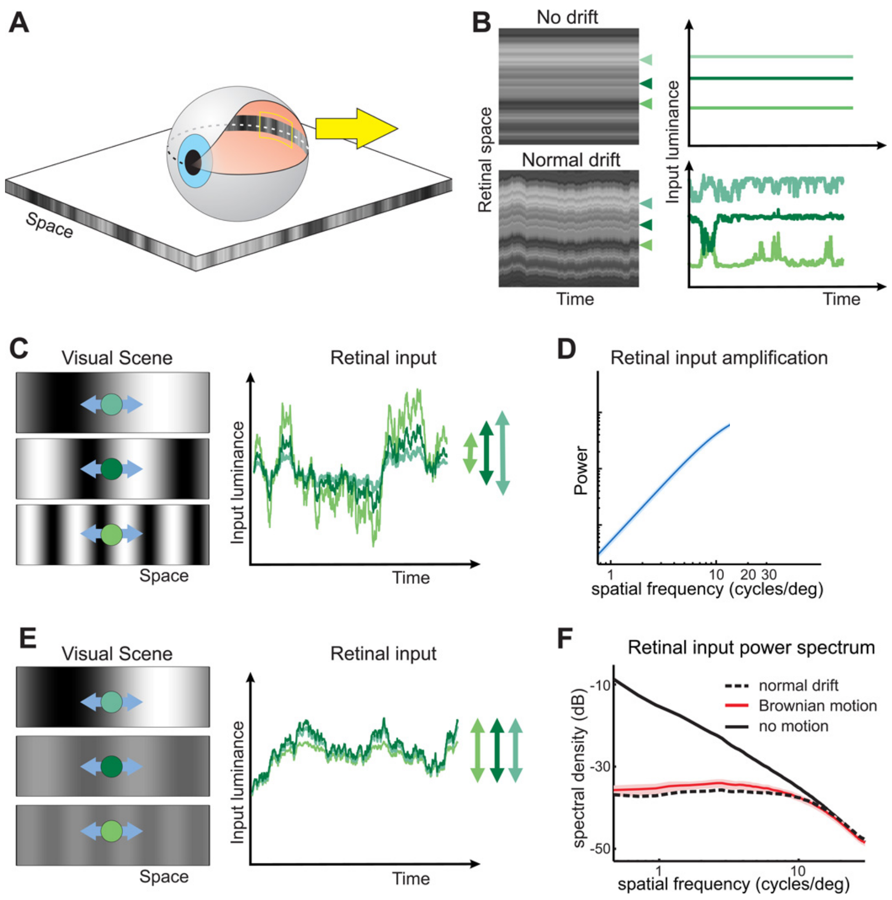
IMPACT OF EYE ANATOMY ON RETINAL IMAGE MOTION

OVERVIEW OF MODELING AND EMPIRICAL WORK

APRIL 21, 20202 LAB MEETING

Temporal Modulations from Fixational Drift Whiten Frequency Spectra

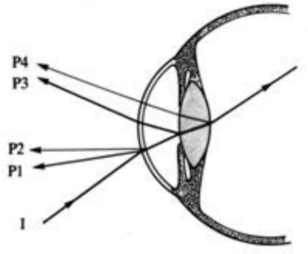


The magnitude of the change in luminance over time on the retina is governed by:

1. the projected image's spatial frequency content
2. **movement of the projected image on the retina**

Rucci & Victor., Trends Neurosci. 2015

RETINAL MOTION IS INFERRED FROM EYE MOTION



However, we <u>do not</u> measure retinal movement directly.

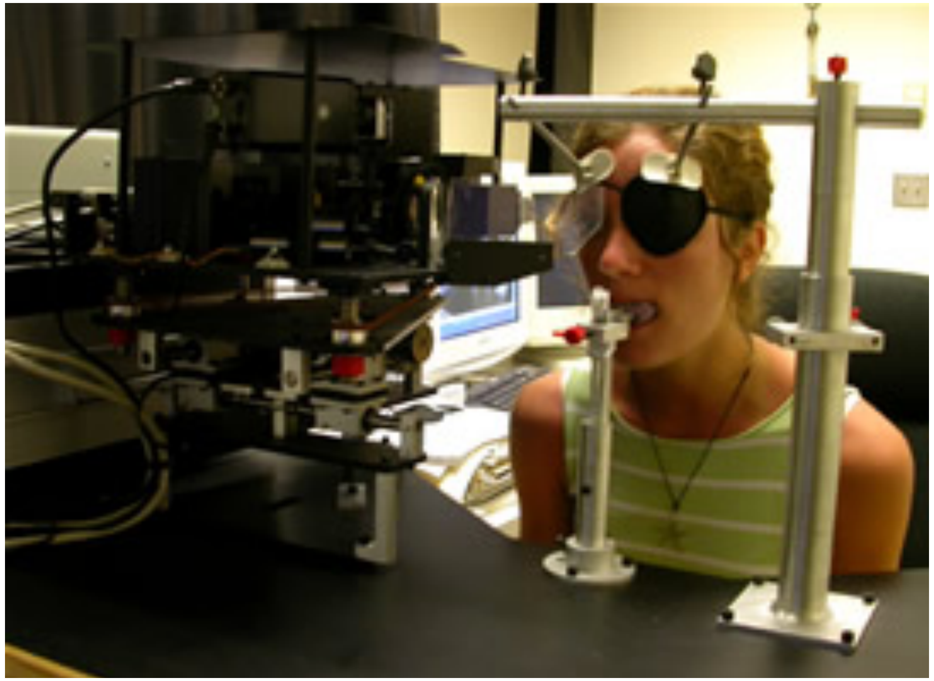
We <u>measure the rotation of the eye</u> as extracted from the relative positons of each the 1st and 4th Purkinje images (i.e., reflections from the cornea and lens).

- The separation between the two images changes proportionally with the sine of the angle of rotation.
- But these images move similarly with eye translation.

In other words, we …

measure **ocular movement** and

infer **retinal movement.**

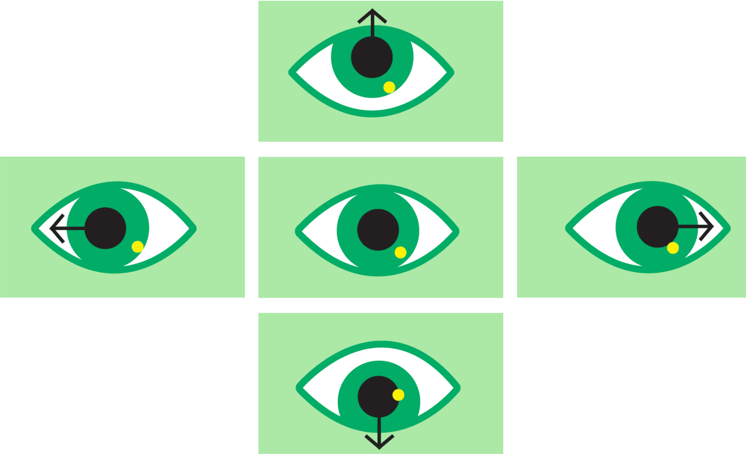


Dual Purkinje Image (DPI) eyetracker by Fourward Technologies, a device that allows measurement of eye movement with high spatial and temporal resolution.

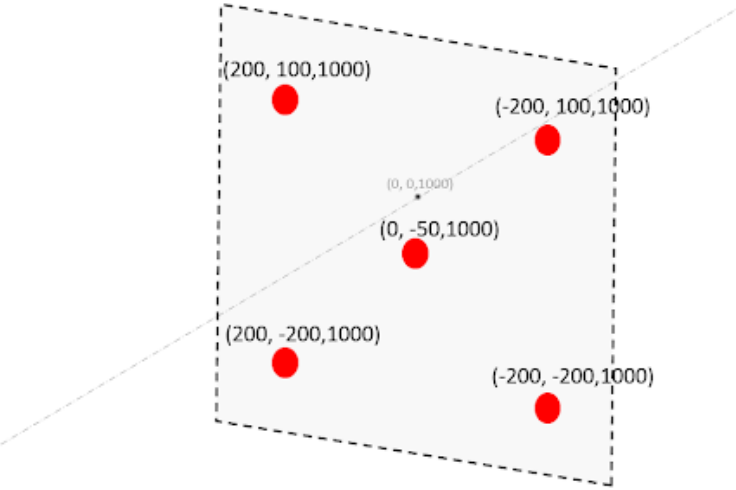
RETINAL MOTION IS INFERRED FROM EYE MOTION

$$\frac{Eye\ Rotation\ \theta\ (deg)}{Time\ (s)}$$

What we try to MEASURE



Cannot ask subjects to ROTATE a certain amount



What we actually RECORD

Instead, ask them to fixate objects at different visual angles

RETINAL MOTION IS INFERRED FROM EYE MOTION

$$\frac{\cancel{Visual\ Angle\ \beta\ (deg)}}{Time\ (s)} \times \frac{Eye\ Rotation\ \theta\ (deg)}{\cancel{Visual\ Angle\ \beta\ (deg)}} = \frac{Retinal\ Distance\ (mm)}{Time\ (s)}$$

What we MEASURE

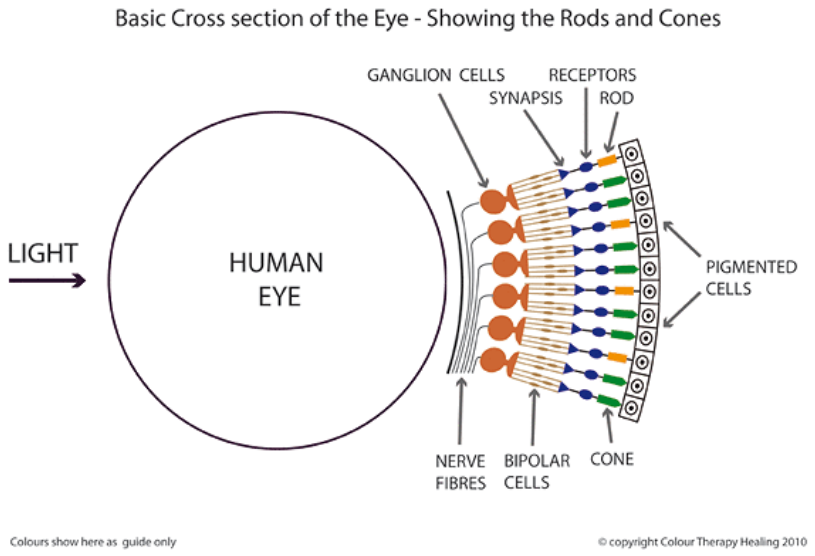
What we INFER

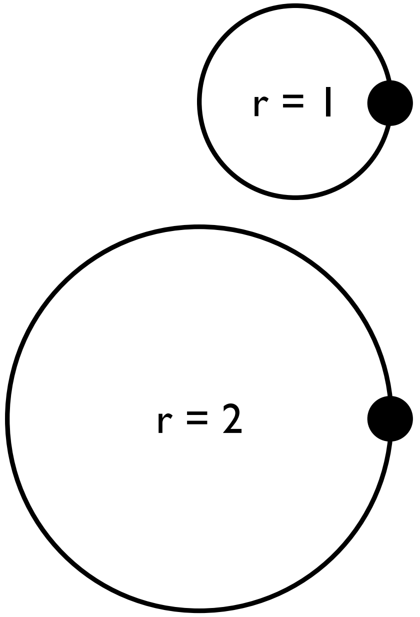
GEOMETRY GOVERNS MOTION TRANSFER WITHIN THE EYE

The exact relationship between **ocular movement**, i.e. the measured rotation of the eye, and movement of the projected **image on the retina** is governed by the **geometry of the eye**.

Arc Length $s = r\Theta$

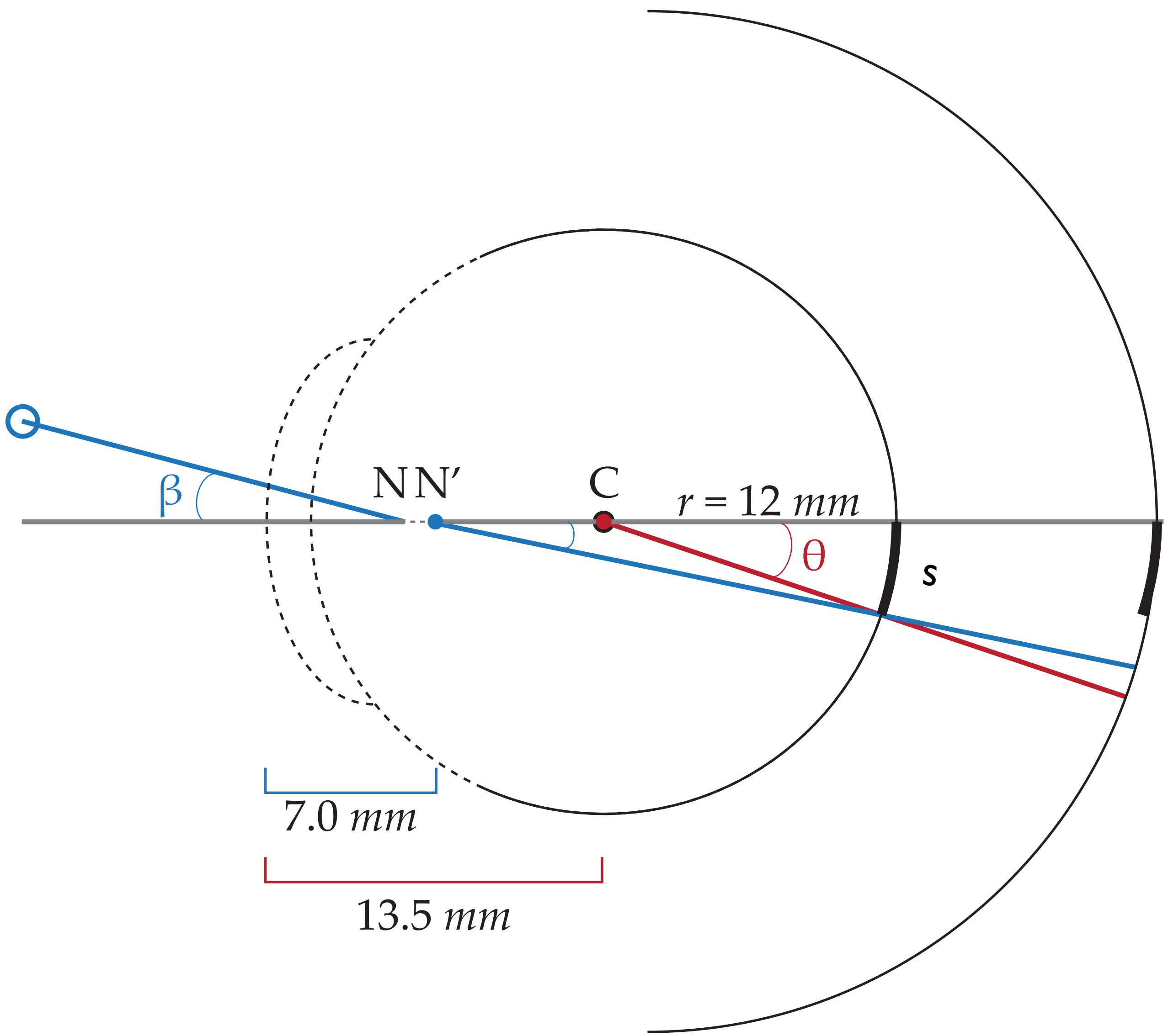
given rotation of $\Theta = \pi/2$





$s = \pi/2$

$s = \pi$

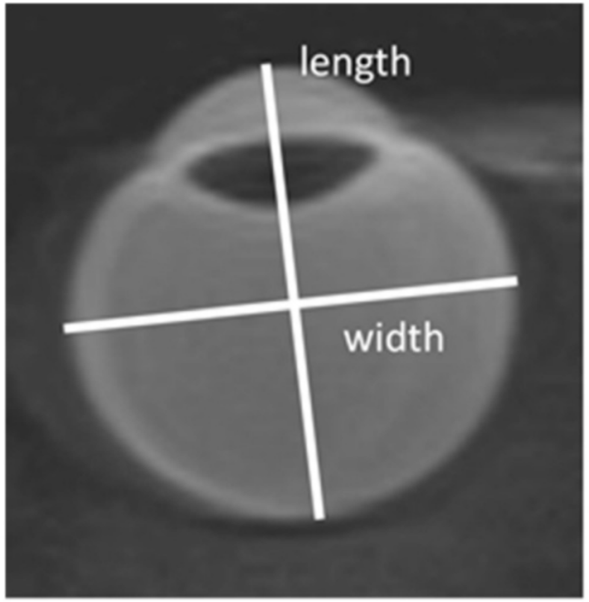

β
N N′
C
r = 12 mm
θ
s
7.0 mm
13.5 mm

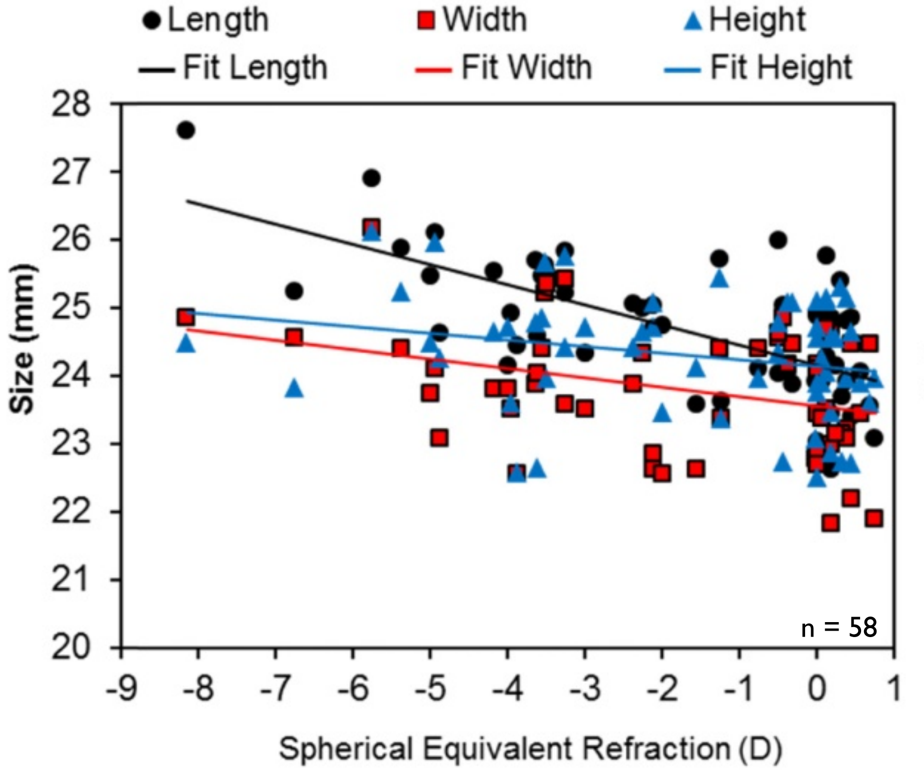
EYE LENGTH VARYS IN THE ADULT POPULATION

Research Article Vol. 8, No. 5 | 1 May 2017 | BIOMEDICAL OPTICS EXPRESS 2386
Biomedical Optics EXPRESS

Three-dimensional MRI study of the relationship between eye dimensions, retinal shape and myopia

JAMES M. POPE,[1,2] PAVAN K. VERKICHARLA,[2,3,4] FARSHID SEPEHRBAND,[2,3] MARWAN SUHEIMAT,[2,3] KATRINA L. SCHMID,[2,3] AND DAVID A. ATCHISON[2,3,*]





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Vision Research 46 (2006) 2236–2250

