Seeing Red: Eyestrain, Accommodation, Color and Reading

Is this comfortable to read?

Or is this more comfortable?

Collaborators

Eric Borsting, OD, MS

Lawrence Stark, PhD

William Ridder III, OD, PhD

Southern California College of Optometry

Chinatsu Tosha, PhD

UCLA Jules Stein Eye Institute

John Stein, FRCP
Nicola Ray, PhD
Susan Fowler, DBO, PhD

Oxford University

Robert Dougherty, PhD

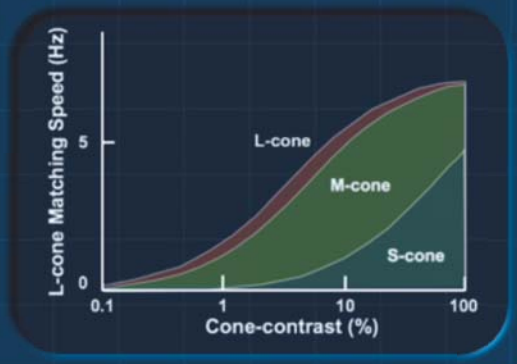
Stanford University

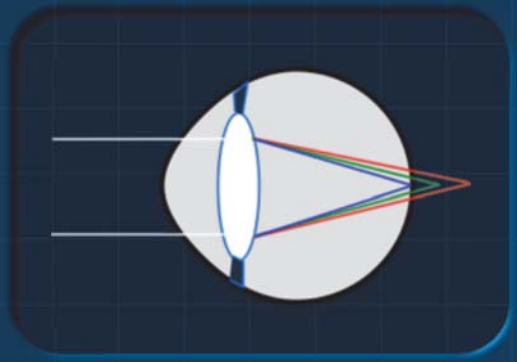
Research supported by grants from

NIH R15EY015922, R15EY021021 and COVD

Overview

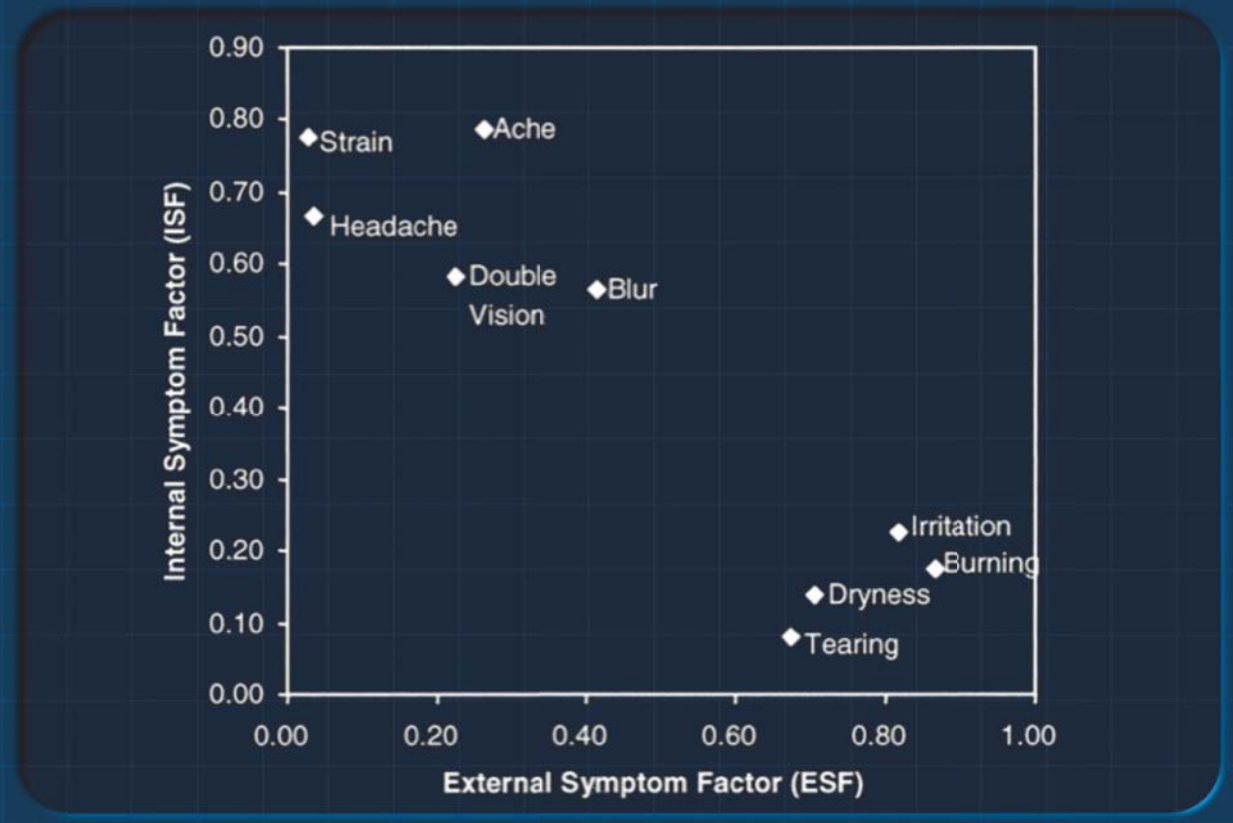
- Eyestrain symptoms
- Accommodation
- Color and reading
- Chromatic aberration
- Summary





1. Describe symptoms and a bit about how they affect reading in skilled college students.
2. Show significant accommodation weakness in symptomatic students.
3. Examine effects of color on reading and make a case that increasing L/M ratio impairs performance.
4. Make a case that chromatic aberration may be the mechanism by which higher L/M ratios increase accommodative demand, increase symptoms, and impair reading performance.