Vision Research

www.elsevier.com/locate/visres

Optical models for human myopic eyes

David A. Atchison *

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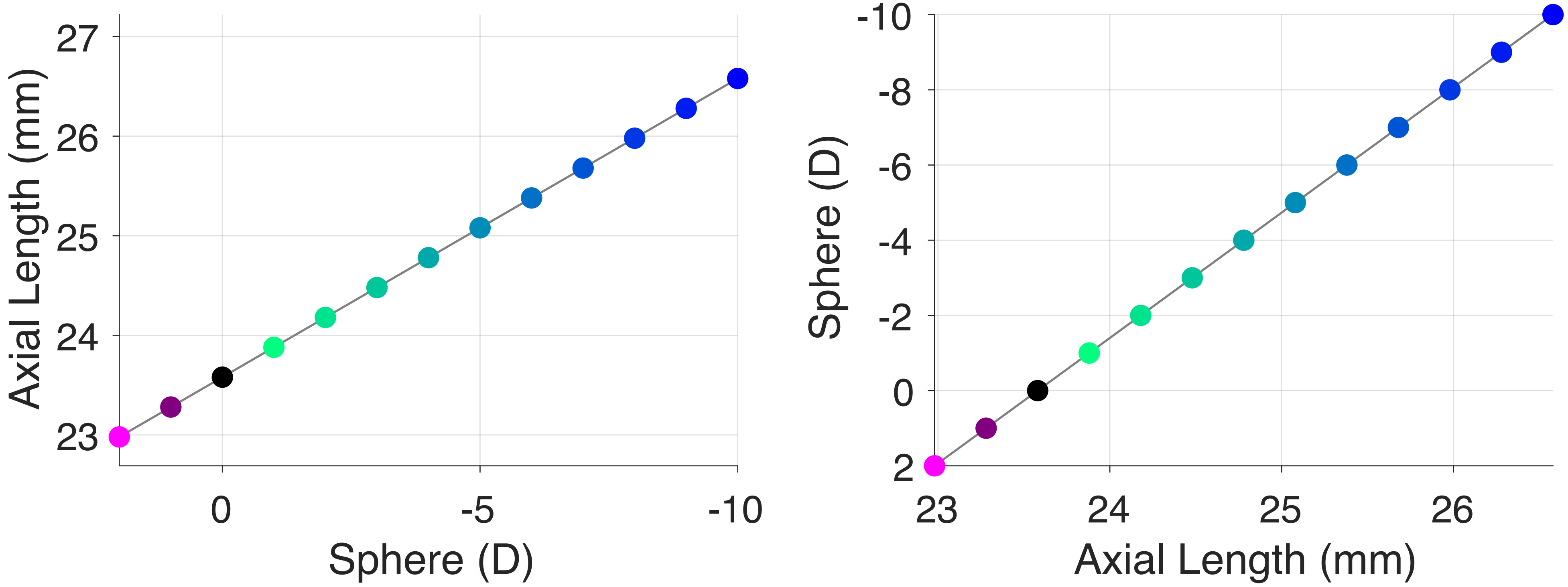
Received 14 September 2005; received in revised form 21 December 2005

Parameters that vary with spherical equivalent refraction (SR):

- Cornea radius of curvature : 7.77 + 0.022SR – flatter *with myopia*
- Retina radius of curvature* : -12.91 – 0.094SR – longer
- Retina asphericity* : 0.27 + 0.026SR – more rounded
- Retinal distance : 16.28 – 0.299SR – longer

EYE LENGTH AS A FUNCTION OF SPHERE



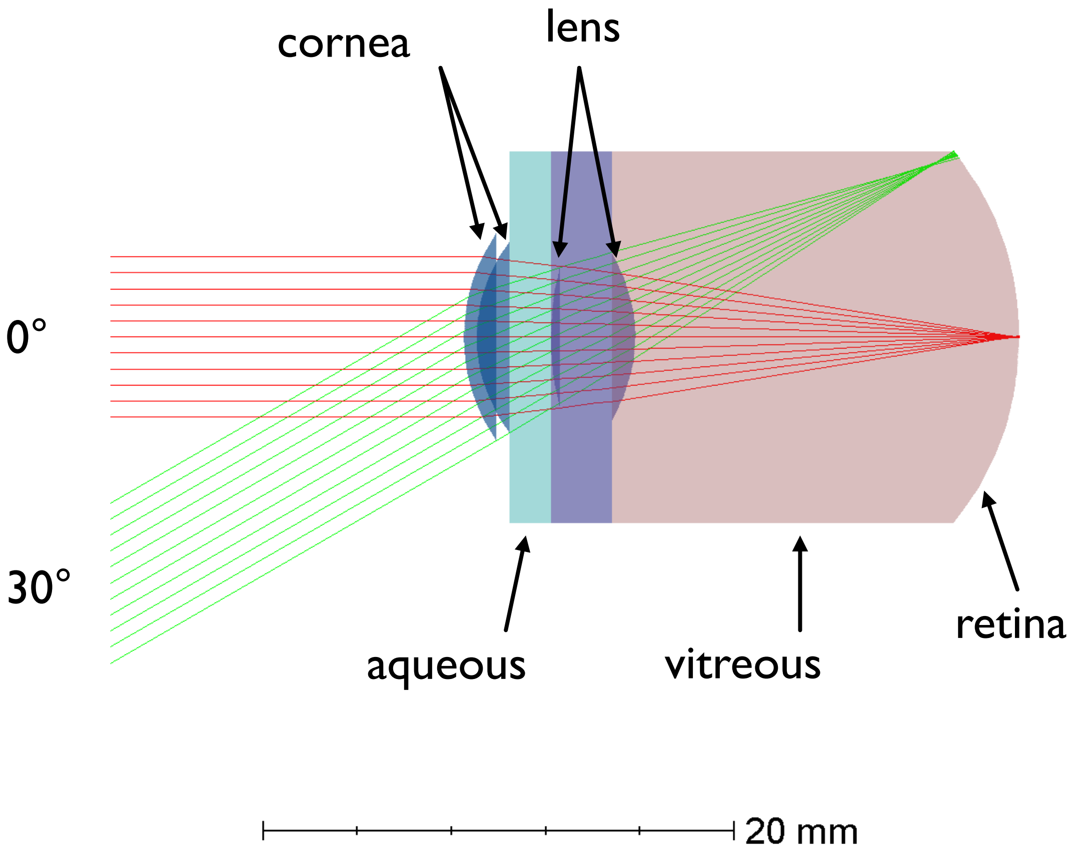
RETINAL MOTION IS INFERRED FROM EYE MOTION

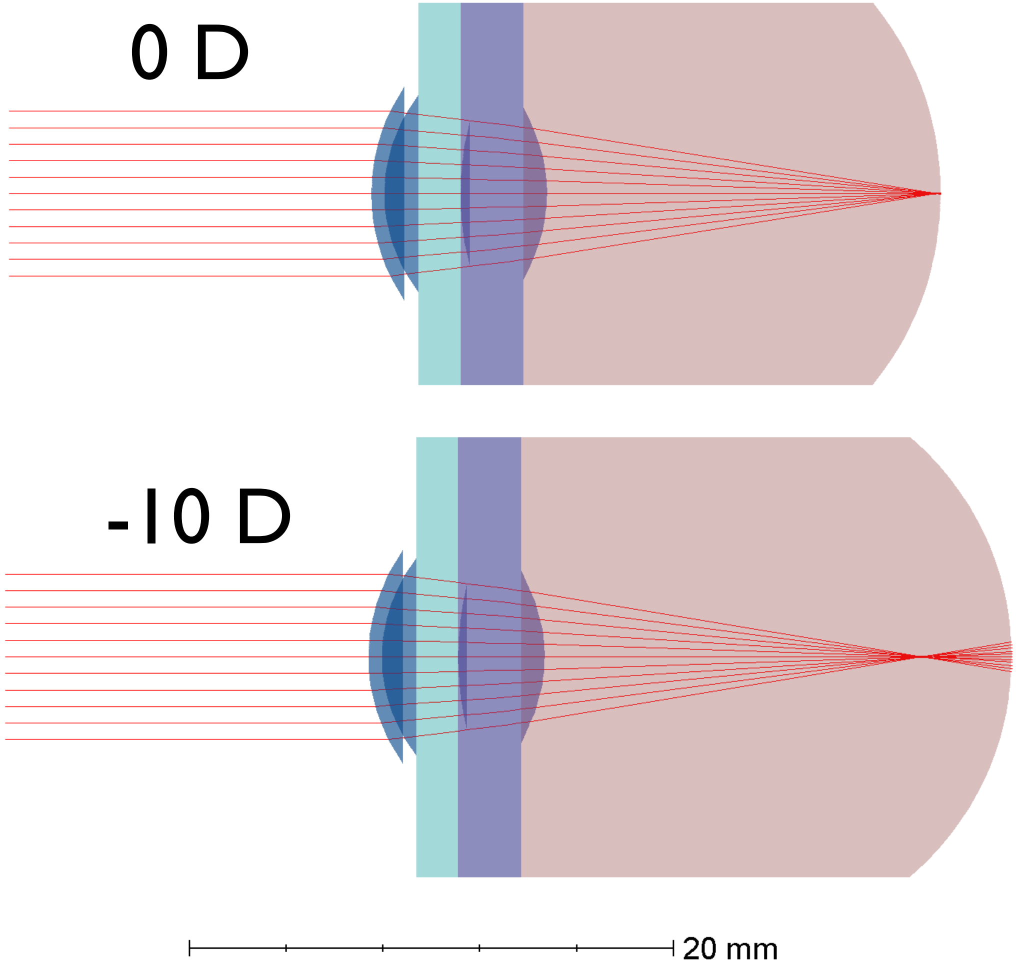
$$\frac{Visual\ Angle\ \beta\ (deg)}{Time\ (s)} \times \frac{Eye\ Rotation\ \theta\ (deg)}{Visual\ Angle\ \beta\ (deg)} \times \frac{Retinal\ Distance\ (mm)}{Eye\ Rotation\ \theta\ (deg)} = \frac{Retinal\ Distance\ (mm)}{Time\ (s)}$$

What we MEASURE

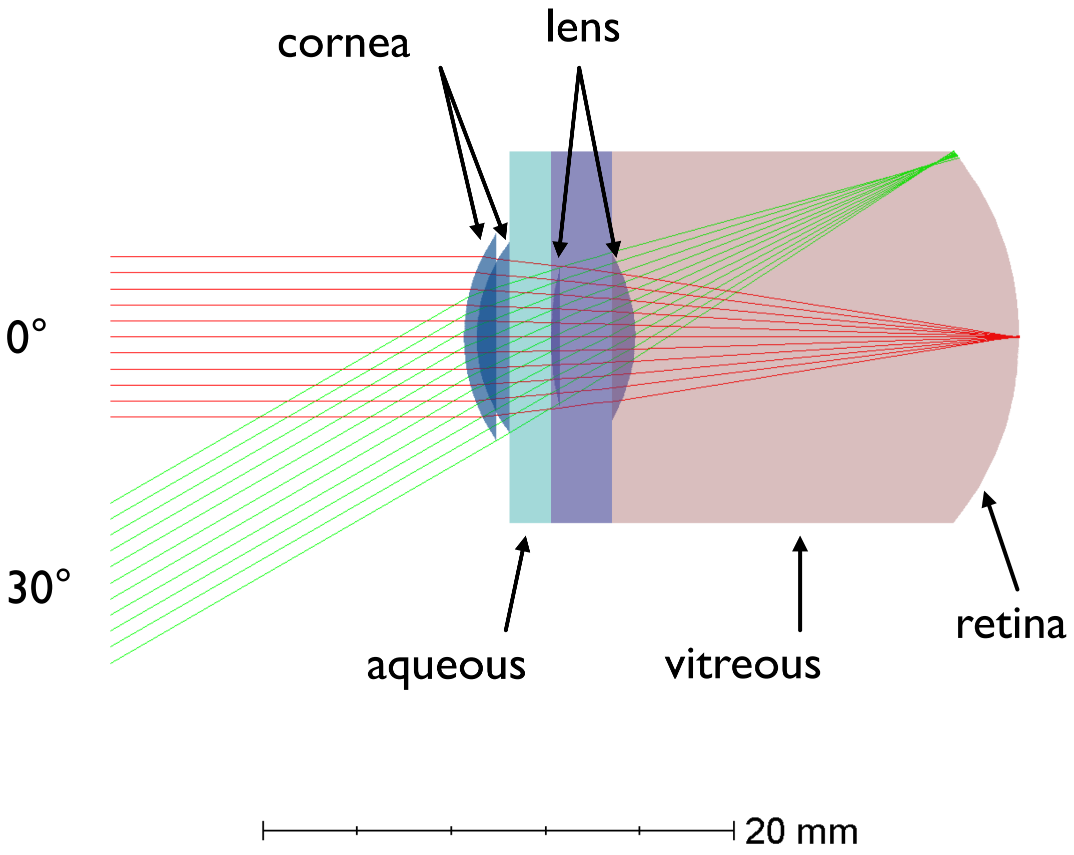
What we INFER

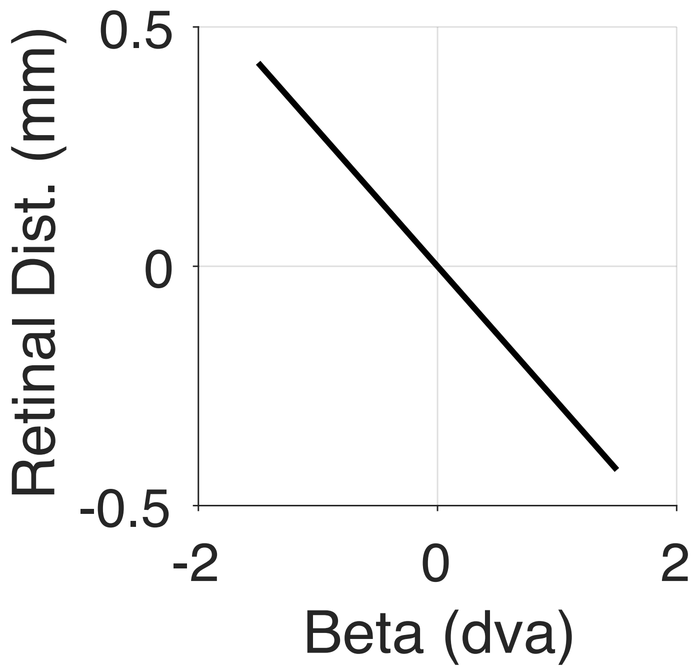
ZEMAX MODELING





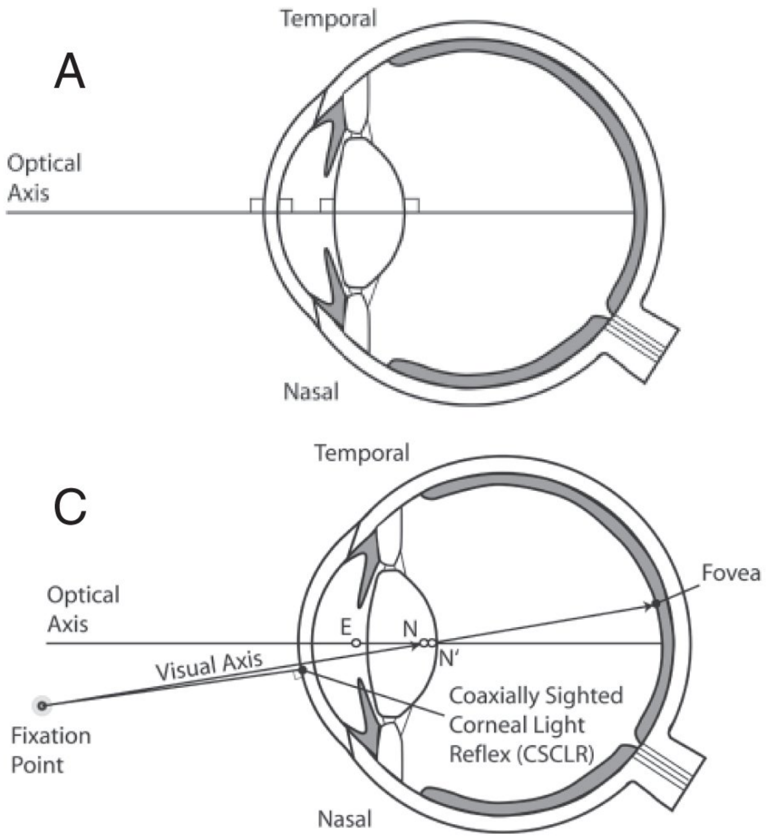
ZEMAX MODELING





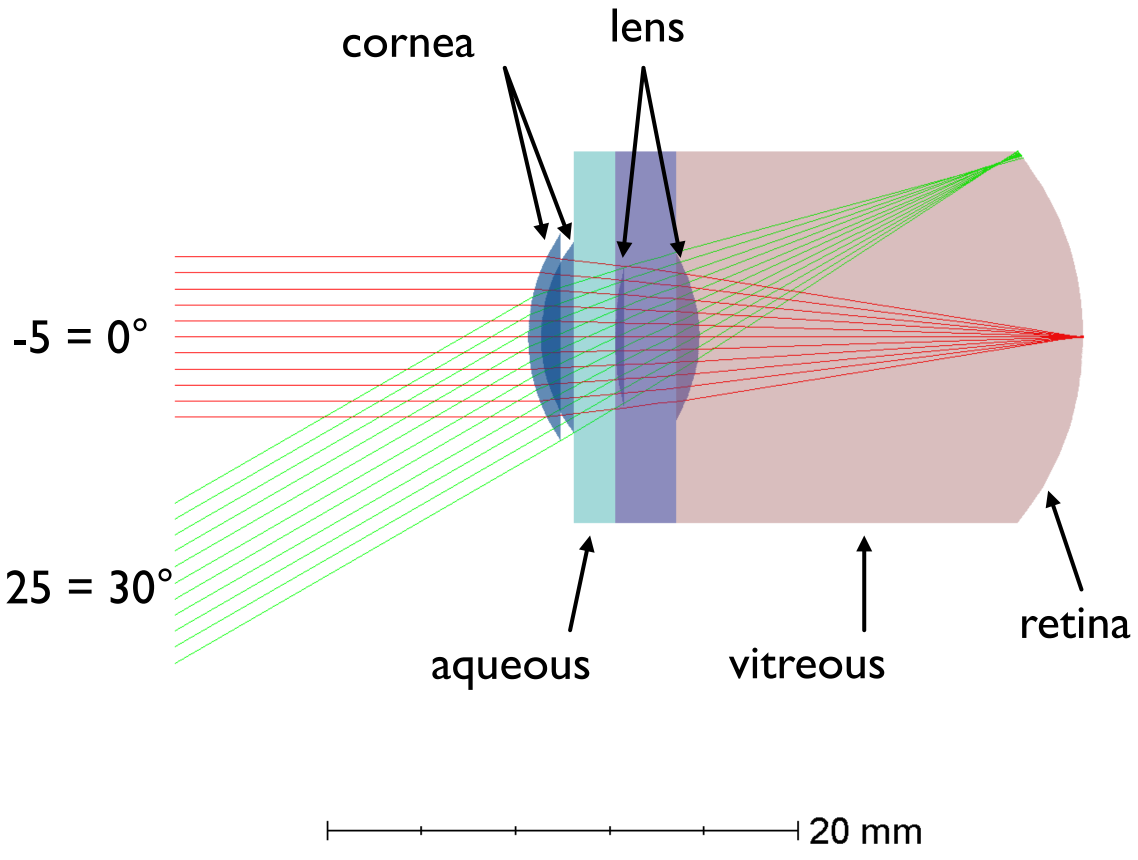
FOVEA IS OFFSET FROM THE OPTICAL AXIS

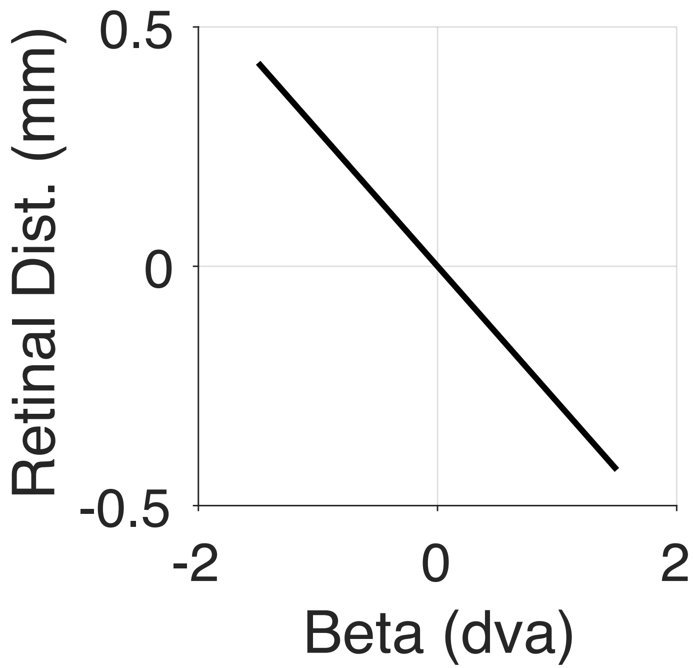
- In the eye, <u>the Optical Axis</u> is a theoretical construct.
  - The surface of the cornea and crystalline lens are not rotationally symmetric nor do they lie on a common line
- In real eyes, the Purkinje images do not align and the surfaces are not rotationally symmetric, so no true Optical Axis of the eye exists
- Even with the Optical Axis defined as the best-fit through the Purkinje images, <u>this axis does not coincide with the fovea</u>**.**
  - Fovea is displaced temporally and slightly inferior