Part 1: Eyestrain

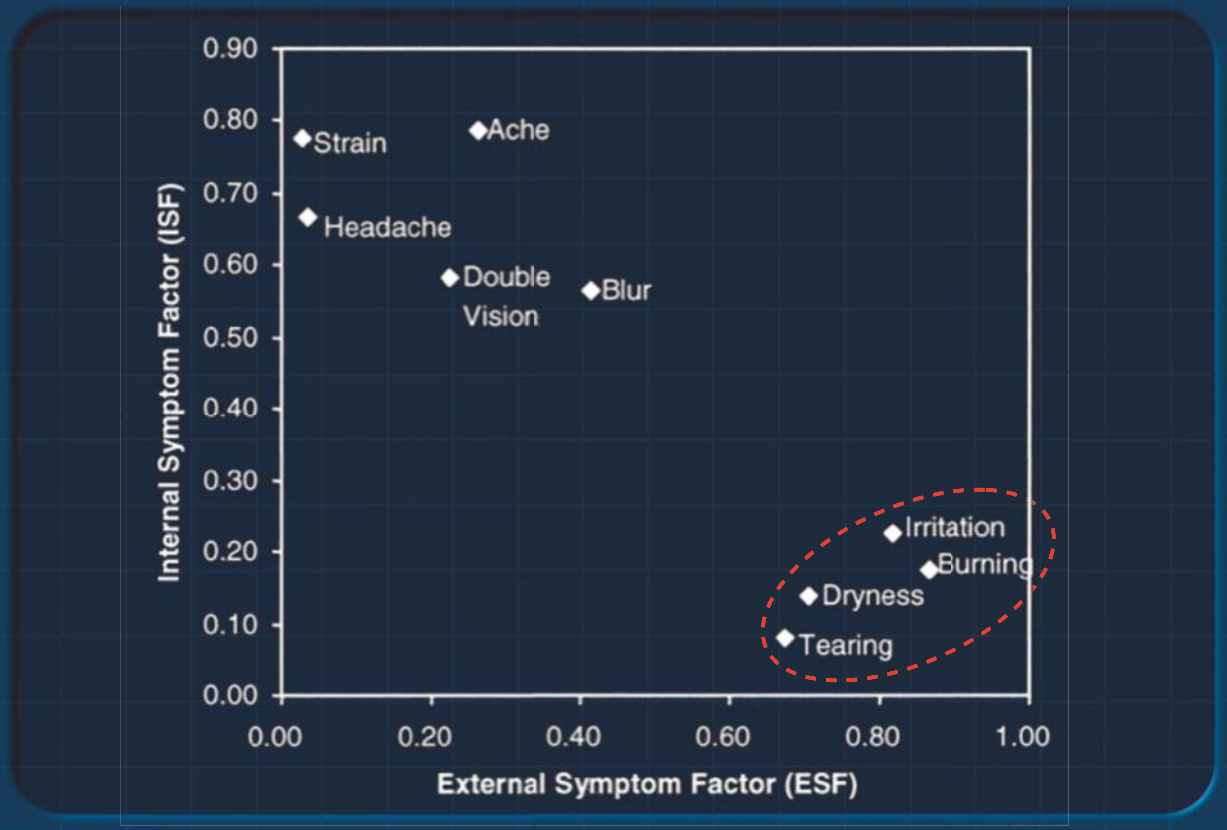


From Sheedy et al. 2003

We use the term Visual Discomfort instead of Visual Stress because we base the term on symptoms alone and not a positive response to the use of a color filter or transparency.

In some studies a child has Visual Stress if they meet two of the following criteria when using colored overlays:
1. Five percent improvement in reading speed on the Rate of Reading test.
2. Self-report reduction in symptoms.
3. Use of the overlay for six months or more.

Part 1: Eyestrain

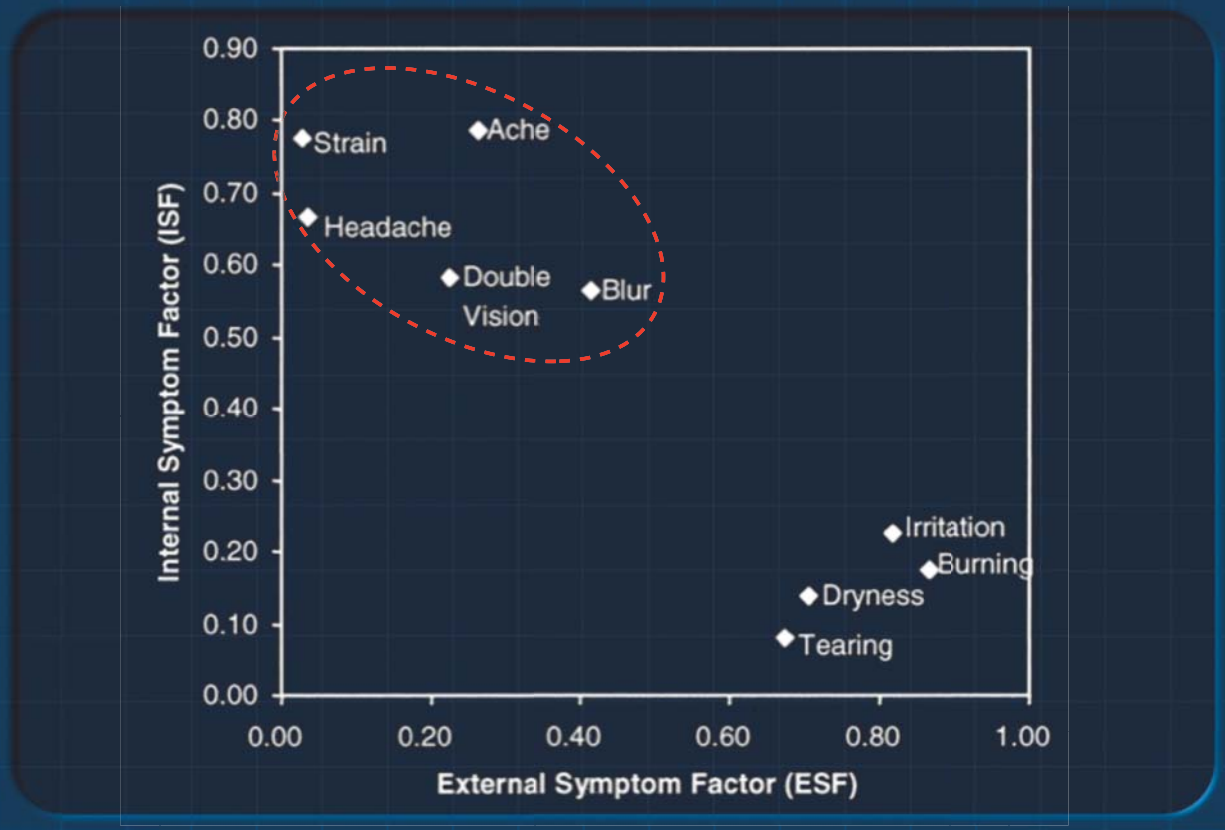


From Sheedy et al. 2003

We use the term Visual Discomfort instead of Visual Stress because we base the term on symptoms alone and not a positive response to the use of a color filter or transparency.

In some studies a child has Visual Stress if they meet two of the following criteria when using colored overlays:
1. Five percent improvement in reading speed on the Rate of Reading test.
2. Self-report reduction in symptoms.
3. Use of the overlay for six months or more.

Part 1: Eyestrain

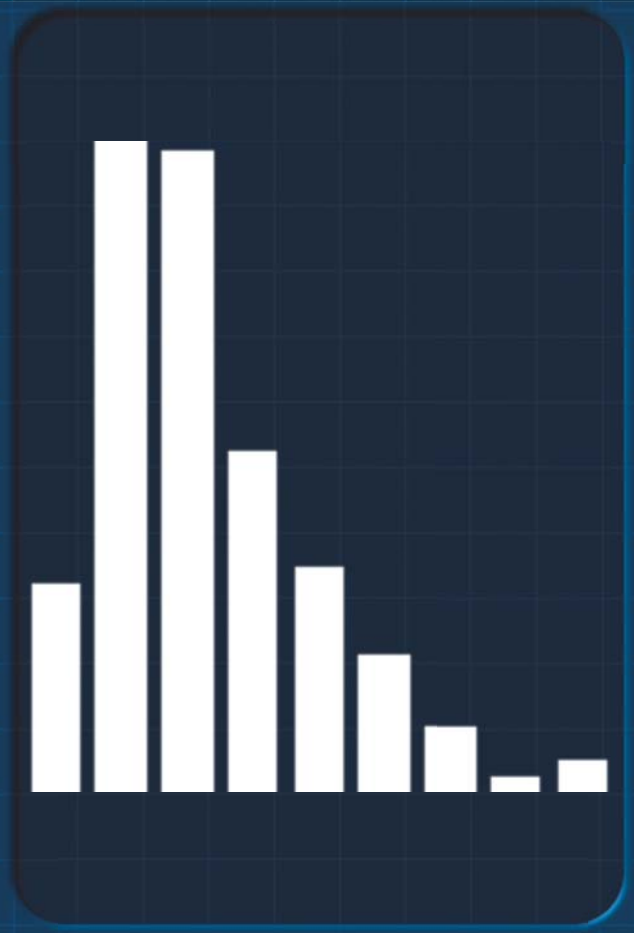


From Sheedy et al. 2003

We use the term Visual Discomfort instead of Visual Stress because we base the term on symptoms alone and not a positive response to the use of a color filter or transparency.

In some studies a child has Visual Stress if they meet two of the following criteria when using colored overlays:
1. Five percent improvement in reading speed on the Rate of Reading test.
2. Self-report reduction in symptoms.
3. Use of the overlay for six months or more.

Symptom prevalence is high among college students



From Borsting et al 2007

- Conlon unidimensional symptom scale
- 17% of student at Claremont Colleges
- 72% female

N = 571. College students are unique: Above average readers; very few with CI in the sample.
Conlon Survey: 23-items, 4-point rating scale. Unidimensional in two separate Rasch analyses.

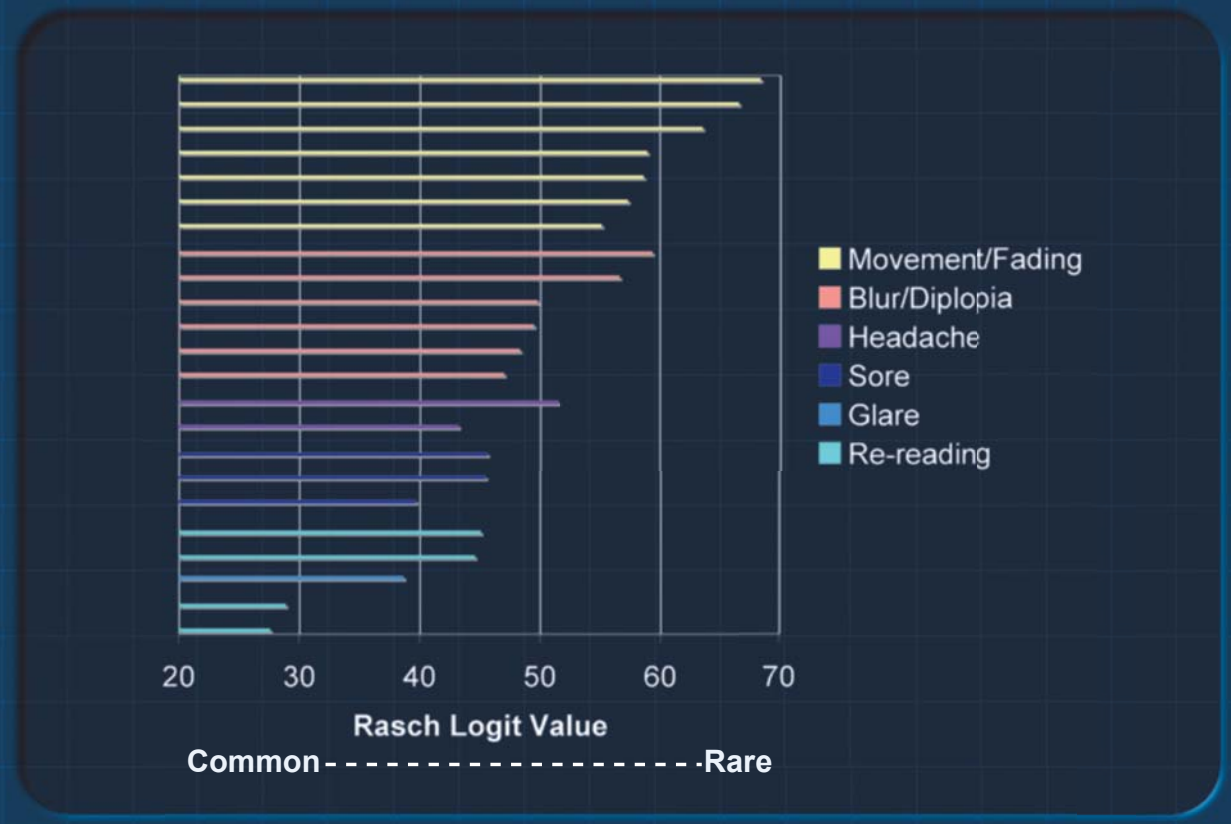
Conlon mean = 15.4 (SD=10.2)

Symptom frequency is broadly distributed

From Borsting et al 2007

Rasch analysis of 23 Conlon et al survey items on 571 students randomly selected from Claremont Colleges.

Symptom frequency is broadly distributed



From Borsting et al 2007

Rasch analysis of 23 Conlon et al survey items on 571 students randomly selected from Claremont Colleges.

How long can you read before symptoms appear?

	Never	1 hr	½ hr	¼ hr
High Group	0%	40%	30%	30%
Low Group	22%	54%	19%	5%

Do symptoms affect grades?

	Never	Few times a year	Every few weeks	Almost always
High Group	19%	12%	46%	23%
Low Group	63%	22%	12%	3%

Total of 75 students (2/3 female)

Mean IQ = 122; Word ID = 110 (94-126); Non-word = 113 (range 94-146)

Screened for normal visual acuity, no constant strabismus, stereopsis, uncorrected refractive error, astigmatism and anisometropia, hyperopia, ocular pathology, or color deficiency.
Learning disabilities, medical condition or medications that could cause visual discomfort or oculomotor dysfunction.

Sample stratified by discomfort symptoms.

How long can you read before symptoms appear?

	Never	1 hr	½ hr	¼ hr
High Group	0%	40%	30%	30%
Low Group	22%	54%	19%	5%

Do symptoms affect grades?