Schwiegerling J. Eye Axes and Their Relevance to Alignment of Corneal Refractive Procedures. *J Refract Surg.* 2013; 29: 515-516. doi: 10.3928/1081597X-20130719-0

ZEMAX MODELING





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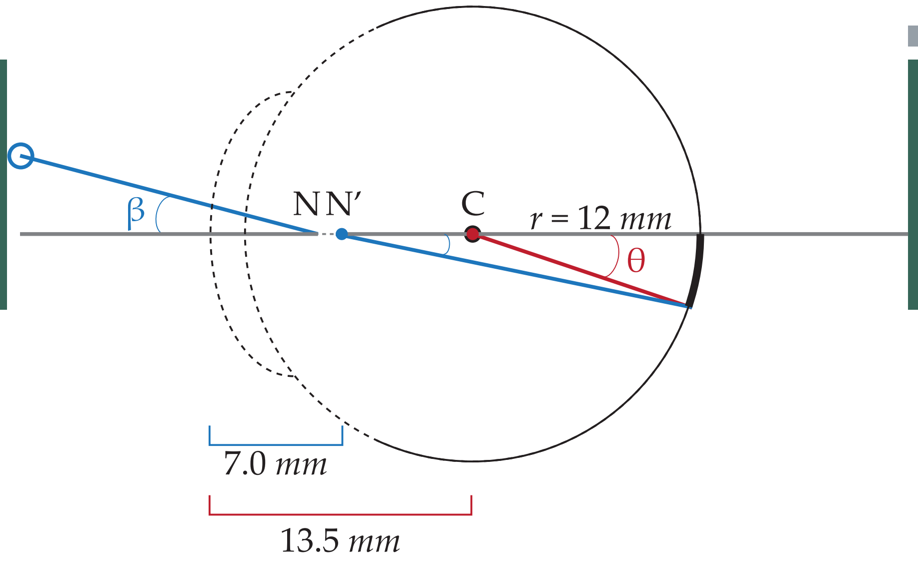

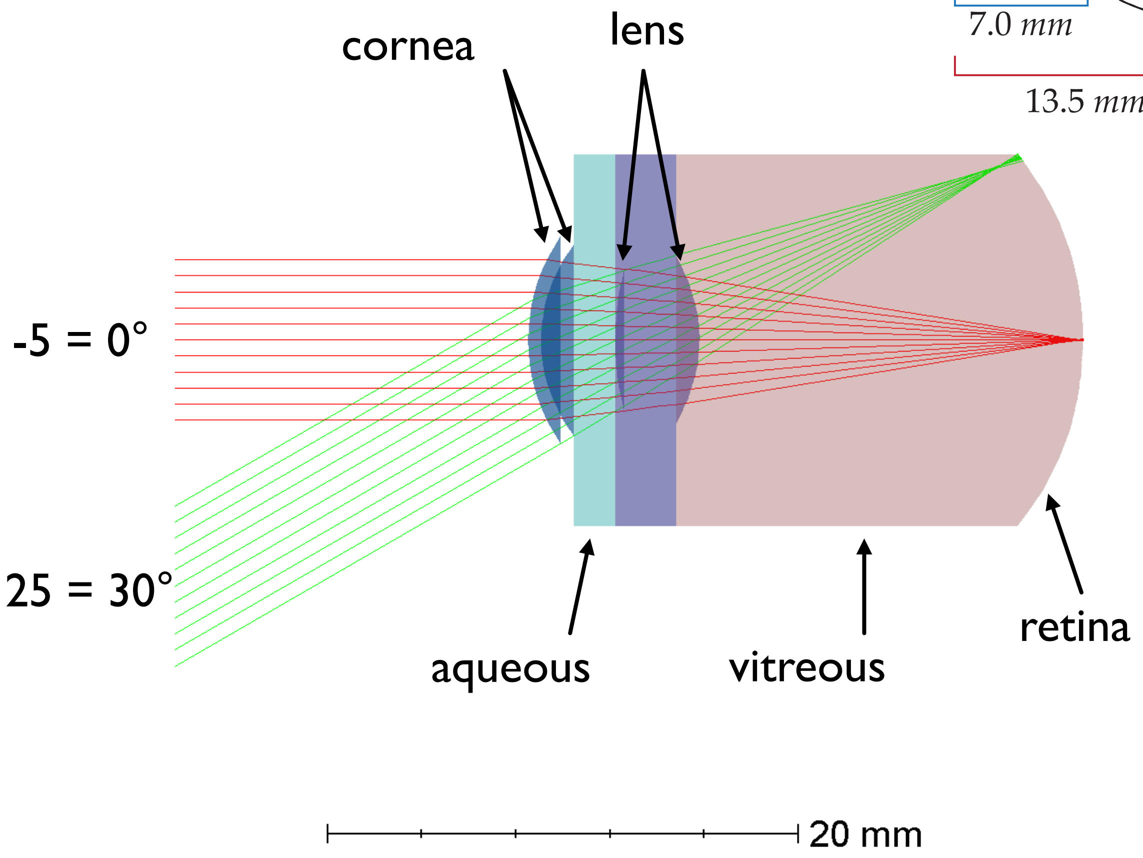

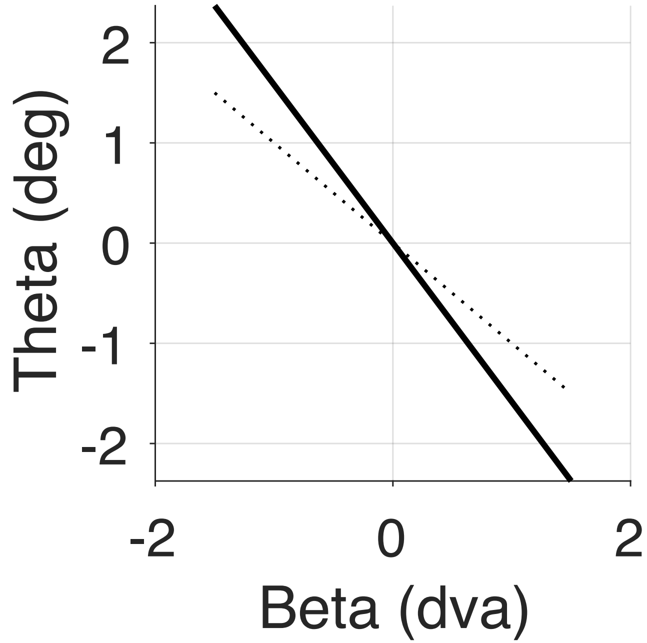

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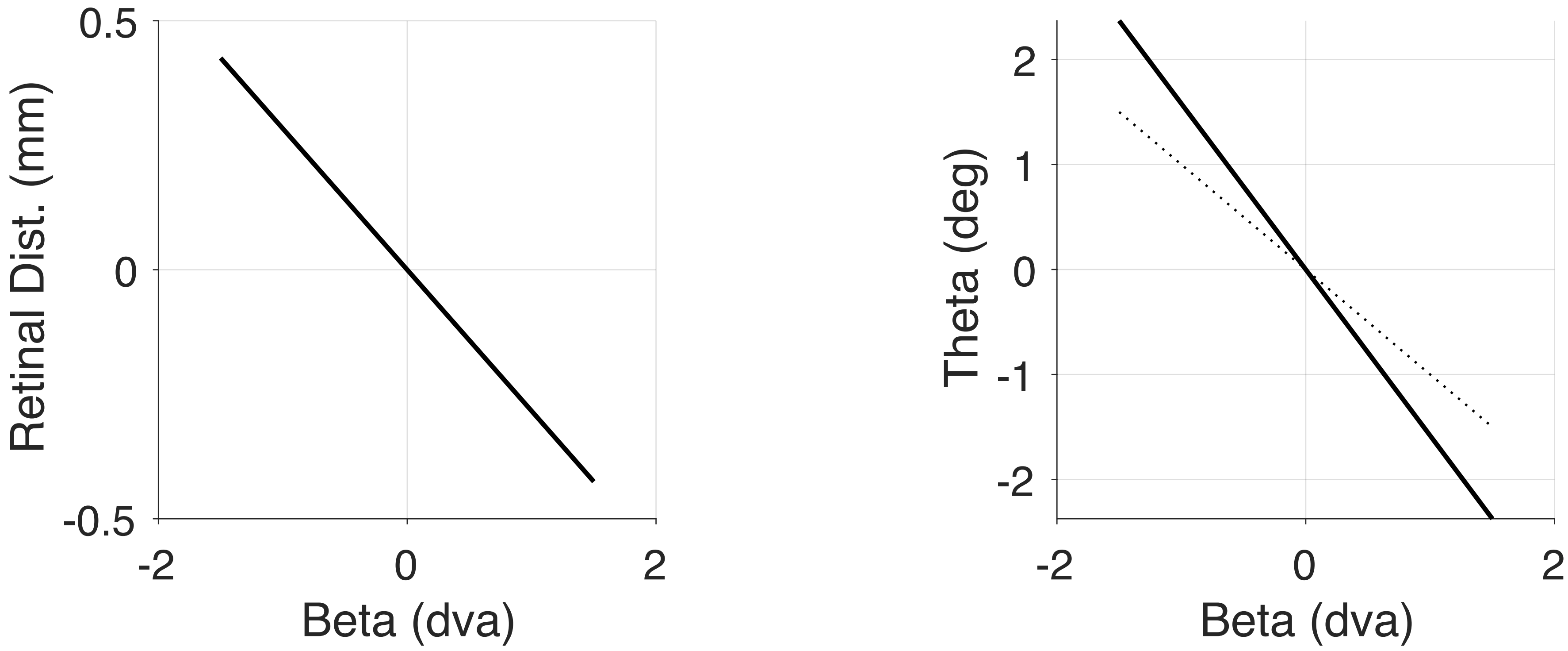

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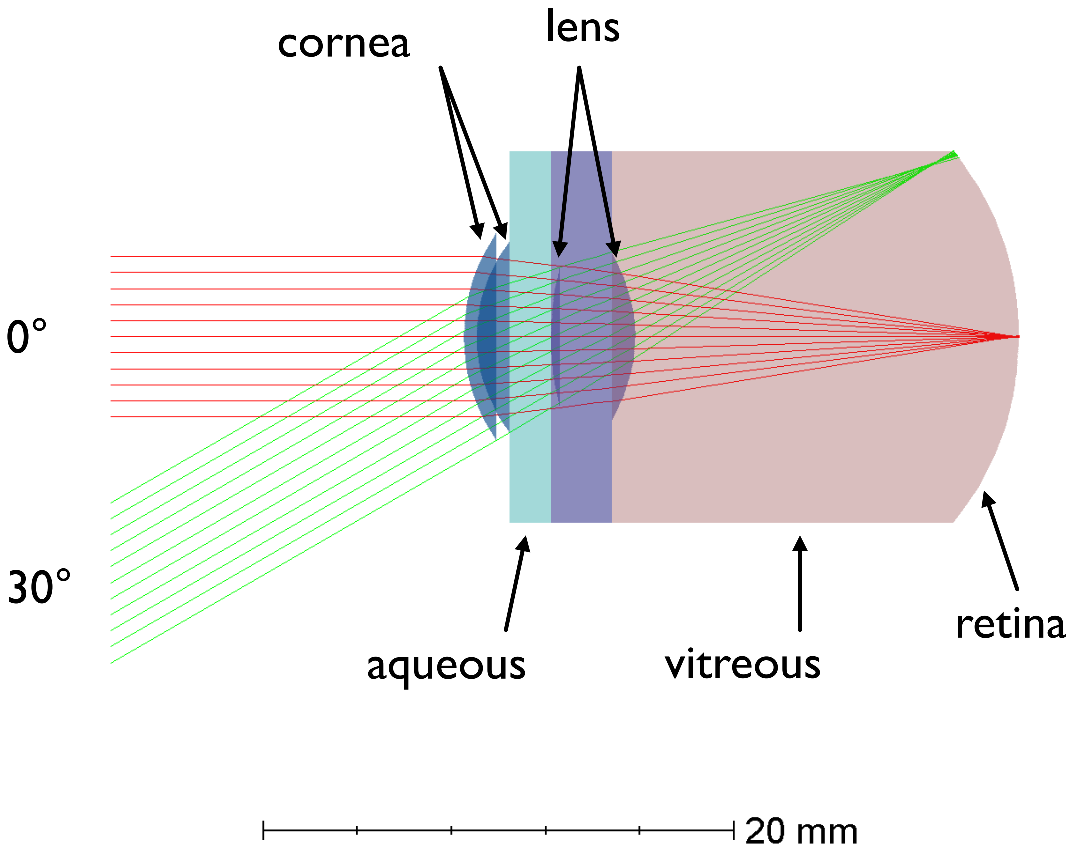

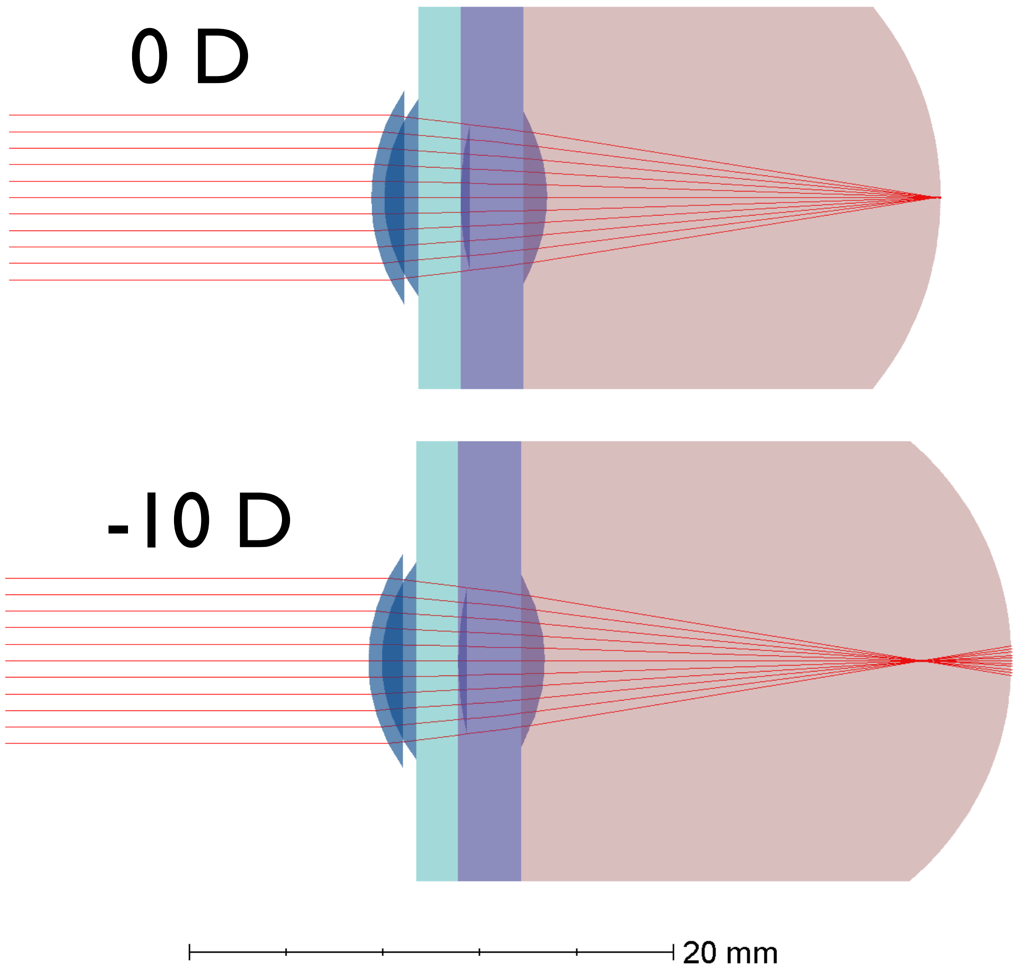

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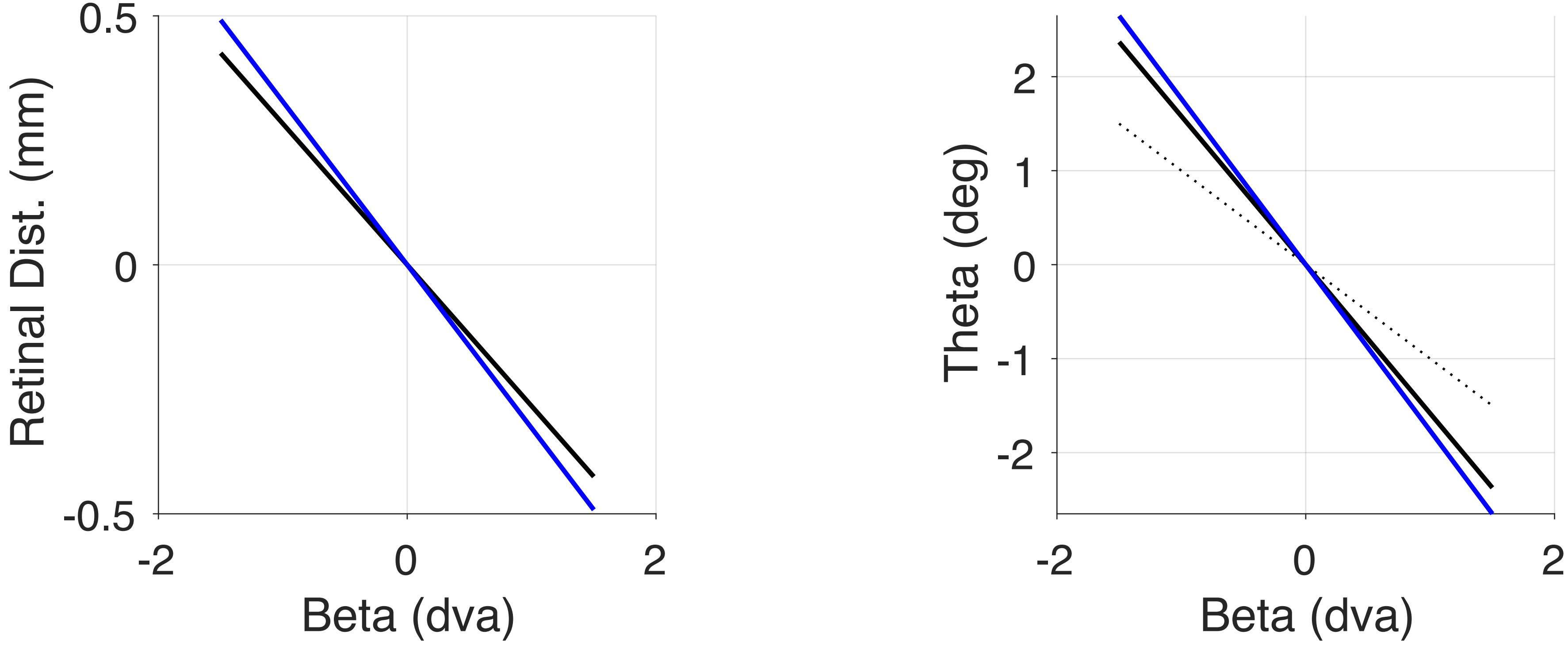


RETINAL MOTION IS INFERRED FROM EYE MOTION

$$\frac{Visual\ Angle\ \beta\ (deg)}{Time\ (s)} \times \boxed{\frac{\boldsymbol{Eye\ Rotation\ \theta\ (deg)}}{\boldsymbol{Visual\ Angle\ \beta\ (deg)}}} \times \boxed{\frac{\boldsymbol{Retinal\ Distance\ (mm)}}{\boldsymbol{Eye\ Rotation\ \theta\ (deg)}}} = \frac{Retinal\ Distance\ (mm)}{Time\ (s)}$$