	Never	Few times a year	Every few weeks	Almost always
High Group	19%	12%	46%	23%
Low Group	63%	22%	12%	3%

Total of 75 students (2/3 female)

Mean IQ = 122; Word ID = 110 (94-126); Non-word = 113 (range 94-146)

Screened for normal visual acuity, no constant strabismus, stereopsis, uncorrected refractive error, astigmatism and anisometropia, hyperopia, ocular pathology, or color deficiency.
Learning disabilities, medical condition or medications that could cause visual discomfort or oculomotor dysfunction.

Sample stratified by discomfort symptoms.

How long can you read before symptoms appear?

	Never	1 hr	½ hr	¼ hr
High Group	0%	40%	30%	30%
Low Group	22%	54%	19%	5%

Do symptoms affect grades?

	Never	Few times a year	Every few weeks	Almost always
High Group	19%	12%	46%	23%
Low Group	63%	22%	12%	3%

Total of 75 students (2/3 female)

Mean IQ = 122; Word ID = 110 (94-126); Non-word = 113 (range 94-146)

Screened for normal visual acuity, no constant strabismus, stereopsis, uncorrected refractive error, astigmatism and anisometropia, hyperopia, ocular pathology, or color deficiency.
Learning disabilities, medical condition or medications that could cause visual discomfort or oculomotor dysfunction.

Sample stratified by discomfort symptoms.

How long can you read before symptoms appear?

	Never	1 hr	½ hr	¼ hr
High Group	0%	40%	30%	30%
Low Group	22%	54%	19%	5%

Do symptoms affect grades?

	Never	Few times a year	Every few weeks	Almost always
High Group	19%	12%	46%	23%
Low Group	63%	22%	12%	3%

Total of 75 students (2/3 female)

Mean IQ = 122; Word ID = 110 (94-126); Non-word = 113 (range 94-146)

Screened for normal visual acuity, no constant strabismus, stereopsis, uncorrected refractive error, astigmatism and anisometropia, hyperopia, ocular pathology, or color deficiency.
Learning disabilities, medical condition or medications that could cause visual discomfort or oculomotor dysfunction.

Sample stratified by discomfort symptoms.

How long can you read before symptoms appear?

	Never	1 hr	½ hr	¼ hr
High Group	0%	40%	30%	30%
Low Group	22%	54%	19%	5%

Do symptoms affect grades?

	Never	Few times a year	Every few weeks	Almost always
High Group	19%	12%	46%	23%
Low Group	63%	22%	12%	3%

Total of 75 students (2/3 female)

Mean IQ = 122; Word ID = 110 (94-126); Non-word = 113 (range 94-146)

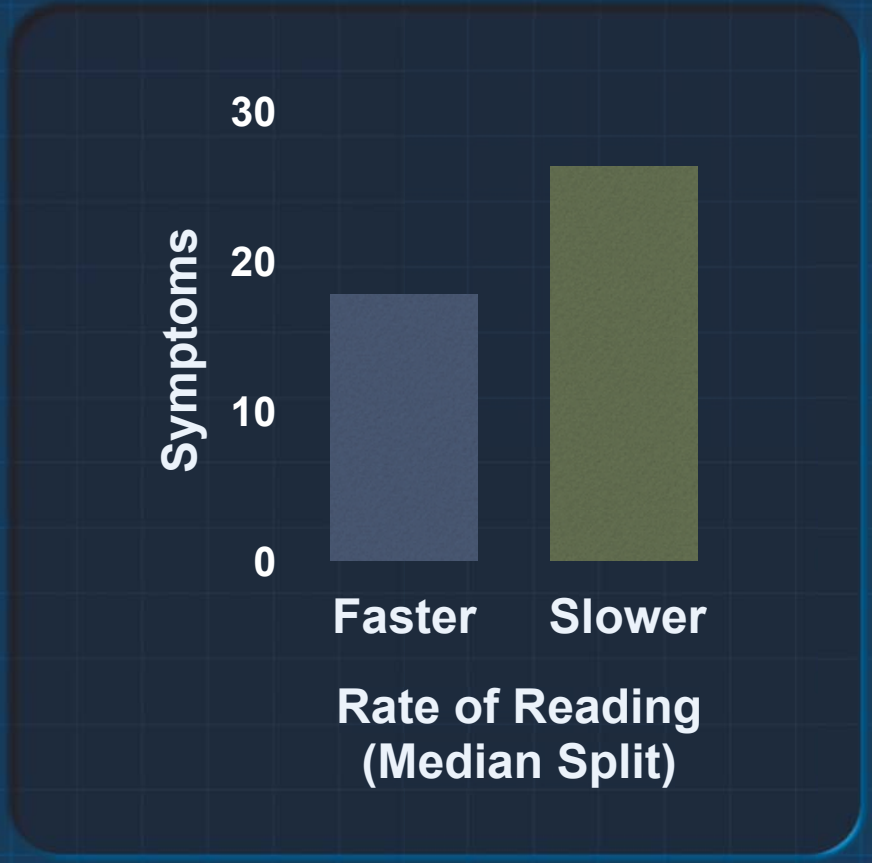
Screened for normal visual acuity, no constant strabismus, stereopsis, uncorrected refractive error, astigmatism and anisometropia, hyperopia, ocular pathology, or color deficiency.
Learning disabilities, medical condition or medications that could cause visual discomfort or oculomotor dysfunction.

Sample stratified by discomfort symptoms.

Rate of reading test

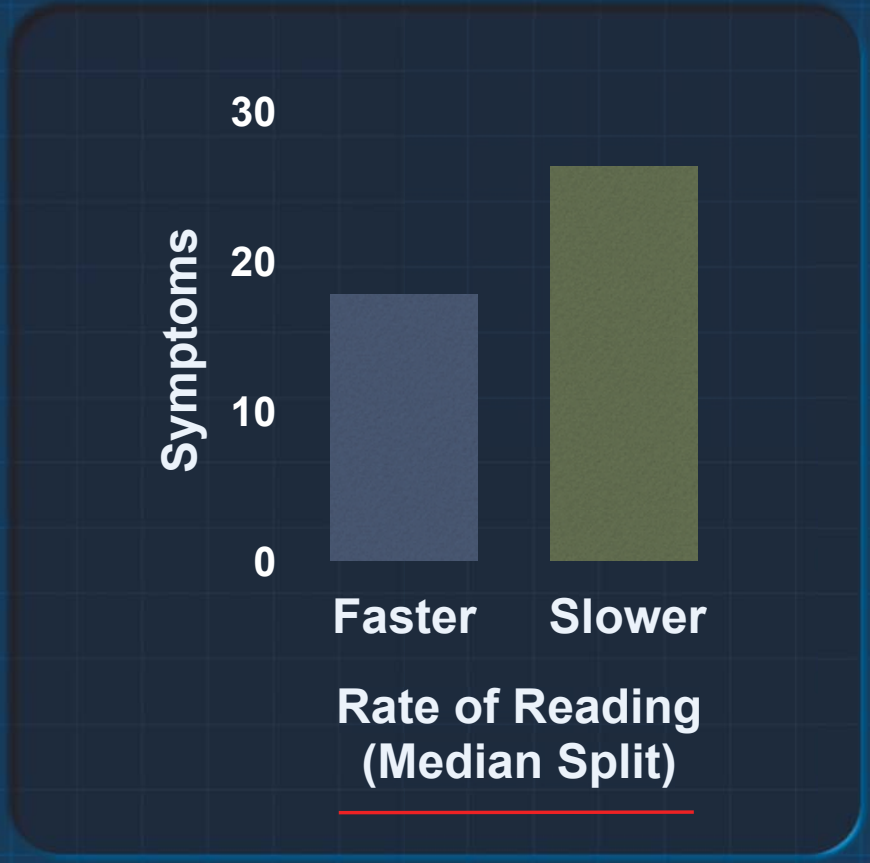
come see the play look up is cat not my and dog for you to the cat up dog and is play come you see for not to look my you for the and not see my play come is look dog cat to up dog to you and play cat up is my not come for the look see play come see cat not look dog is my up the for to and you to not cat for look is my and up come play you see the dog my play see to for you is the look up cat not dog come and look to for my come play the dog see you not cat up and is up come look for the not dog cat you to see is and my play is you dog for not cat my look come and up to play see the see the look dog and not is you come up to my for cat play not up play my is dog you come look for see and to the cat look up come and is my cat not dog you see for to play the my you is look the dog play see not come and to cat for up for the to and you cat is look up my not dog play see come you look see and play to the is cat not come for my up dog come not to play look the and dog see is cat up you for my and is for dog come see the cat up look you play my not to dog you cat to and play for not come up the see look my is the come to up cat my see dog you not look is play and for

Slower readers are more symptomatic



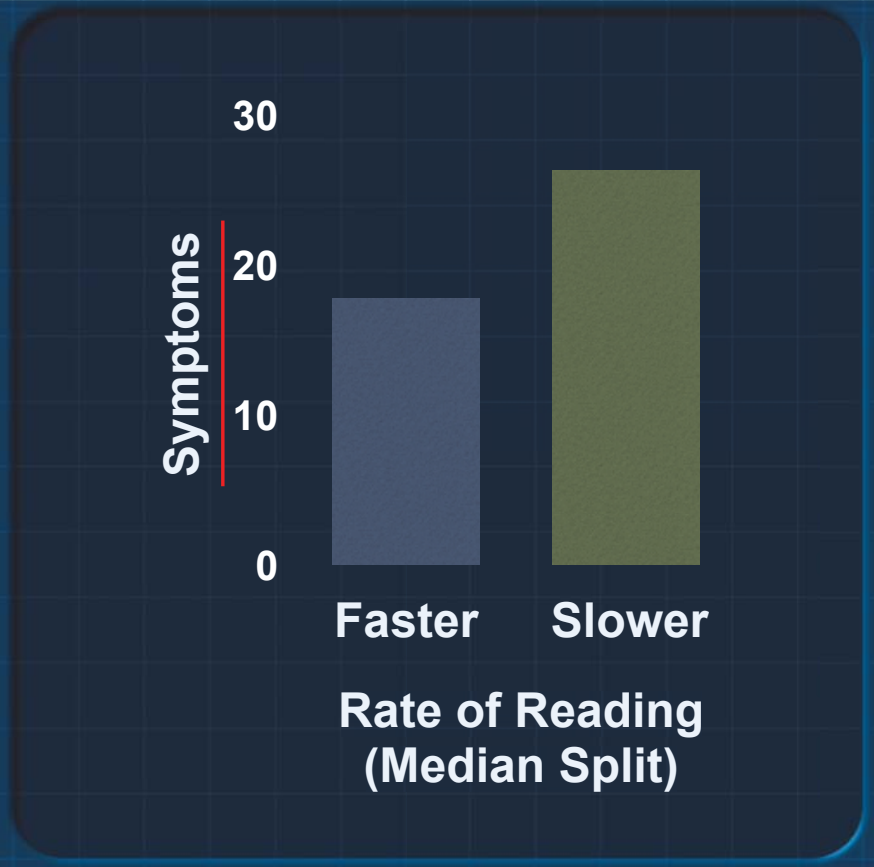
t(63) = 3.16, p = 0.003

Slower readers are more symptomatic



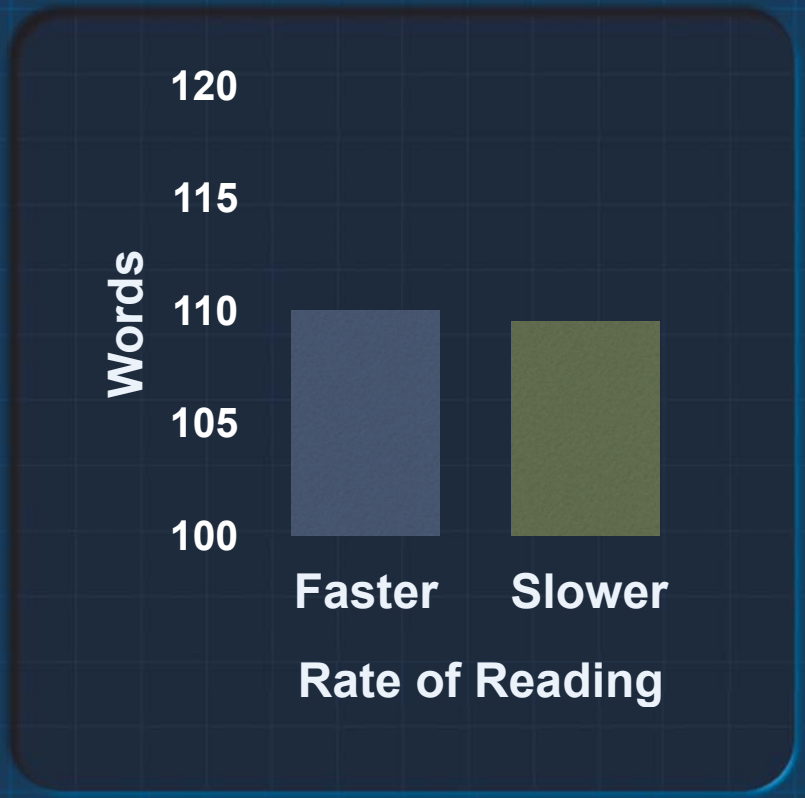
t(63) = 3.16, p = 0.003

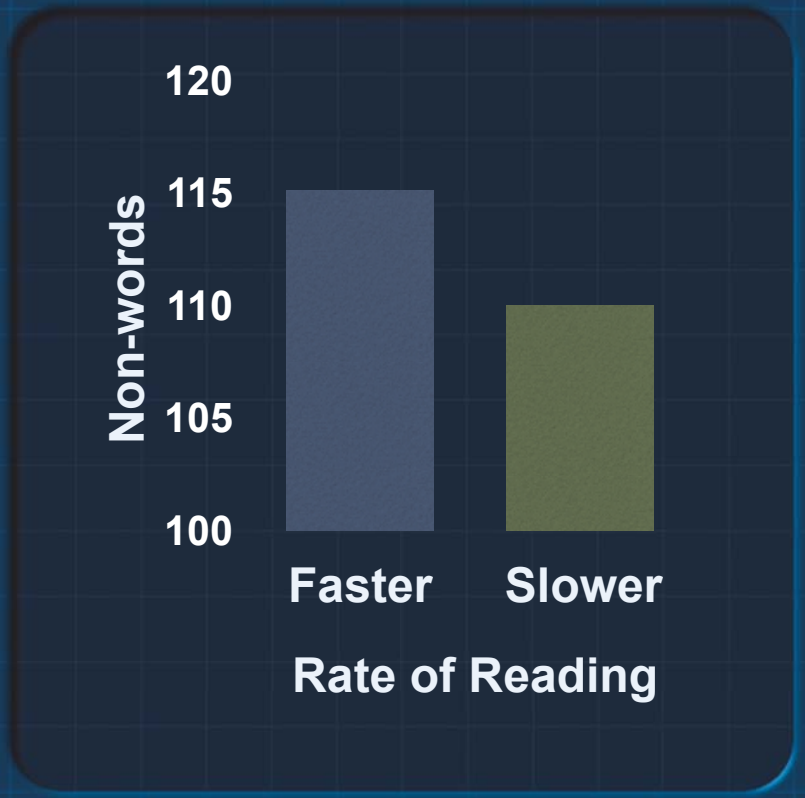
Slower readers are more symptomatic



t(63) = 3.16, p = 0.003