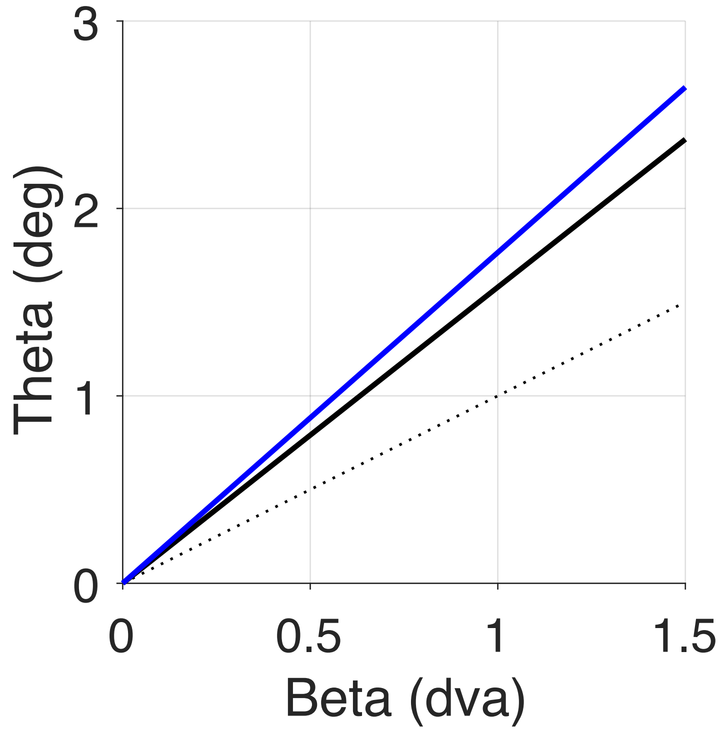
What we MEASURE

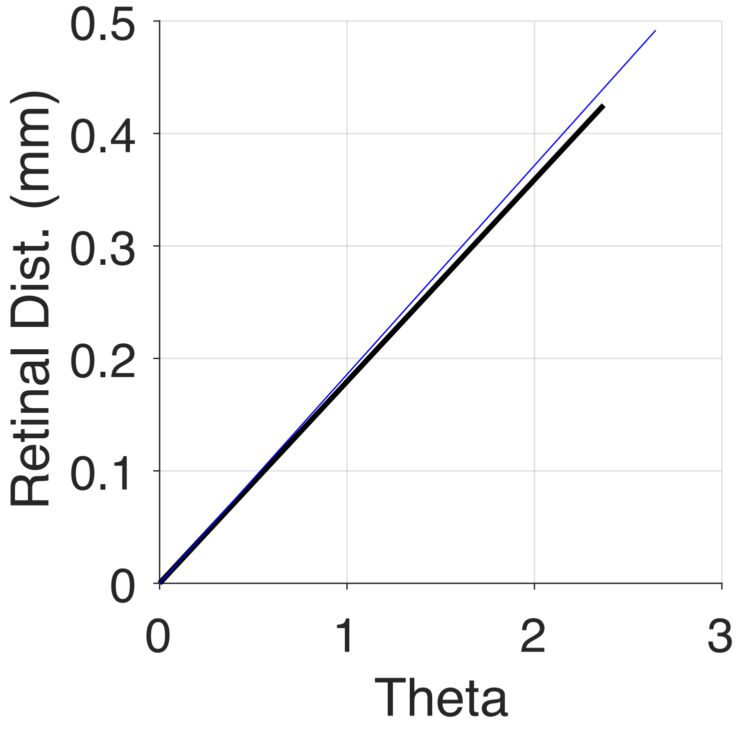
What we INFER

RETINAL MOTION IS INFERRED FROM EYE MOTION

$$\frac{\textit{Eye Rotation } \theta \ (deg)}{\textit{Visual Angle } \beta \ (deg)}$$

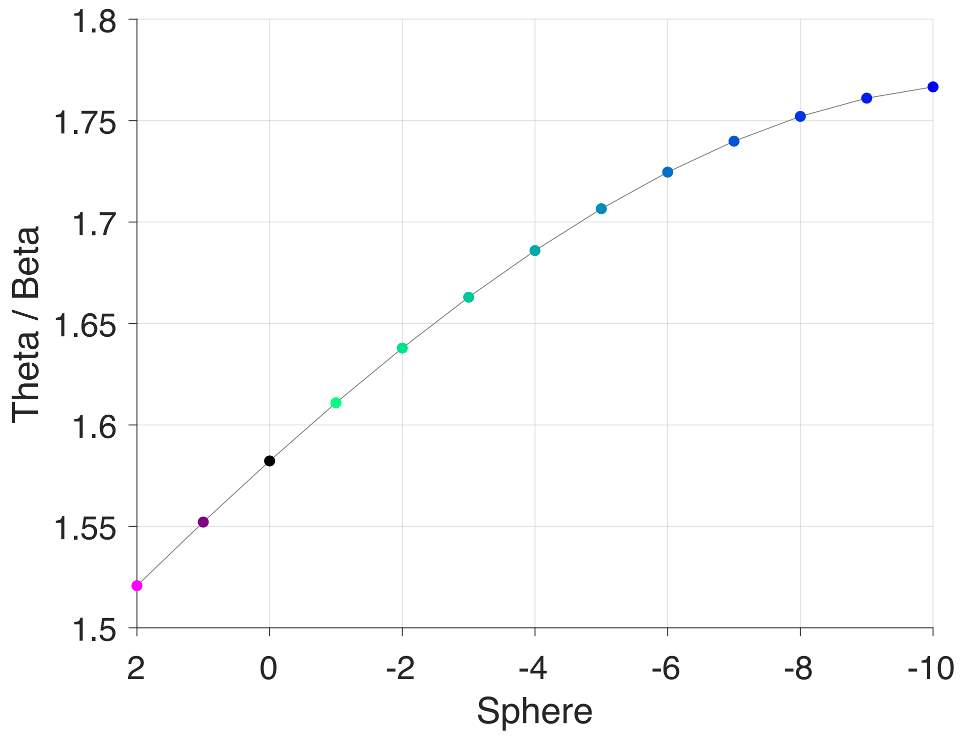
$$\frac{\textit{Retinal Distance } (mm)}{\textit{Eye Rotation } \theta \ (deg)}$$



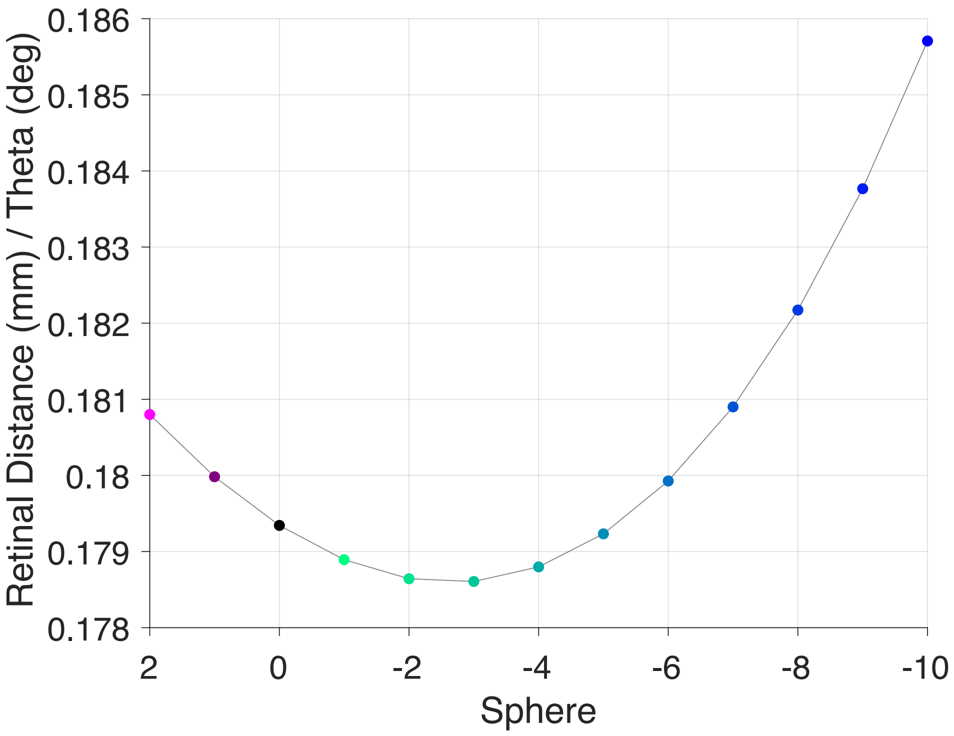


RETINAL MOTION IS INFERRED FROM EYE MOTION

$$\frac{\boldsymbol{Eye\ Rotation\ \theta\ (deg)}}{\boldsymbol{Visual\ Angle\ \beta\ (deg)}}$$



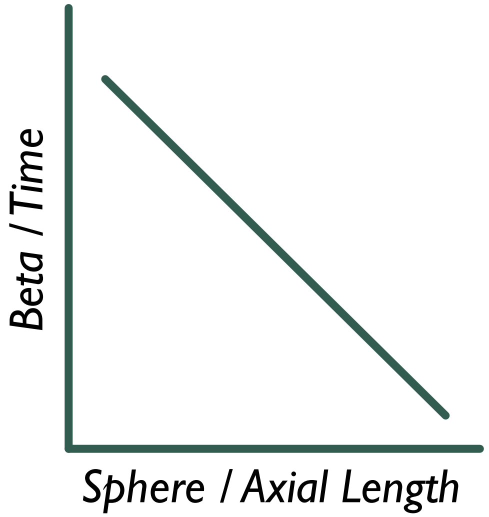
$$\frac{\boldsymbol{Retinal\ Distance\ (mm)}}{\boldsymbol{Eye\ Rotation\ \theta\ (deg)}}$$

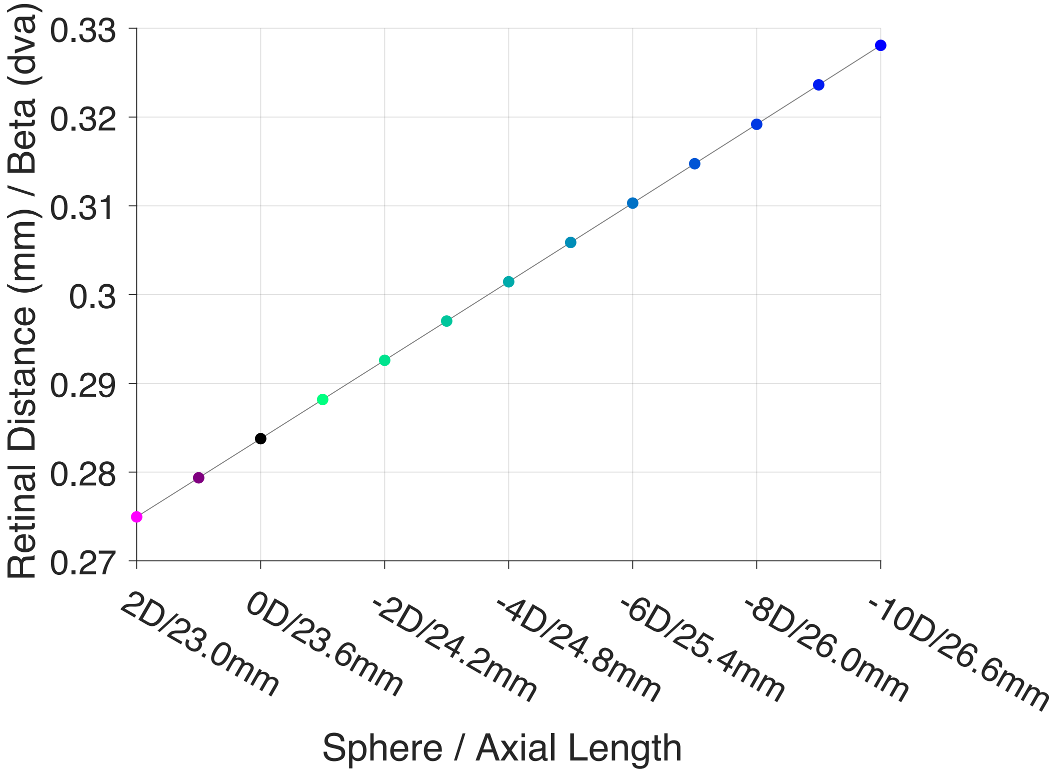


RETINAL MOTION IS INFERRED FROM EYE MOTION

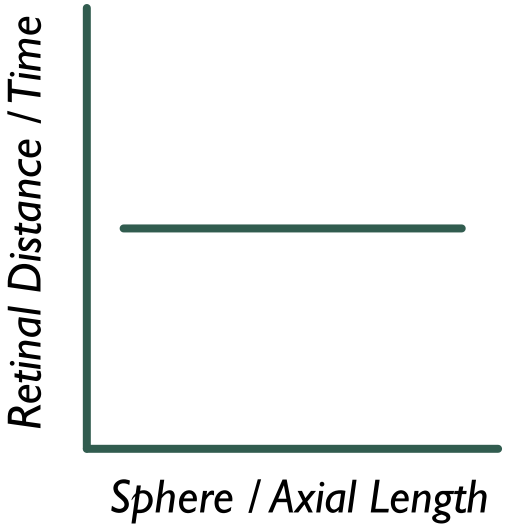
$$\frac{\text{Visual Angle } \beta \text{ (deg)}}{\text{Time (s)}} \times \frac{\cancel{\textbf{Eye Rotation } \boldsymbol{\theta} \textbf{ (deg)}}}{\textbf{Visual Angle } \boldsymbol{\beta} \textbf{ (deg)}} \times \frac{\textbf{Retinal Distance (mm)}}{\cancel{\textbf{Eye Rotation } \boldsymbol{\theta} \textbf{ (deg)}}} = \frac{\text{Retinal Distance (mm)}}{\text{Time (s)}}$$

What we MEASURE

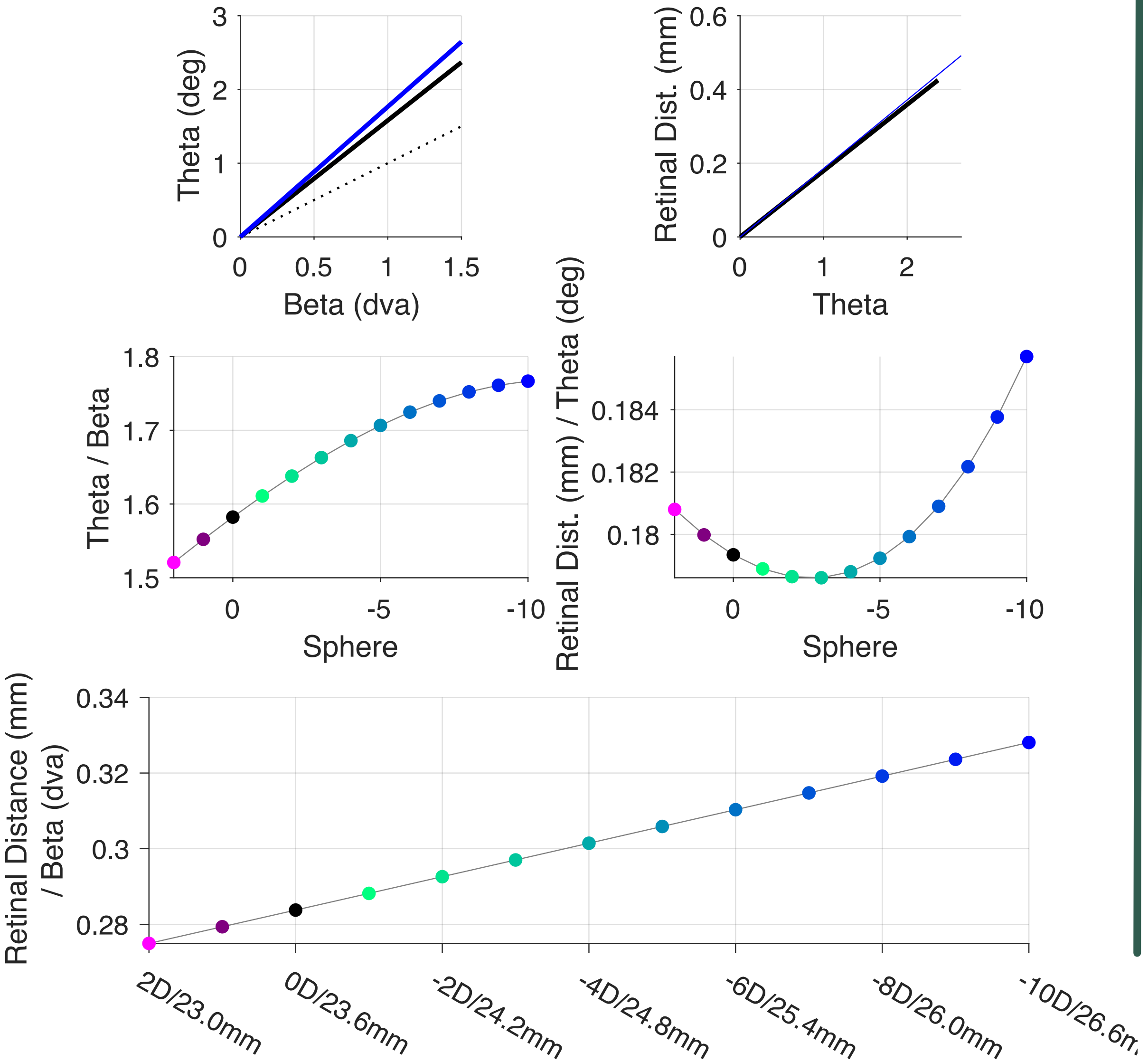




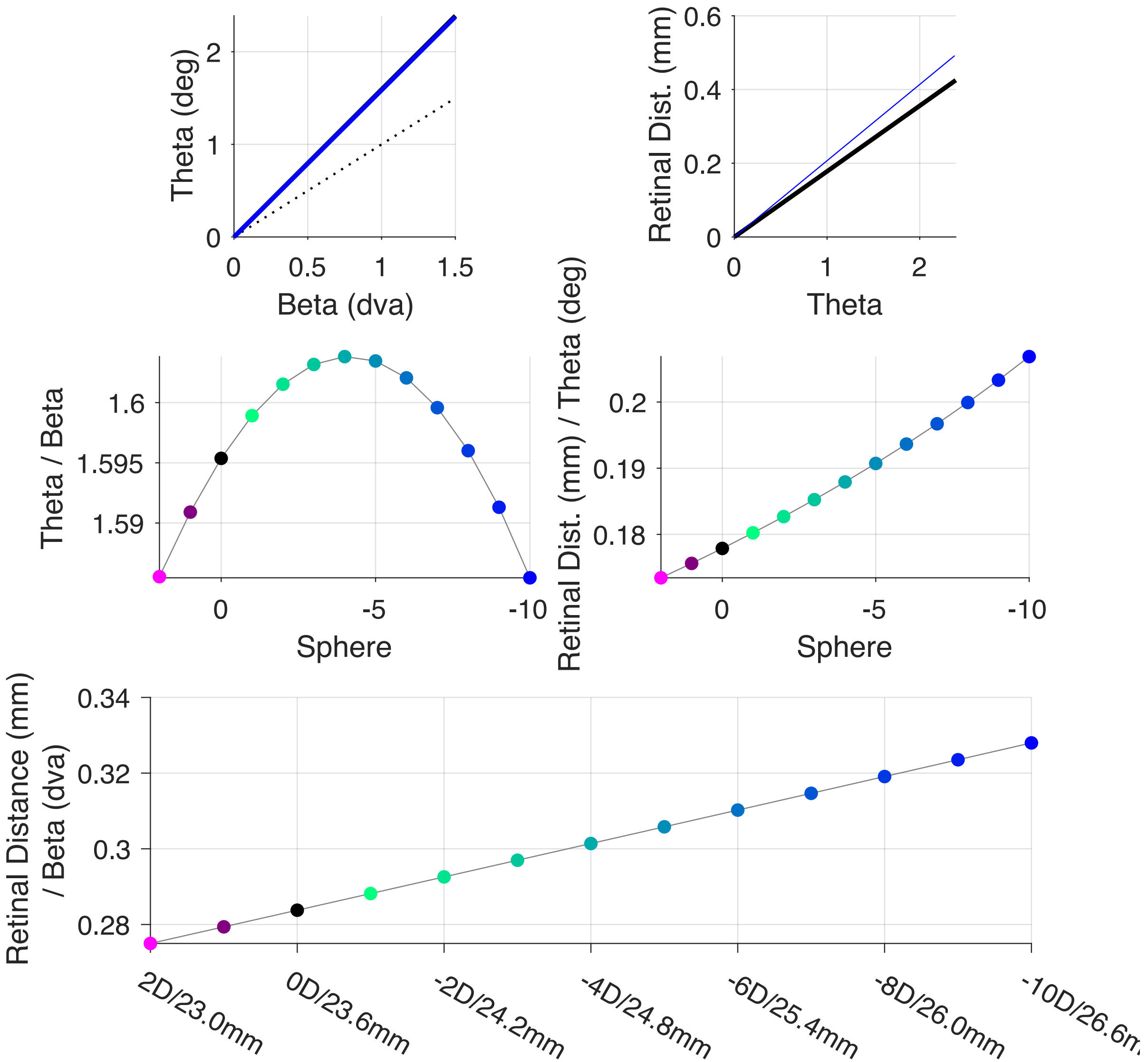
What we INFER



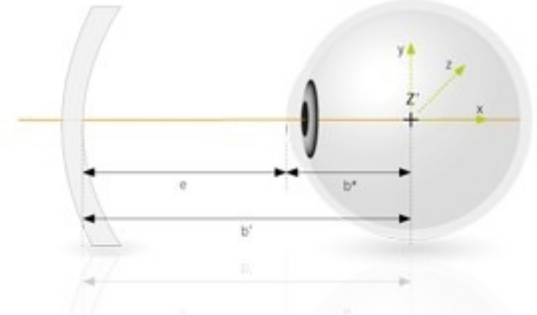
FIXED ECOR

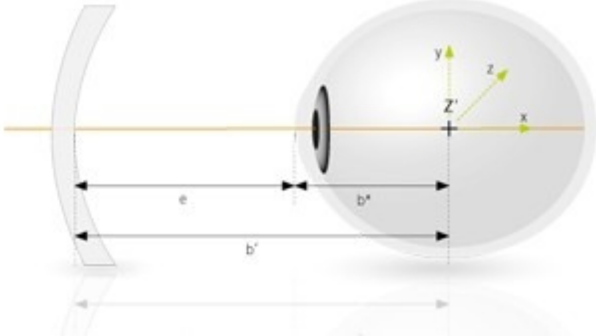


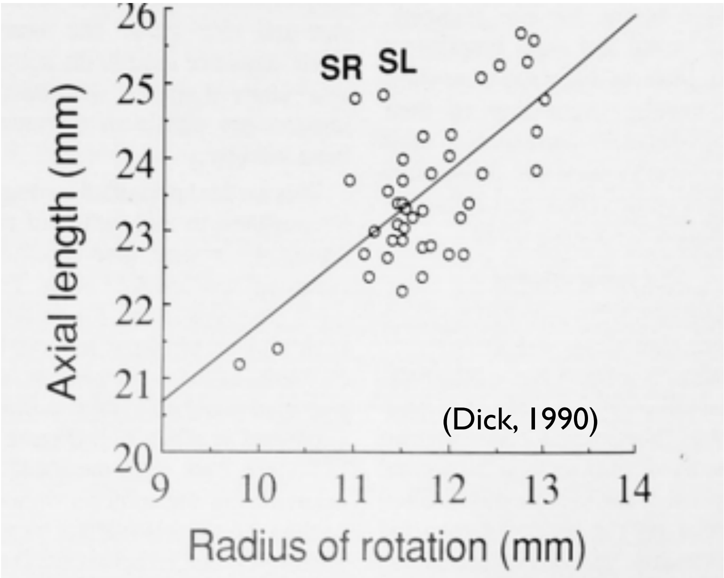
ECOR = RETINA CENTER



Does the center of rotation of the eye move as the eye grows longer?







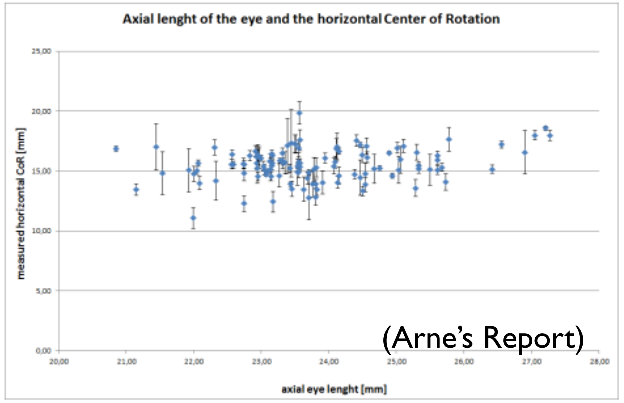


Figure 1. The relationship between the axial length of the eye and its horizontal center of rotation for the 118 eyes.

STUDY OVERVIEW

How does ocular motion transfer to retinal motion?

MODELING

How do we expect
eye geometry to impact
retinal motion?

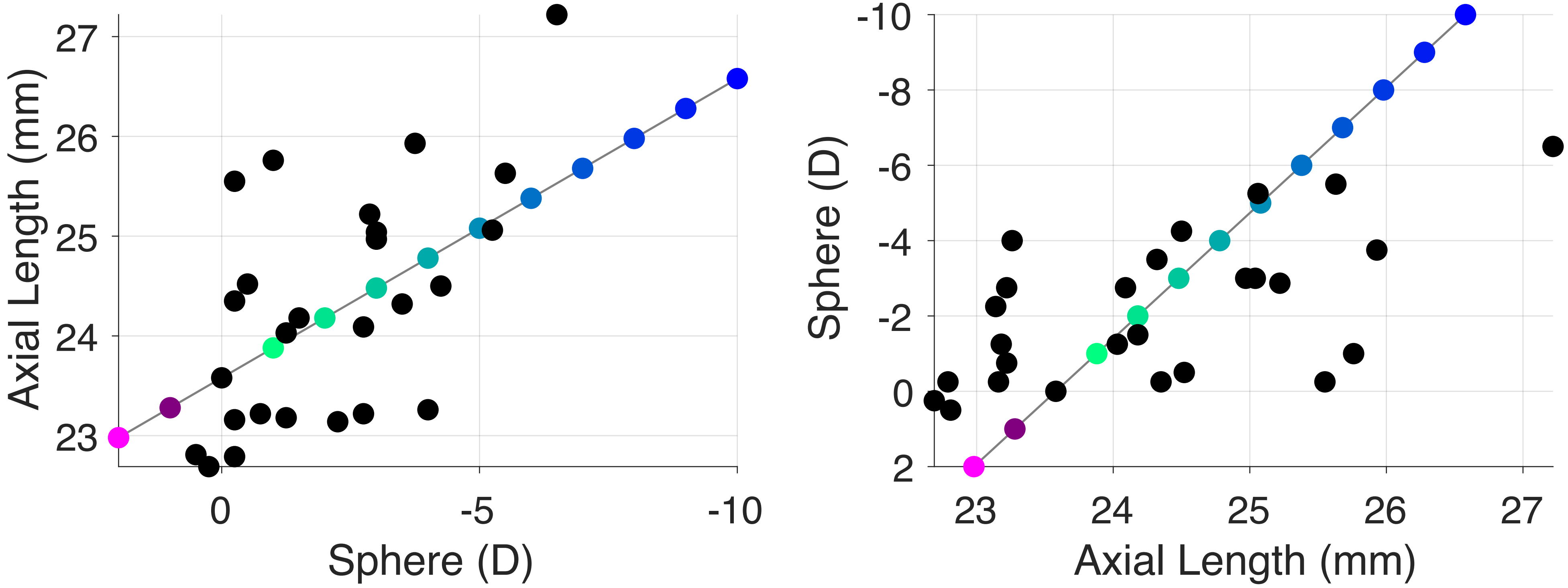
EMPERICAL

Can we see differences in either:

eye movement?

visual performance?

MEASURED VS. PREDICTED AXIAL LENGTH

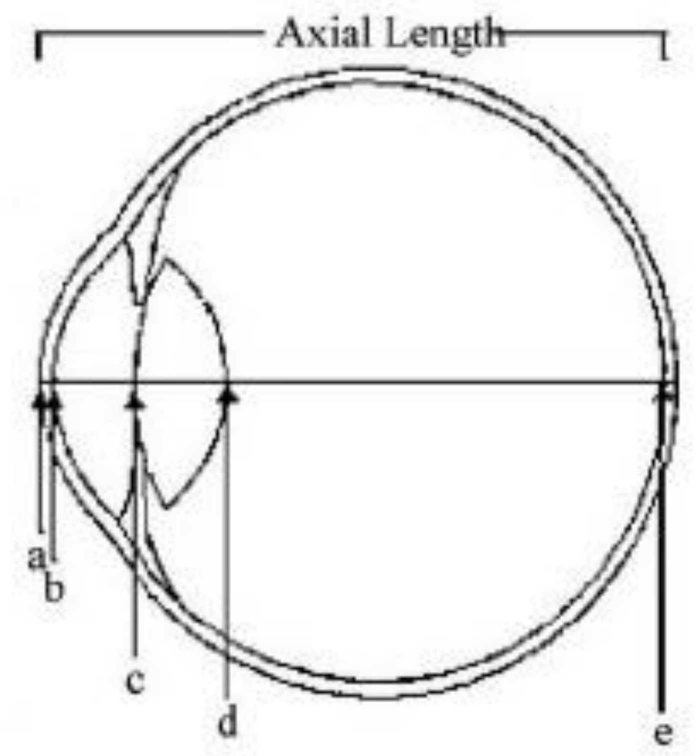


N = 25

ANATOMICAL MEASUREMENTS

MEASUREMENTS

- IOL Master
  - Gives Axial Length
- Autorefractor
  - Gives us prescription
- OCT (Optical Coherence Tomography)
  - Gives us retinal thicknesses
- IOP Measurements (Inter Ocular Pressure)
  - Gives us pressure of the eye



https://www.dizziness-and-balance.com/disorders/visual/postcataract.html

MEASUREMENTS

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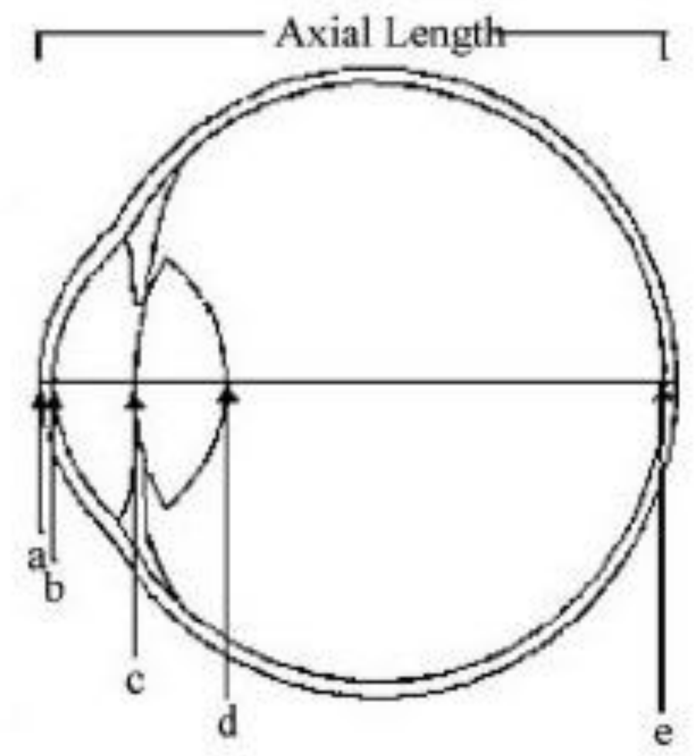

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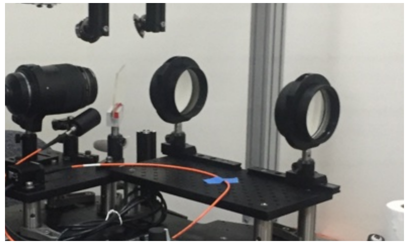
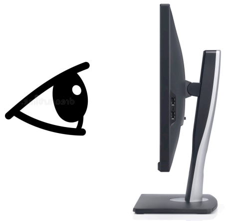
BADAL

BADAL MECHANICS

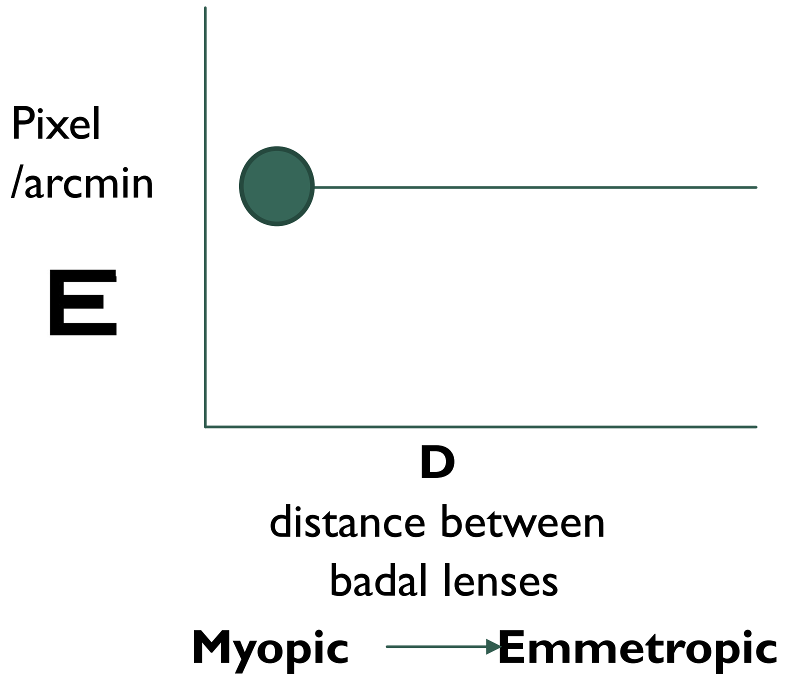




- Myopia forces you to move objects closer in order to focus those objects on the retina.
- When you move these objects closer, the pixel/arcmin ratio also increases.
- Badal offers a way to change the size of the image (aka move it virtually) without sacrificing the pixel/arcmin ratio.

BADAL MECHANICS

"Perfect World"

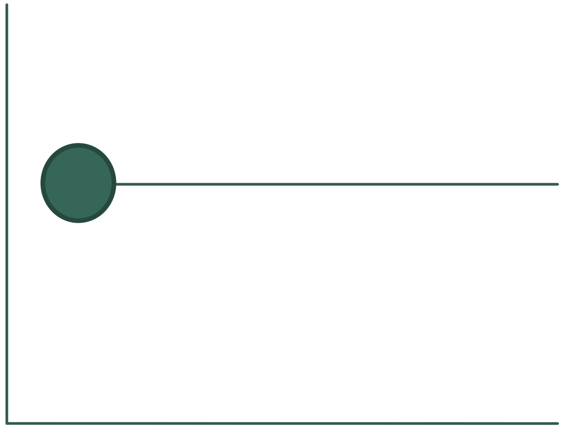


BADAL MECHANICS

“Perfect World”

Pixel
/arcmin

E



D
distance between
badal lenses

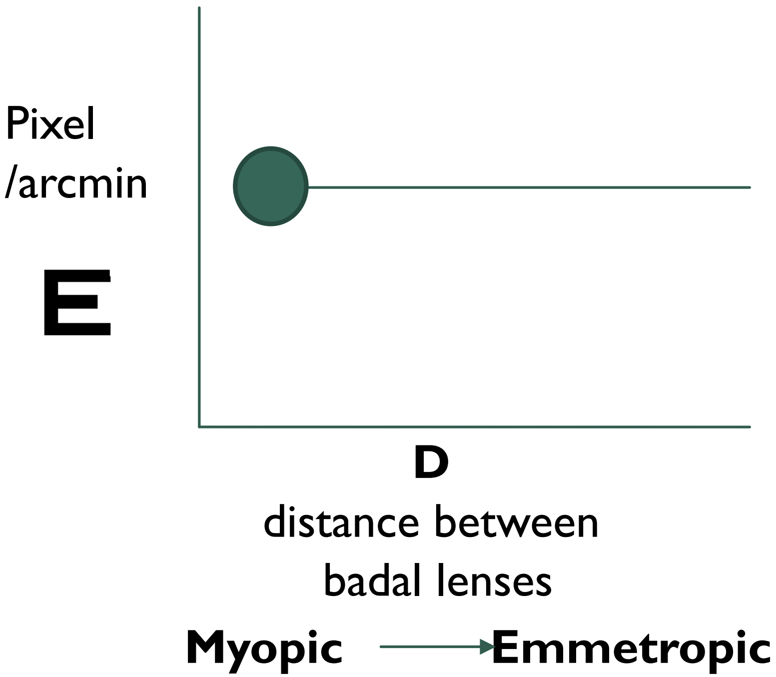
Myopic → **Emmetropic**

MAGNIFICATION

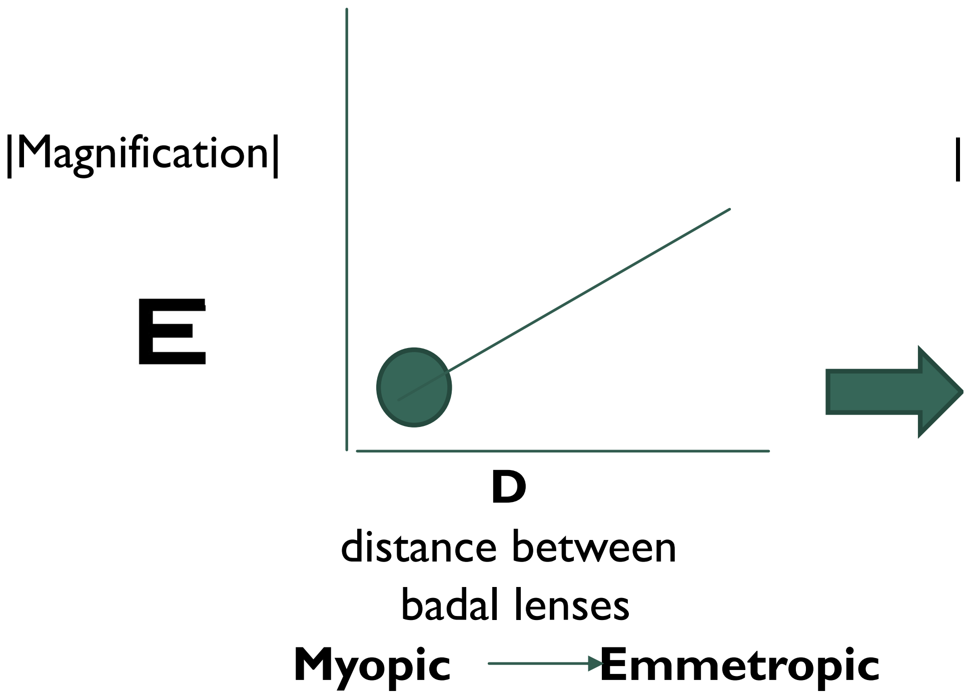
The badal introduces
Magnification factor

BADAL MECHANICS

"Perfect World"



MAGNIFICATION



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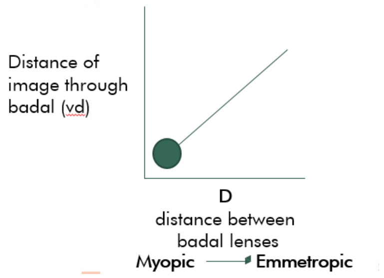
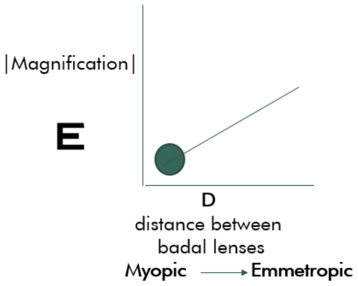
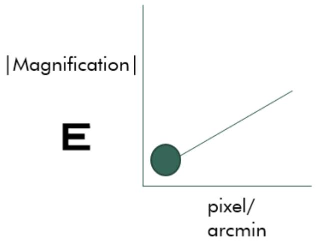
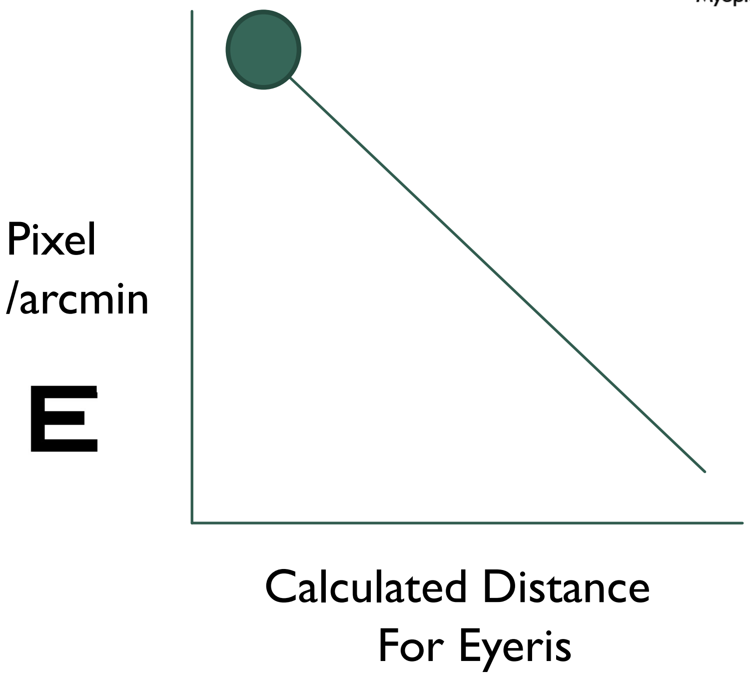
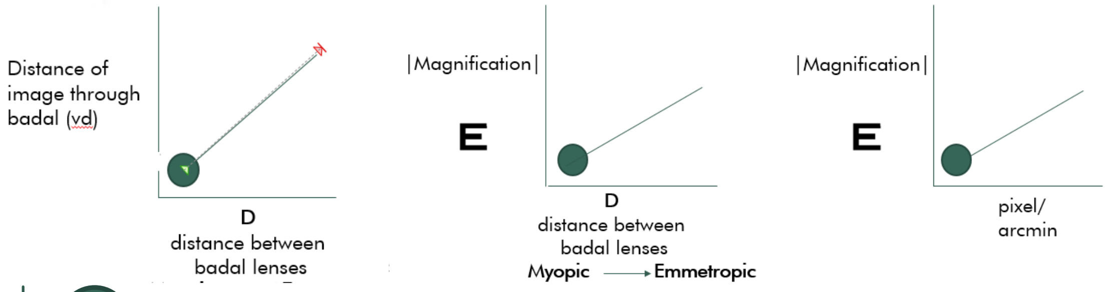