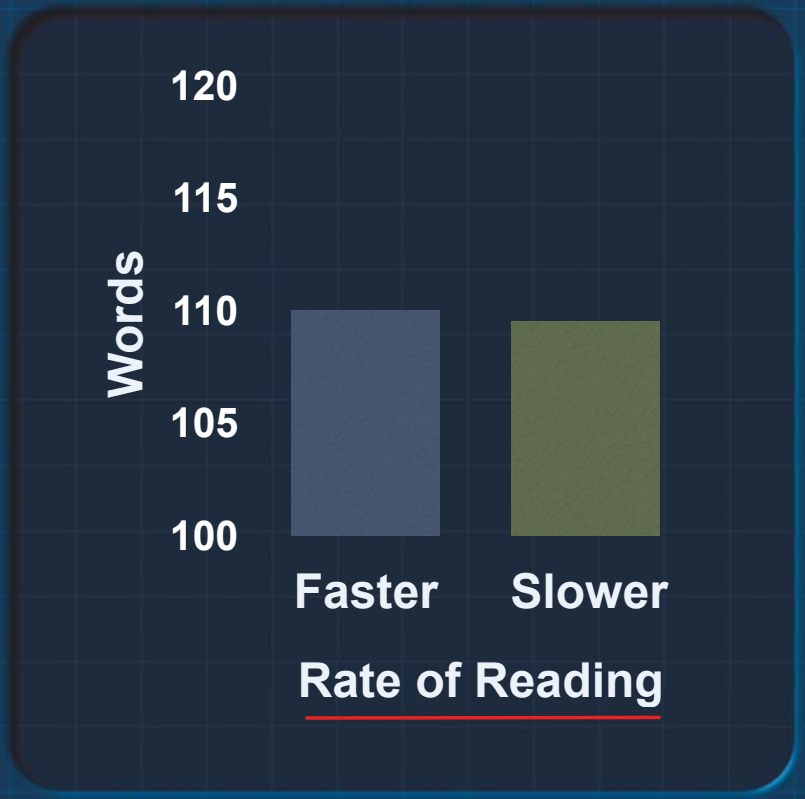
Groups have similar vocabularies and phonological skills

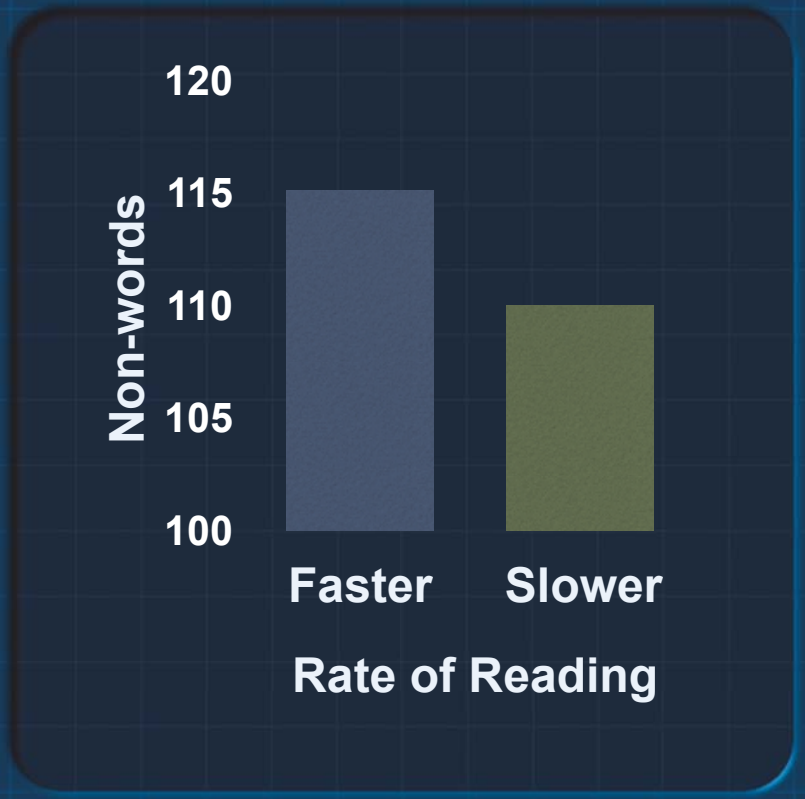




1. These results imply that reading speed is the primary reading measure impacted in this college sample.
2. Methods of measuring reading fluency is lacking.