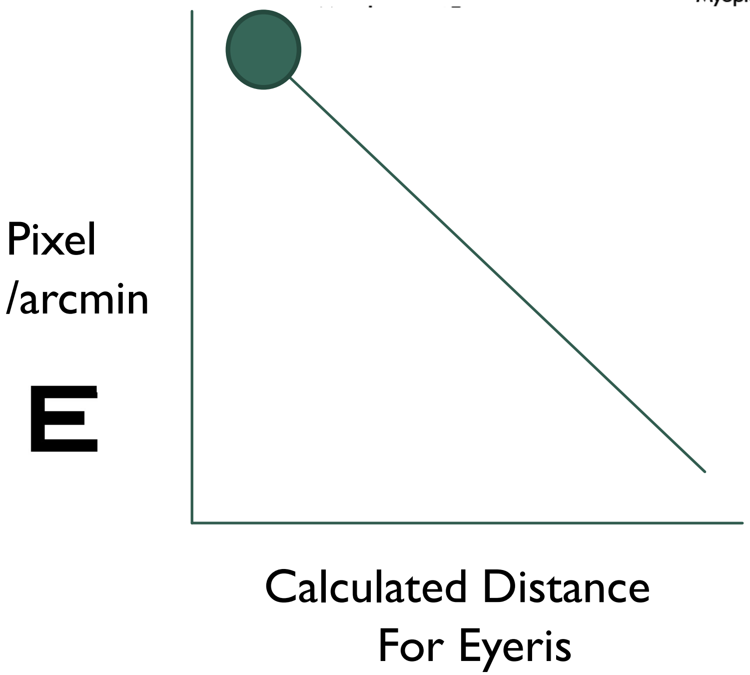


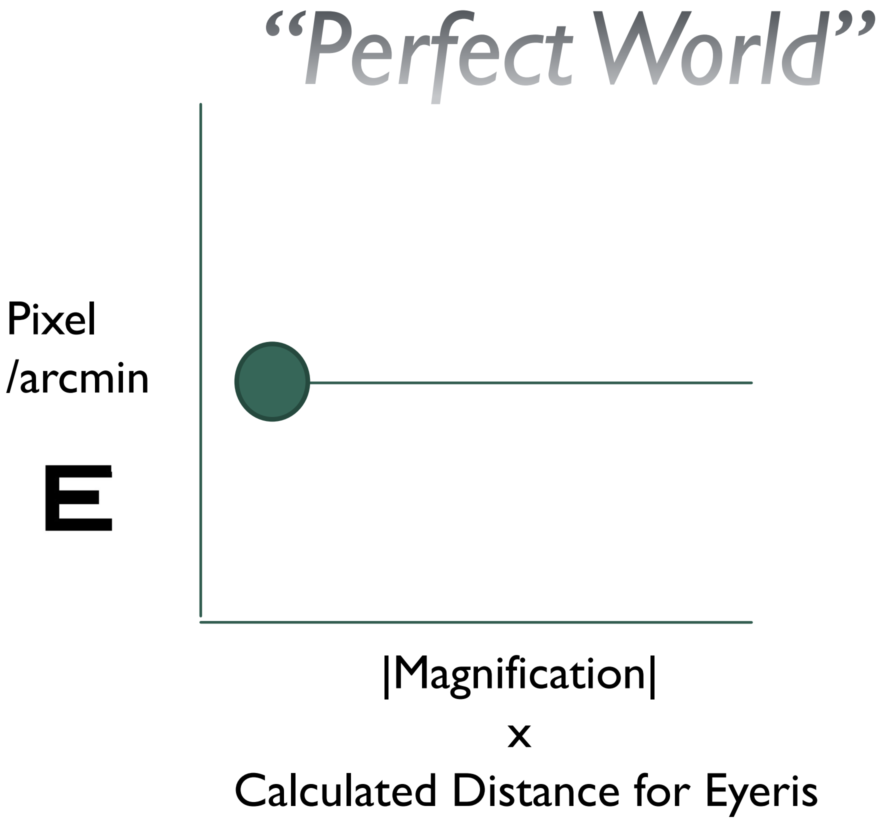




BADAL MECHANICS



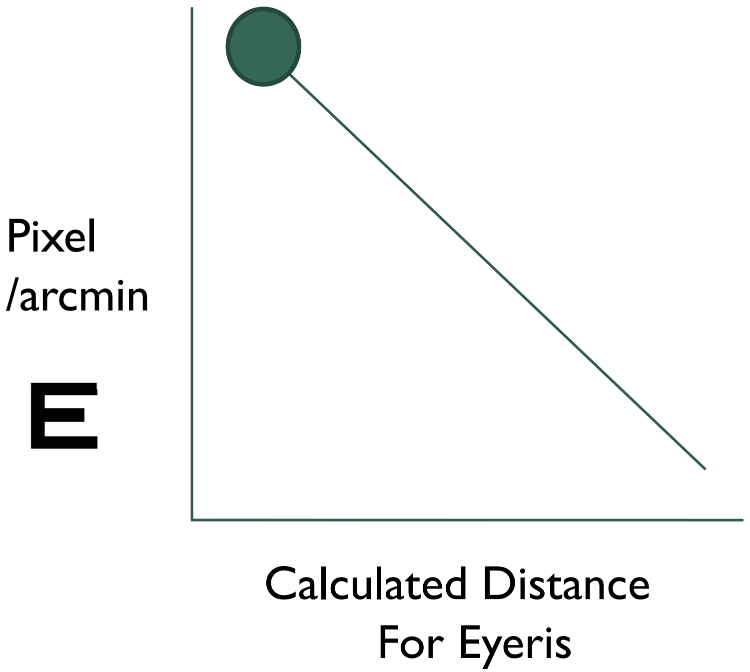


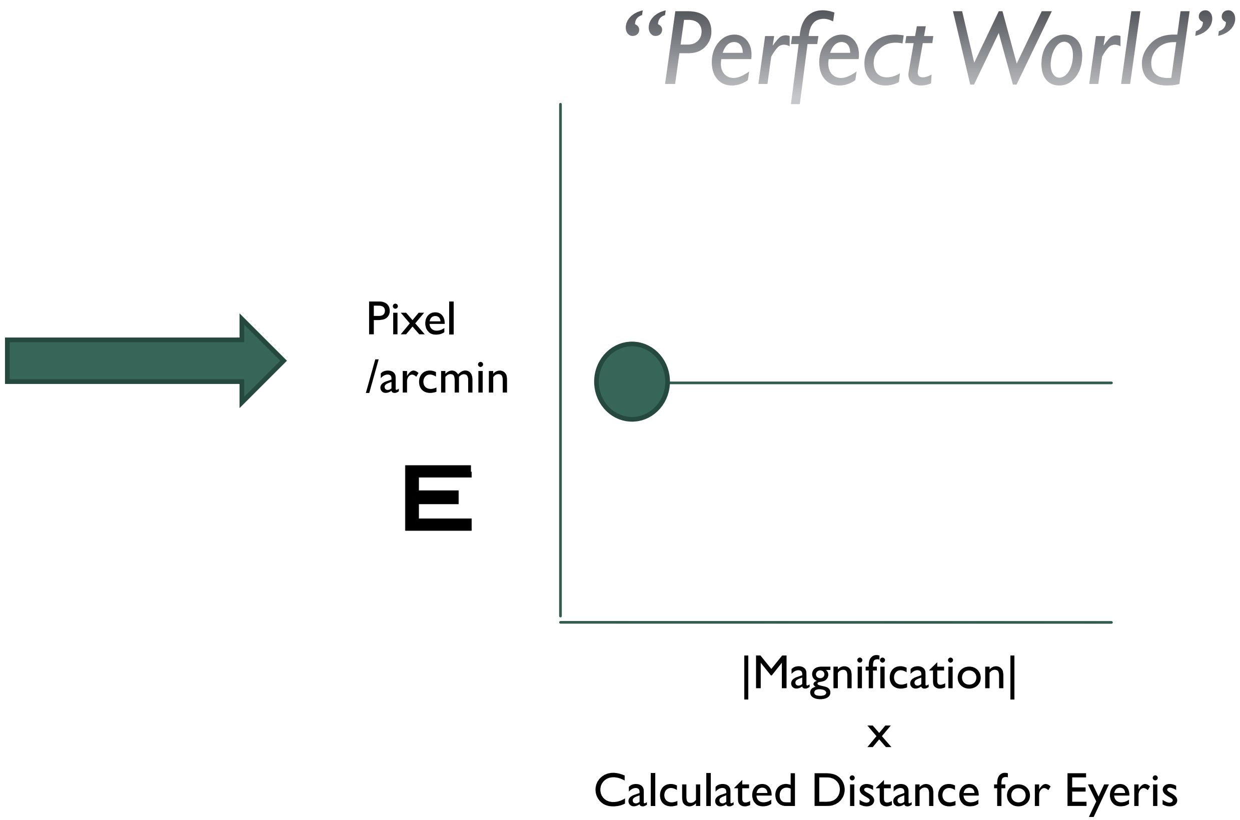


BADAL MECHANICS

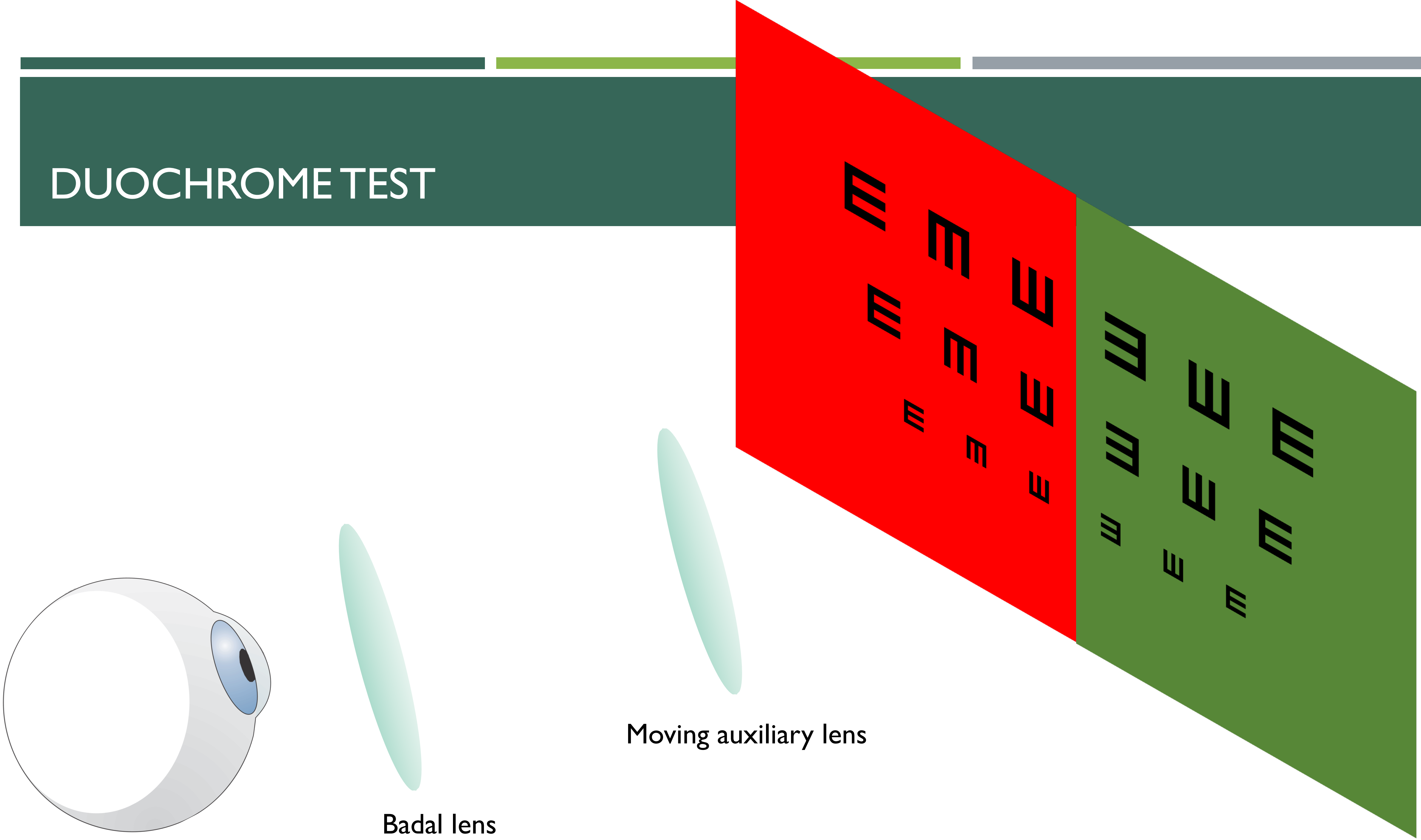
No matter the distance between badal lenses,

Pixel/Arcmin Ratio is the same.



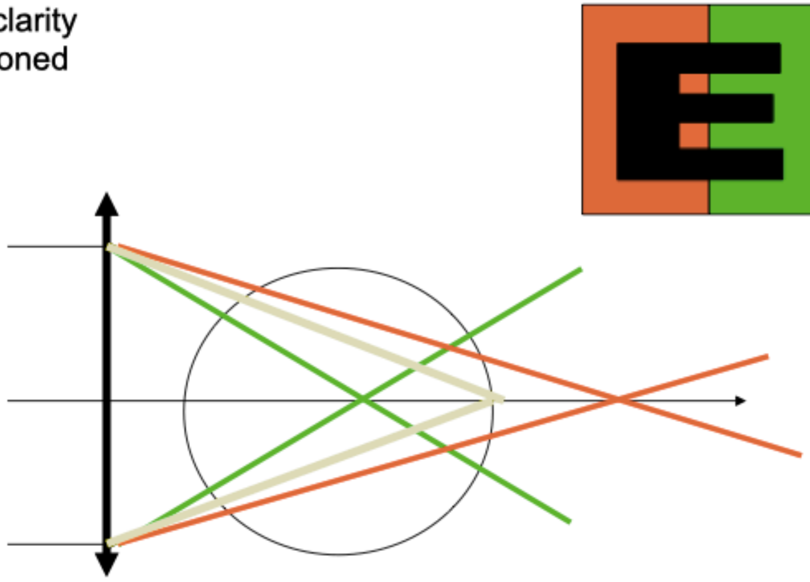


DUOCHROME TEST



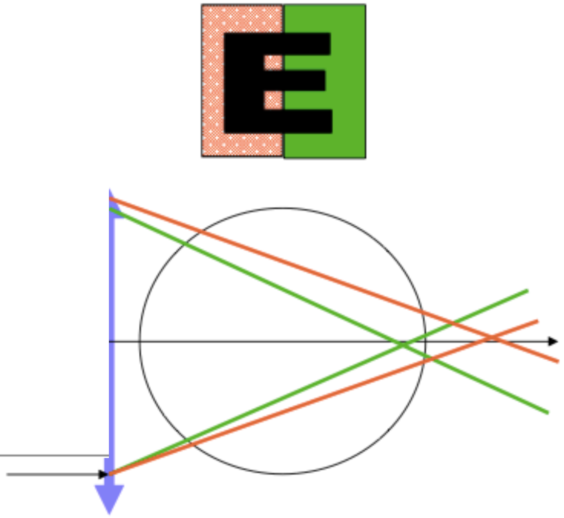
DUOCHROME TEST

Red clarity= green clarity then image is positioned correctly.



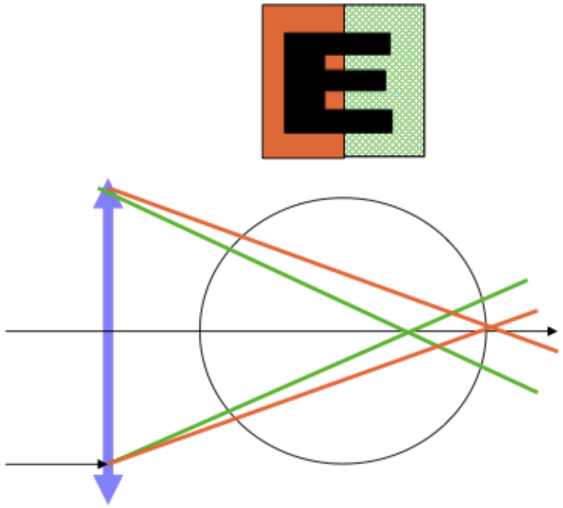
534
560
564

Over-correction



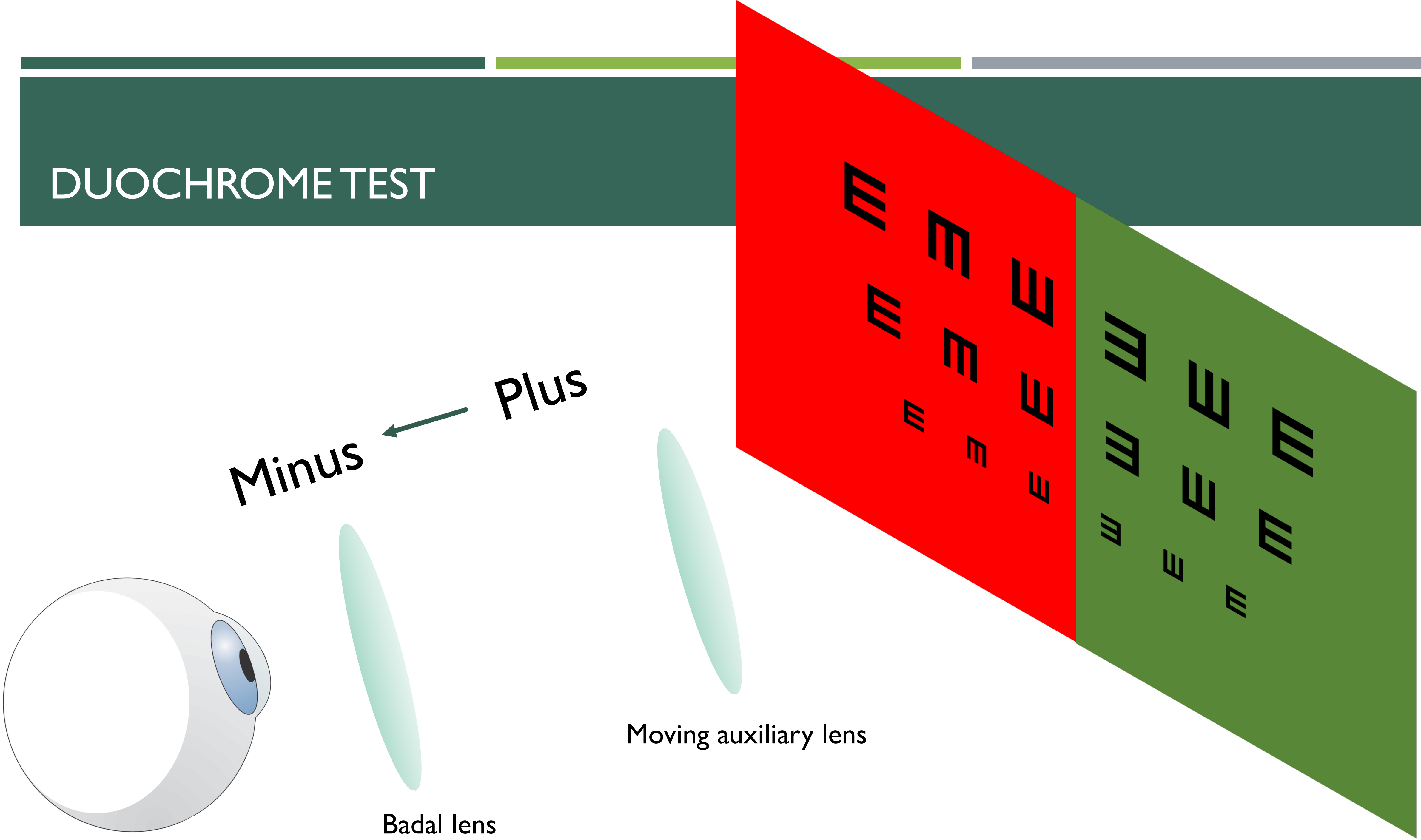
Too much minus green is clearer

Under-correction



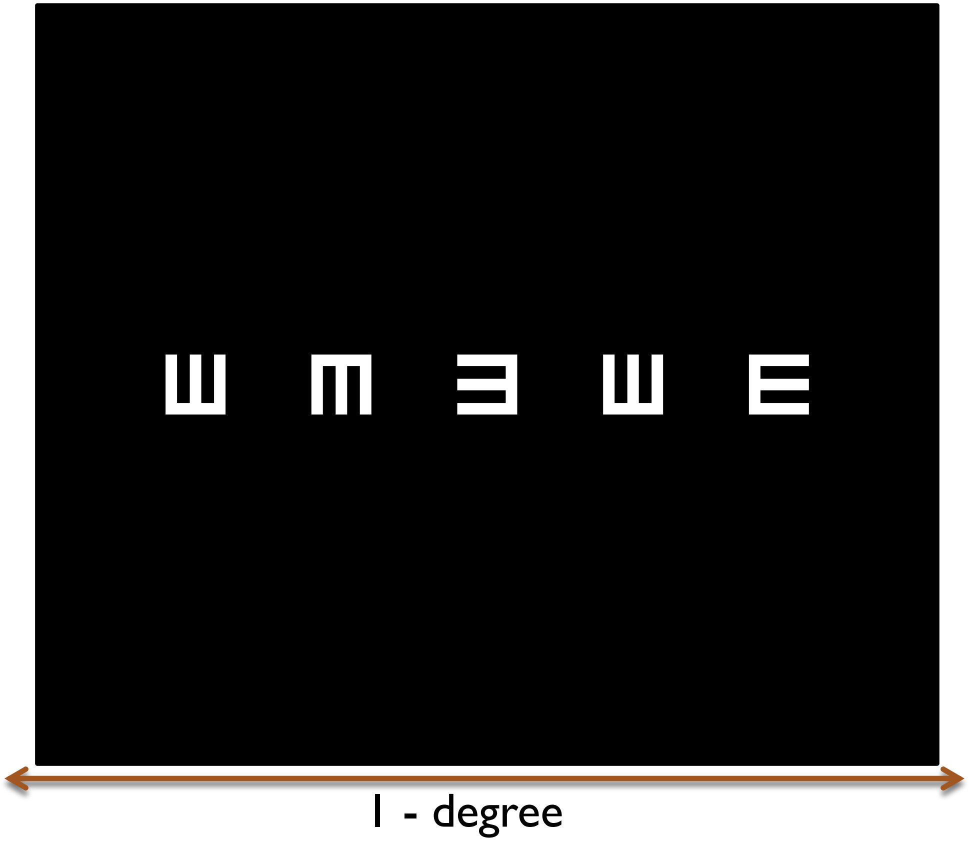
Too much plus red is clearer

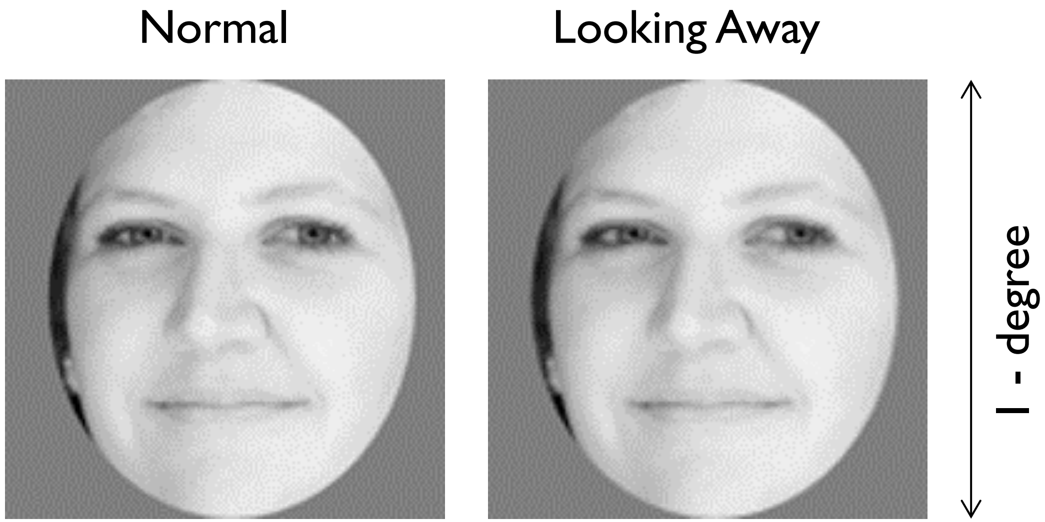
DUOCHROME TEST



EXPERIMENTAL TASKS & RESULTS

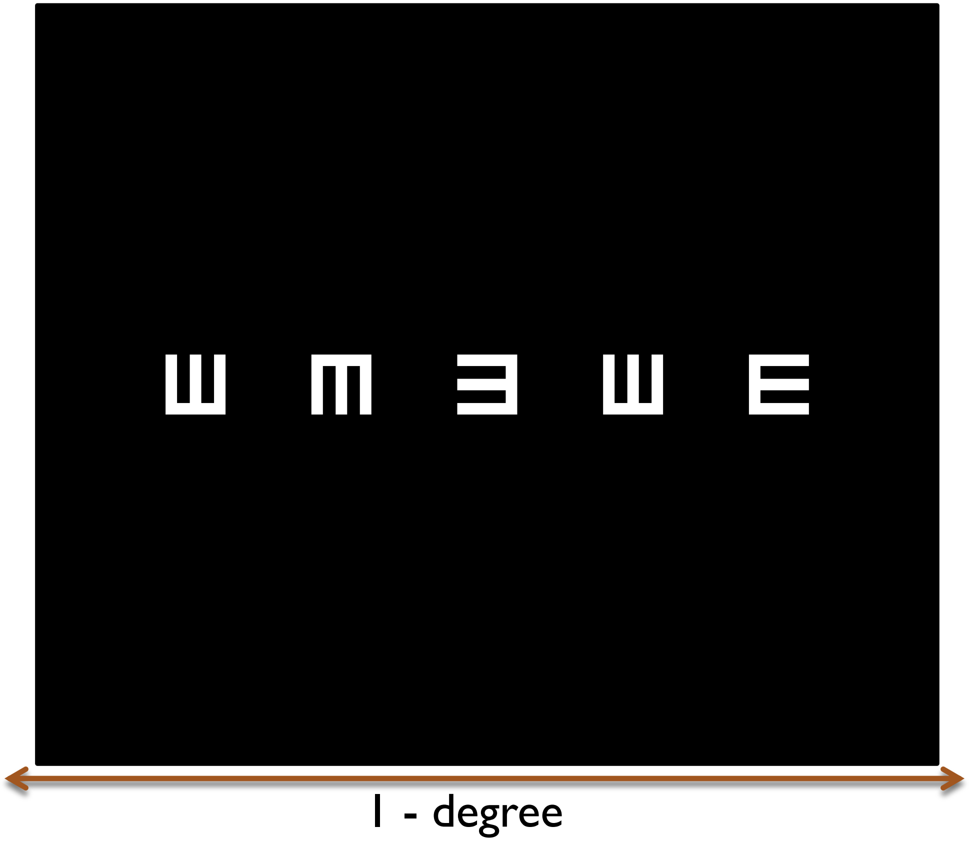
HIGH ACUITY TASKS





Intoy & Rucci (2020), Shelchkova et al (2019)

SNELLEN TEST

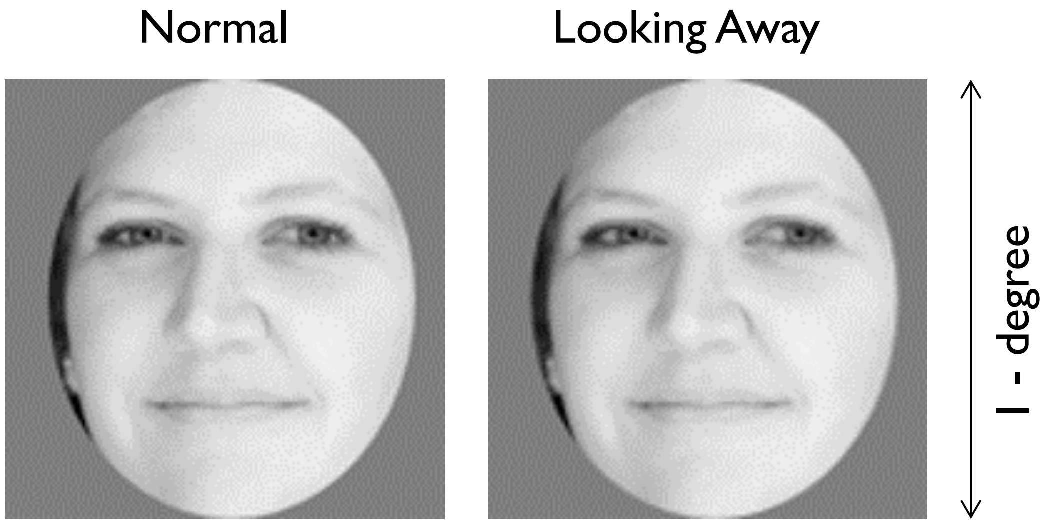


- Snellen Eye Chart – 20/20 Line
- Orientation Discrimination Task
- Self-paced
- Subjects were able to achieve 75% performance for some contrast level

Intoy & Rucci (2020)

HIGH ACUITY TASKS

- Gaze direction discrimination task
- 1.5 second duration
- Subjects performed around chance level



Shelchkova et al (2019)

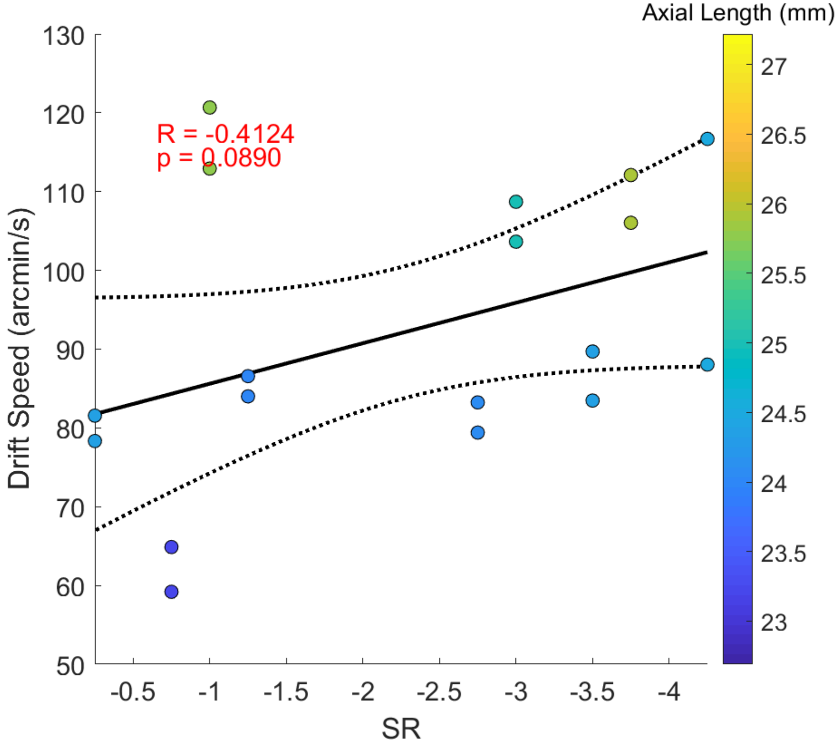
DATA COLLECTION

- Snellen data
  - visually verified
  - many drifts were invalidated for bad-tracking in some subjects
  - Segments that start with 200ms of blink or no-track are discarded
- Faces data
  - only MAC and M008 visually verified
  - Trials with blinks or no tracks are discarded

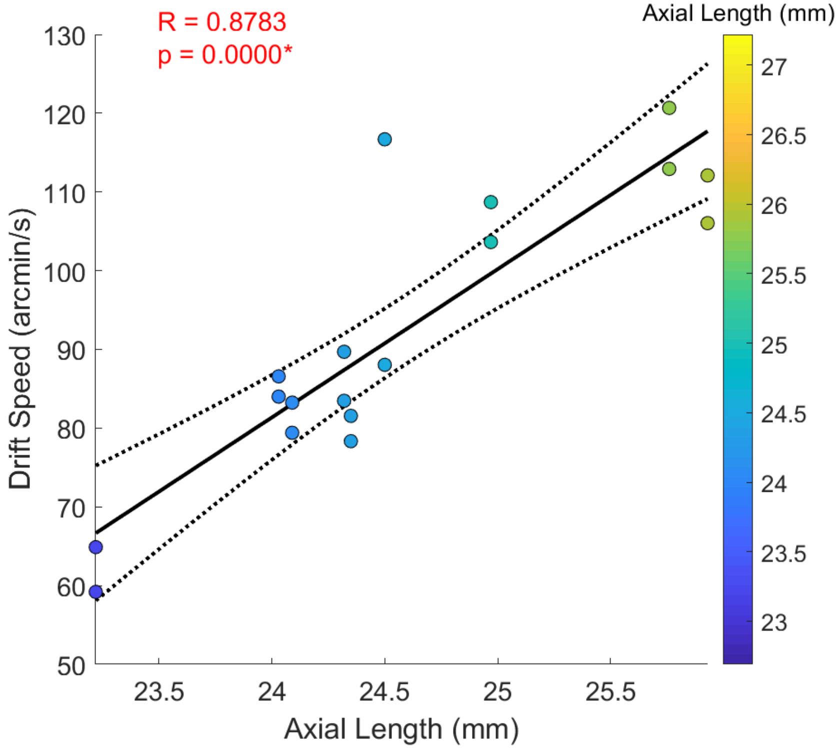
	Snellen			Faces		
Subject	# Trials	# Drifts	# Saccs	# Trials	# Drifts	# Saccs
MAC	106	460	1012	79	83	84
M008	45	104	1162	105	30	79
M010	108	560	857	100	132	65
M012	94	363	811	114	164	86
M020	87	77	686	73	38	45
M021	127	254	798	107	73	77
M022	97	46	593	110	15	175
M023	61	44	792	88	33	99
M055	95	67	395	150	127	40

*To boost numbers in preliminary data, Snellen and faces data are plotted together so that there are two data points per subject.

RESULTS: DRIFT SPEED

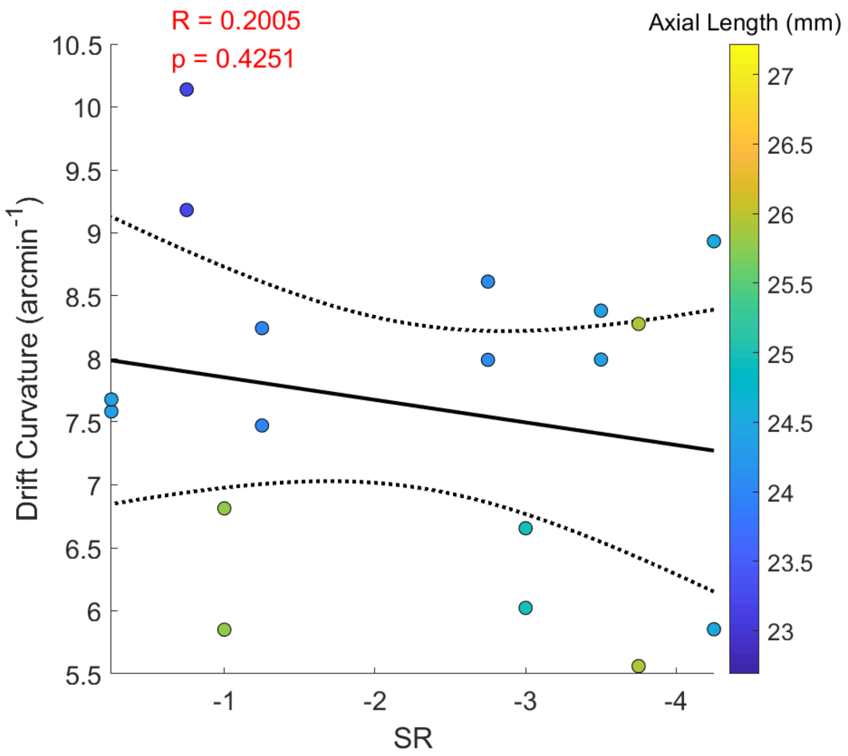


Drift speed is **not** strongly correlated with Spherical Refraction.

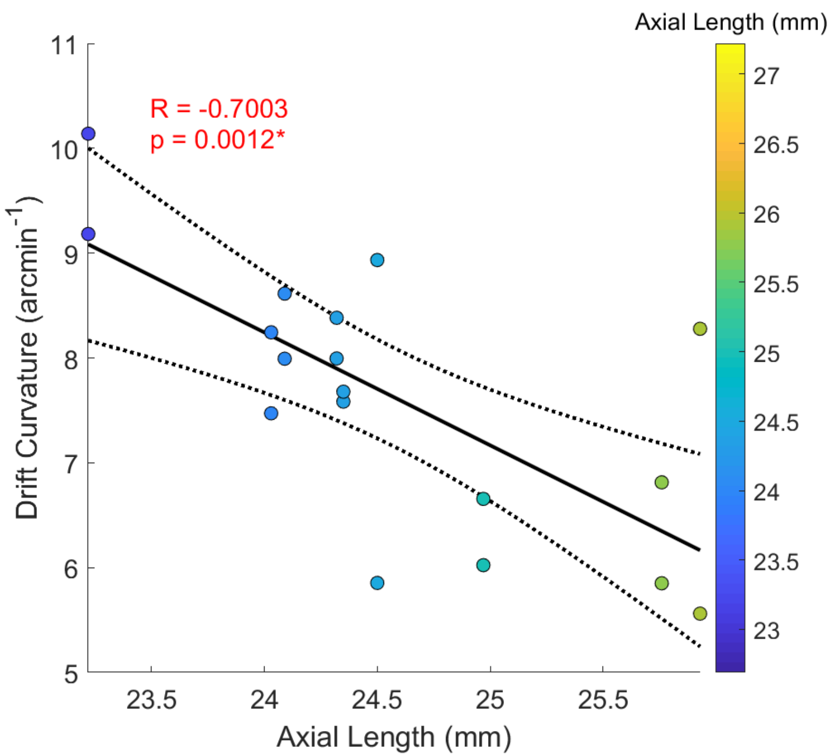


Drift speed is strongly correlated with Axial Length.

RESULTS: DRIFT CURVATURE

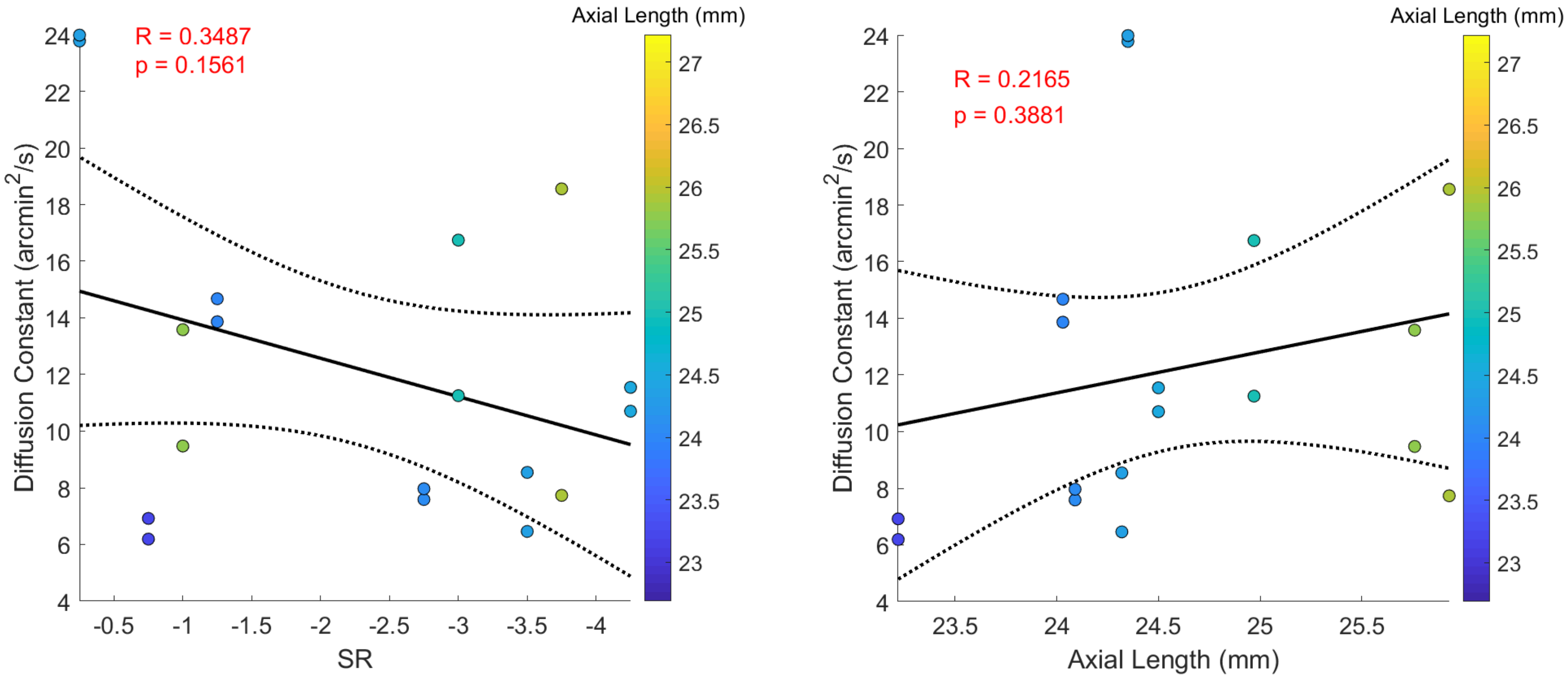


Drift curvature is **not** correlated with Spherical Refraction.