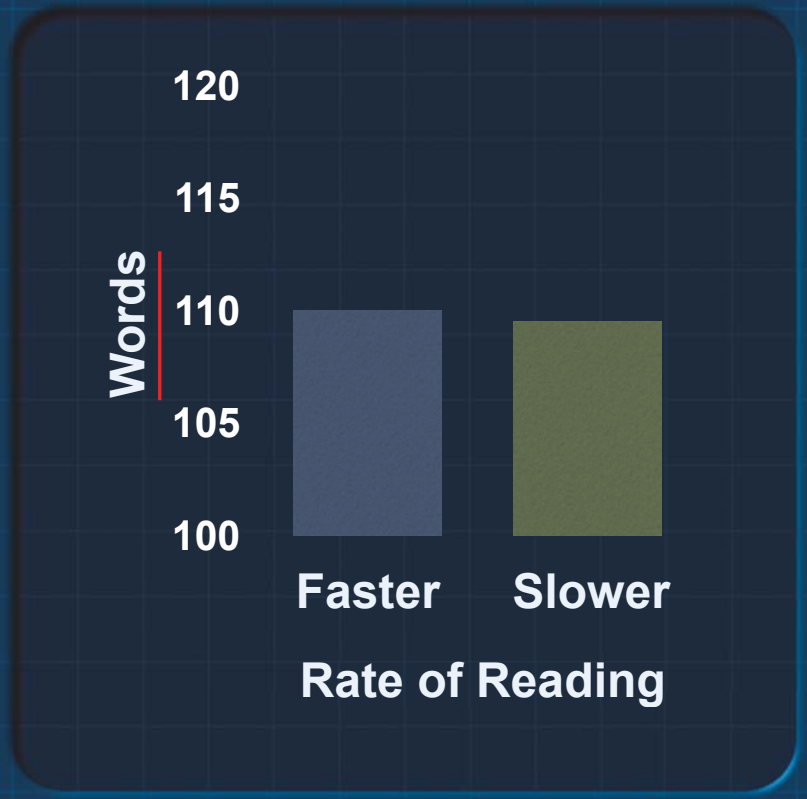
Groups have similar vocabularies and phonological skills

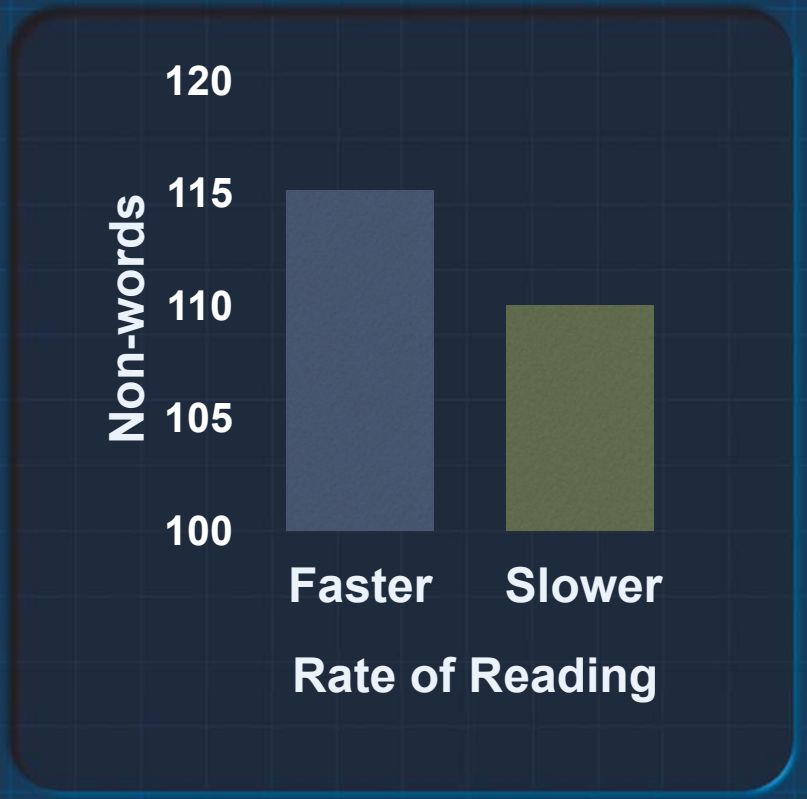




1. These results imply that reading speed is the primary reading measure impacted in this college sample.
2. Methods of measuring reading fluency is lacking.

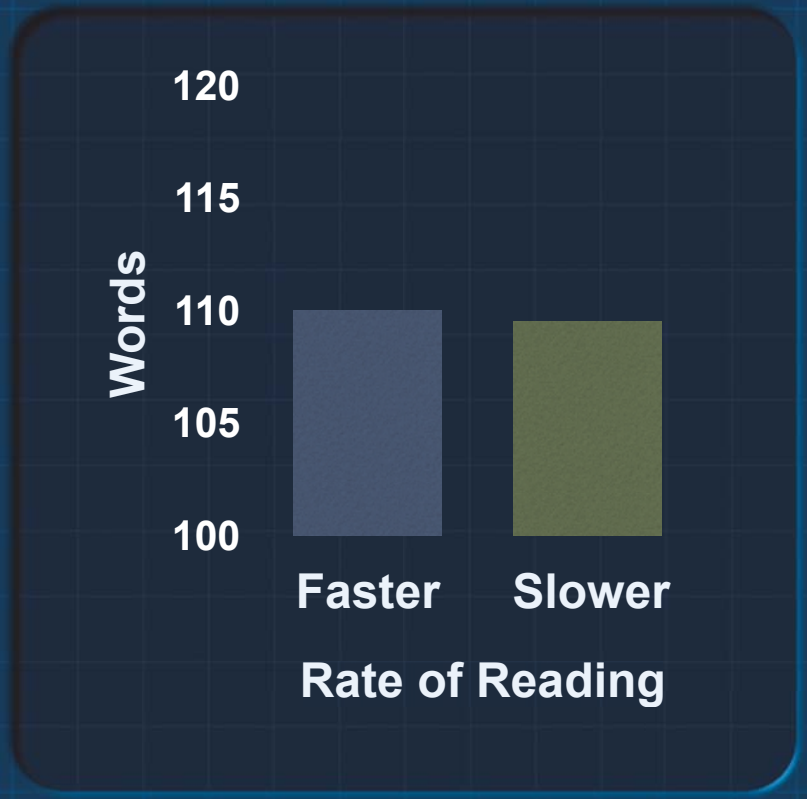
Groups have similar vocabularies and phonological skills

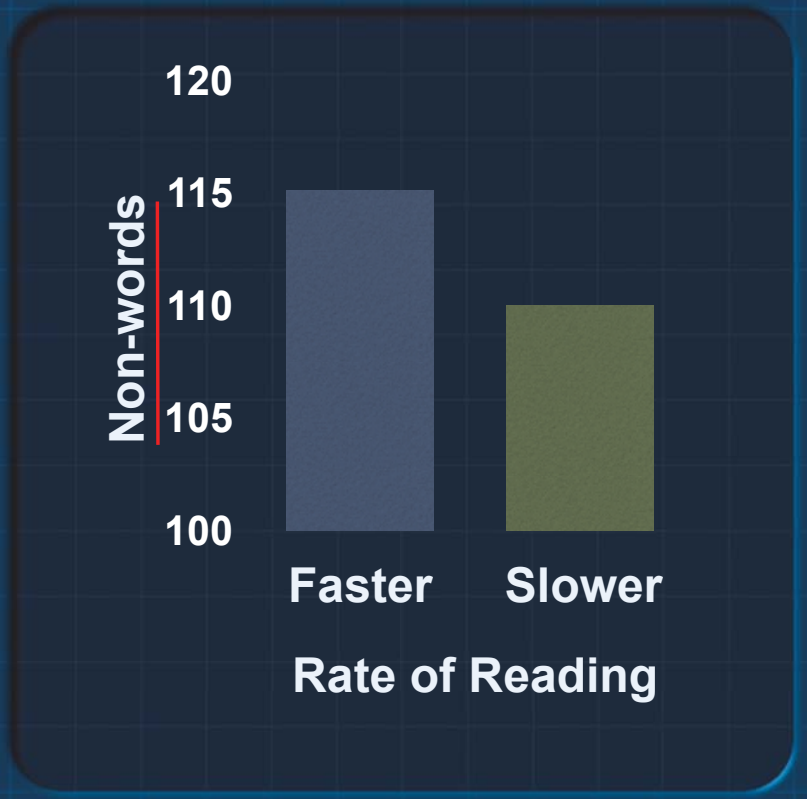




1. These results imply that reading speed is the primary reading measure impacted in this college sample.
2. Methods of measuring reading fluency is lacking.