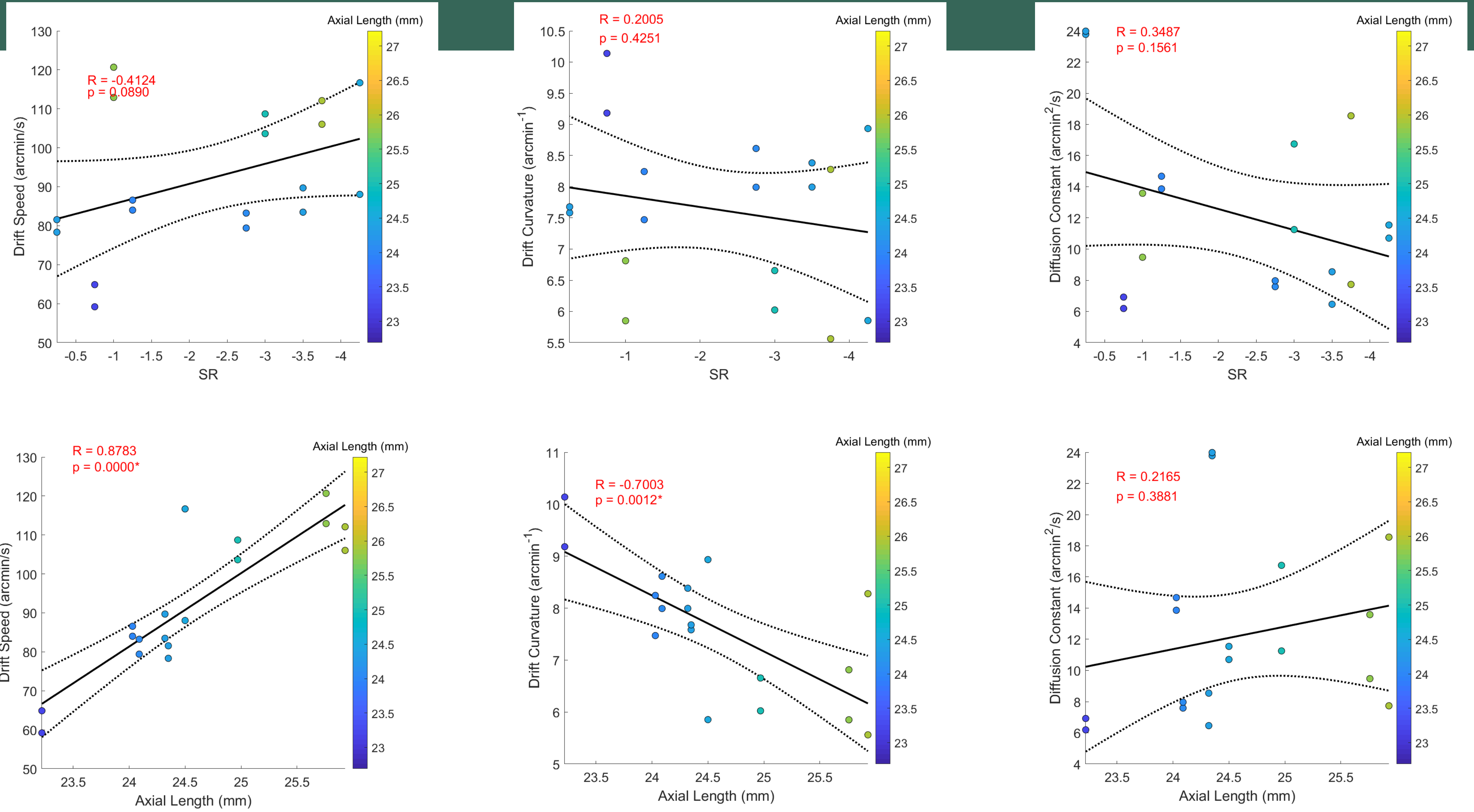
Drift curvature is strongly correlated with Axial Length.

RESULTS: DRIFT DIFFUSION

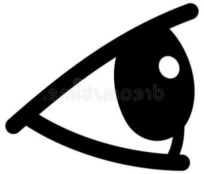


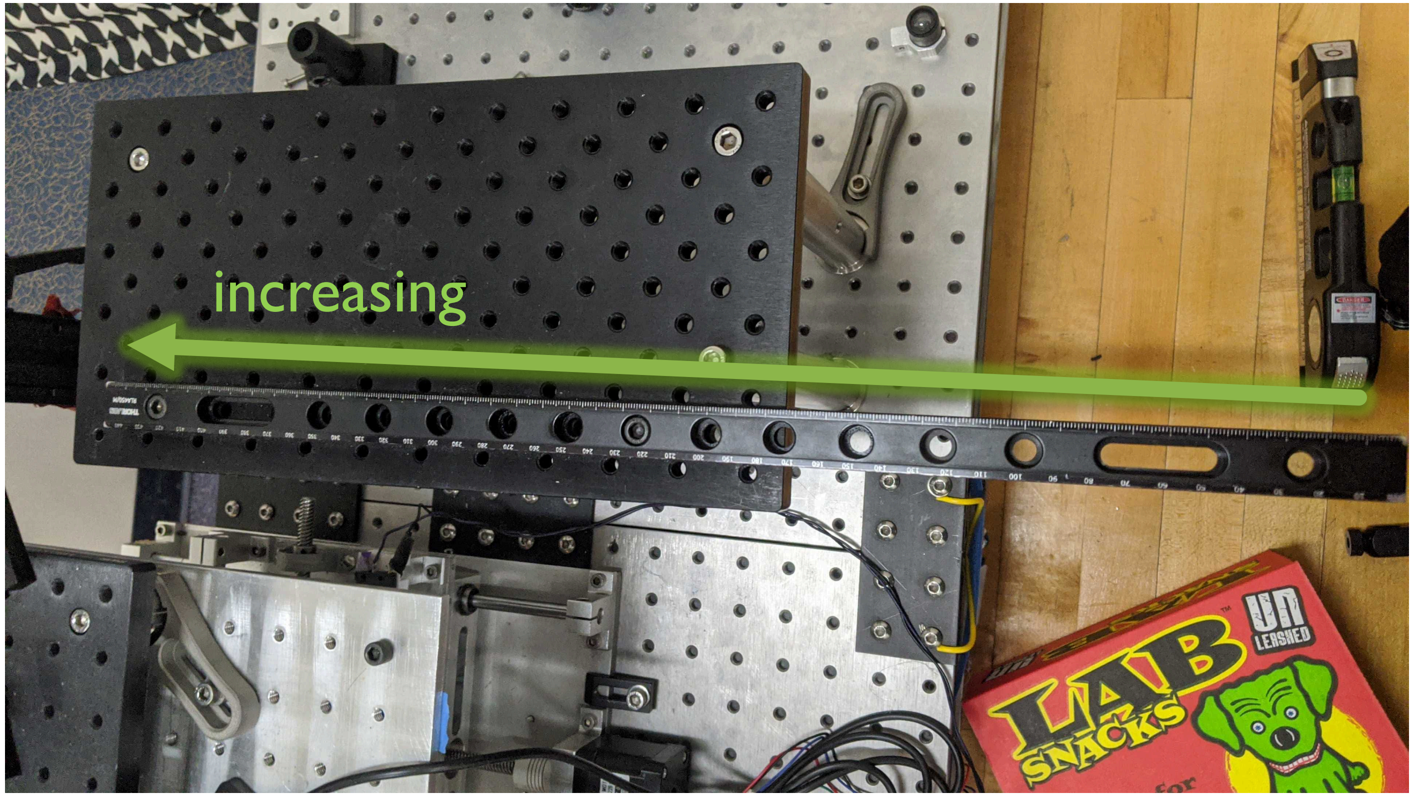
Diffusion constant is not correlated with Spherical Refraction or Axial Length.

RESULTS: DRIFT SUMMARY



CAVEAT WITH PRELIMINARY DATA



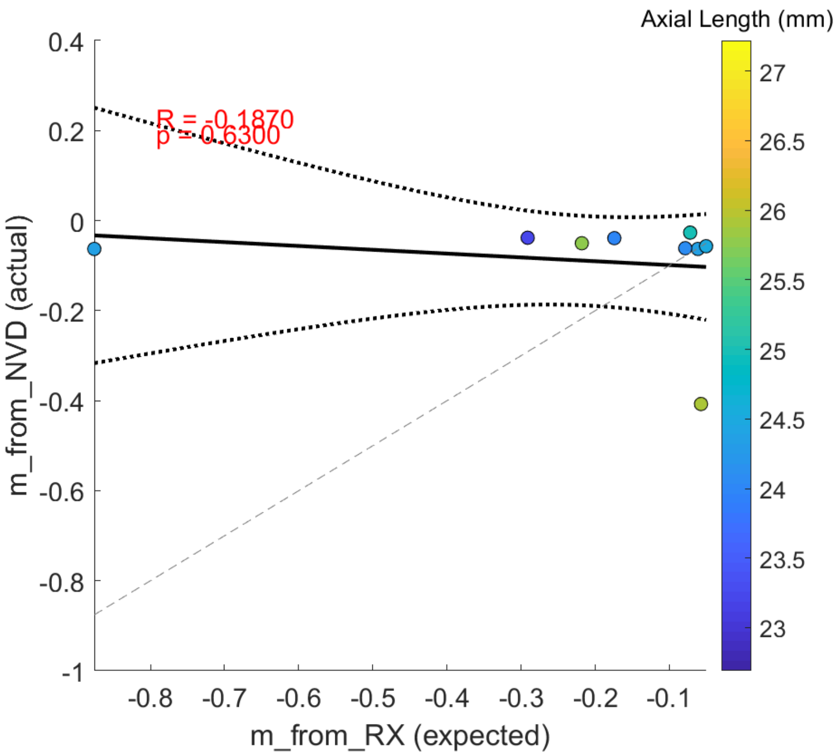


SHOULD BE: increasing

BADAL MINIFICATION

Badal minification applied with incorrect lens distance reading.

We corrected for this.

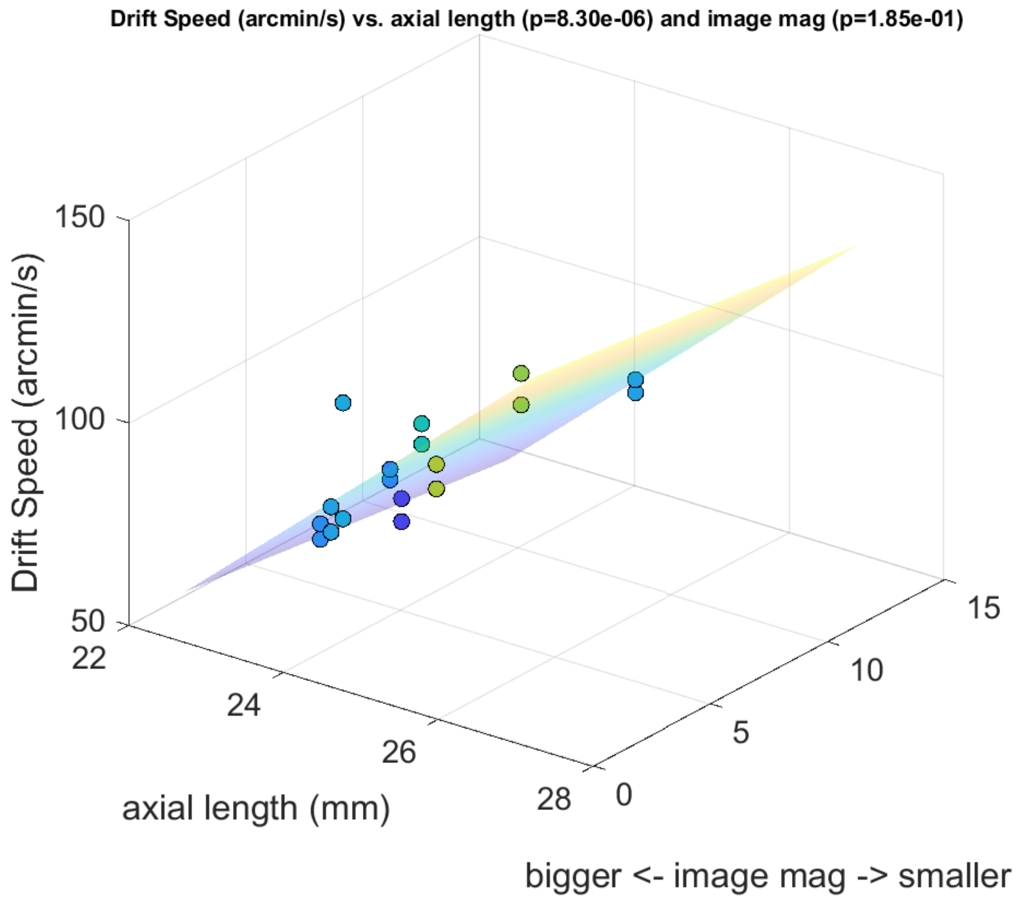


The minification of the image on the monitor through the badal is given by the ratio of these two values.

Expected badal minification given subjects' spherical refraction.

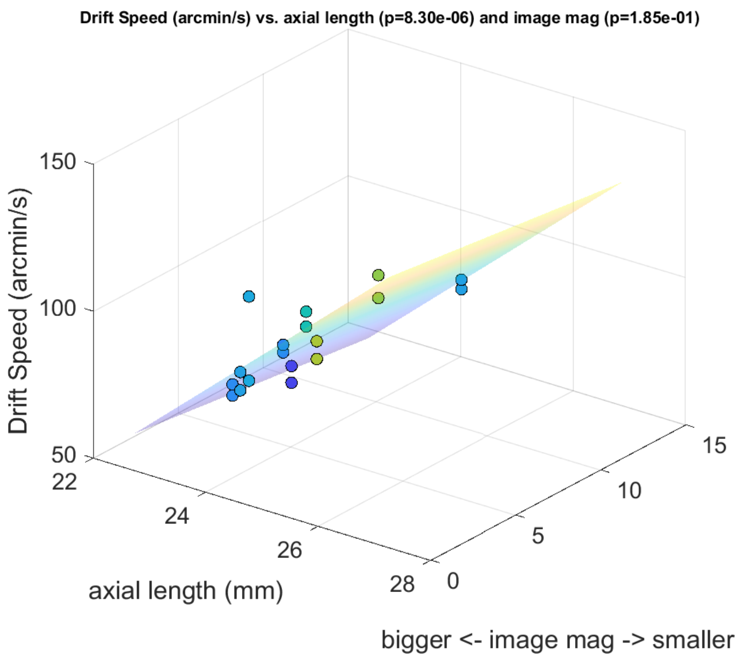
The subjects likely experienced this.

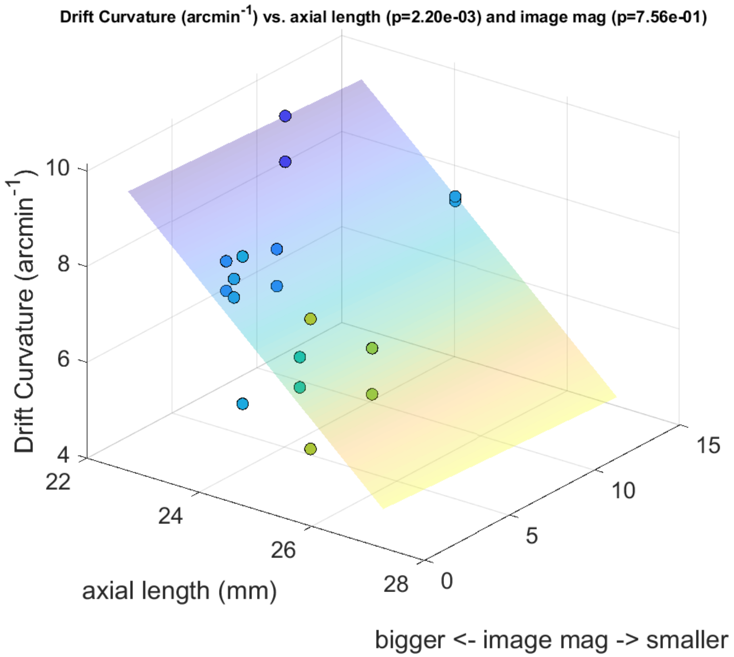
RESULTS: DRIFT AND IMAGE MINIFICATION

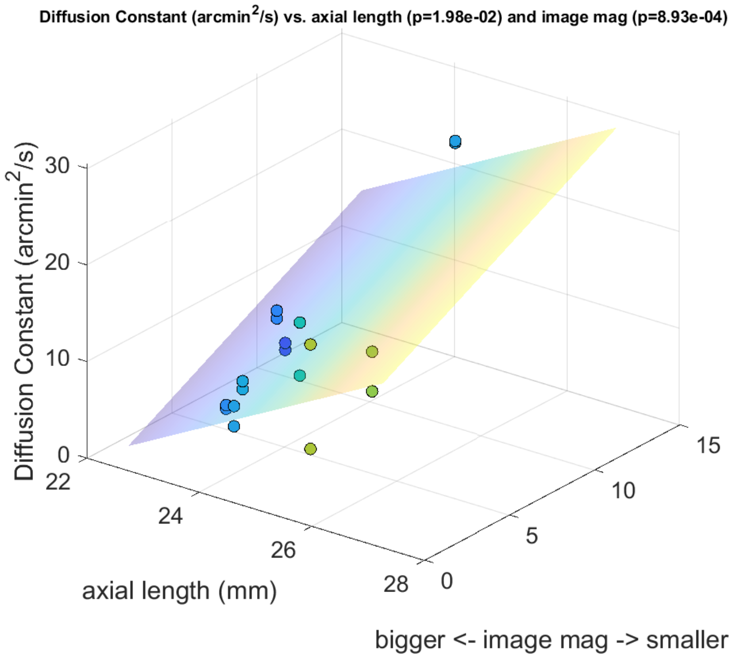


- Regress drift characteristics against both axial length and image magnification.
- (open 3d figures in matlab)
- **Drift speed and curvature** varies significantly with axial length, *not* image magnification.
  - Drift speed increases as image becomes smaller.
- **Drift diffusion** varies significantly with both axial length and image magnification.

RESULTS: DRIFT AND IMAGE MAGNIFICATION







THINGS TO CONSIDER FOR THE FUTURE

THINGS TO CONSIDER

Potential Introduction of Errors	Ways to Improve	Cons
Auto-refractors are not 100% reliable **- Studies have shown they are only ~80% reliable without dilation, with increasing error with age.**	**Include a full refraction with initial exam.**	**Time costly**
Subjects do a poor job of self correcting with badal lens	Pre-Set badal to be near prescription	Does not account for CYL
Current IRB doesn't allow for sex difference analysis - Could also cover details in Cortical Blindness study		

https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1444-0938.1998.tb06729.x
https://journals.lww.com/optvissci/Fulltext/2004/01000/Accuracy_of_Noncycloplegic_Autorefraction_in.10.aspx

THINGS TO CONSIDER

- Our current method of axial length measurement is the "Gold Standard"
  - Another viable option includes B-OCT

https://www.hindawi.com/journals/joph/2019/9192456/

THANK YOU