Groups have similar vocabularies and phonological skills





1. These results imply that reading speed is the primary reading measure impacted in this college sample.
2. Methods of measuring reading fluency is lacking.

CITT-RS oral reading

Reading Error	Proportion
Substitution	45.2%
5-second Pause	0.0%
10-second Decoding	0.3%
Self-correction	18.0%
Addition	4.3%
Repetition	21.5%
Mispronunciation	4.9%
Skipping a line	0.2%
Omitting a word	5.5%

GORT 4
N=36

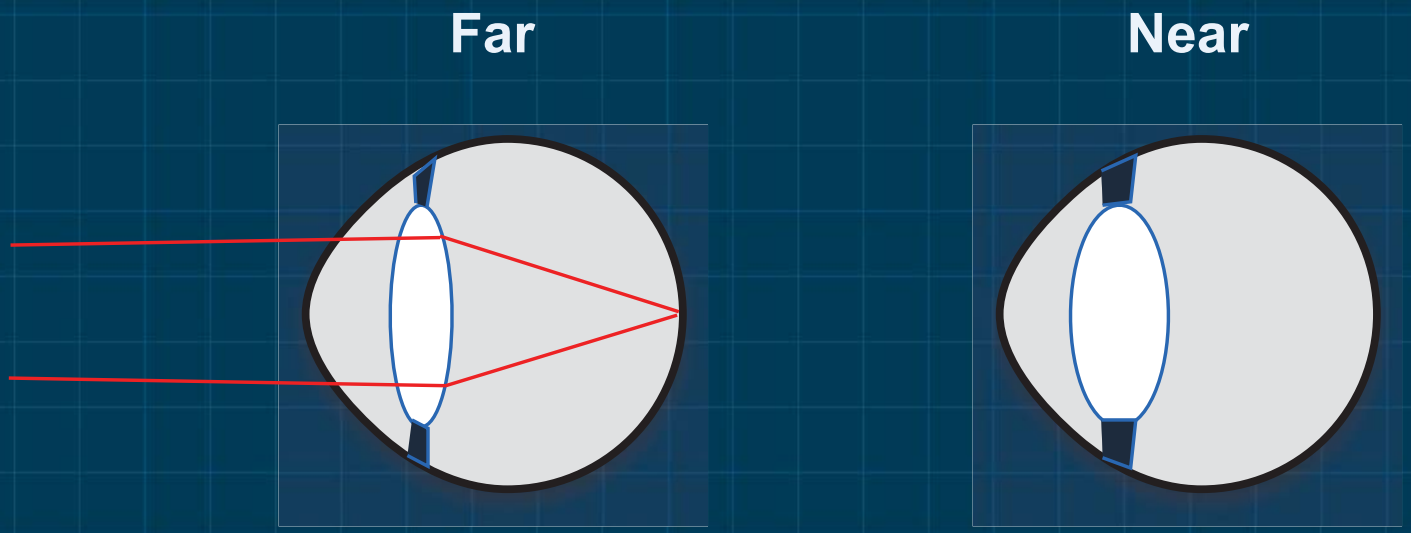
Eyestrain summary

- Common in college students, especially women.
- Headaches & blur more frequent; text distortions less common.
- Symptoms accumulate over 15-30 minutes.
- Impair reading speed, primarily through repetition errors.

Part 2: Accommodation

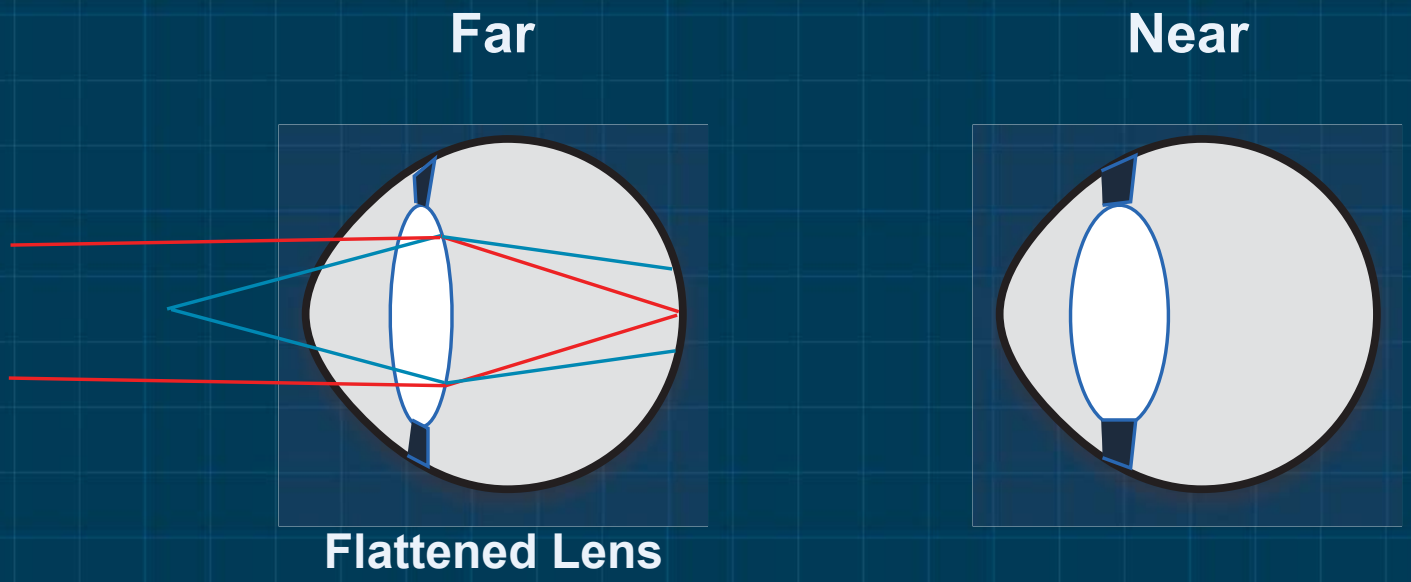
1. Accommodation weakness was a common problem control at near.

Part 2: Accommodation



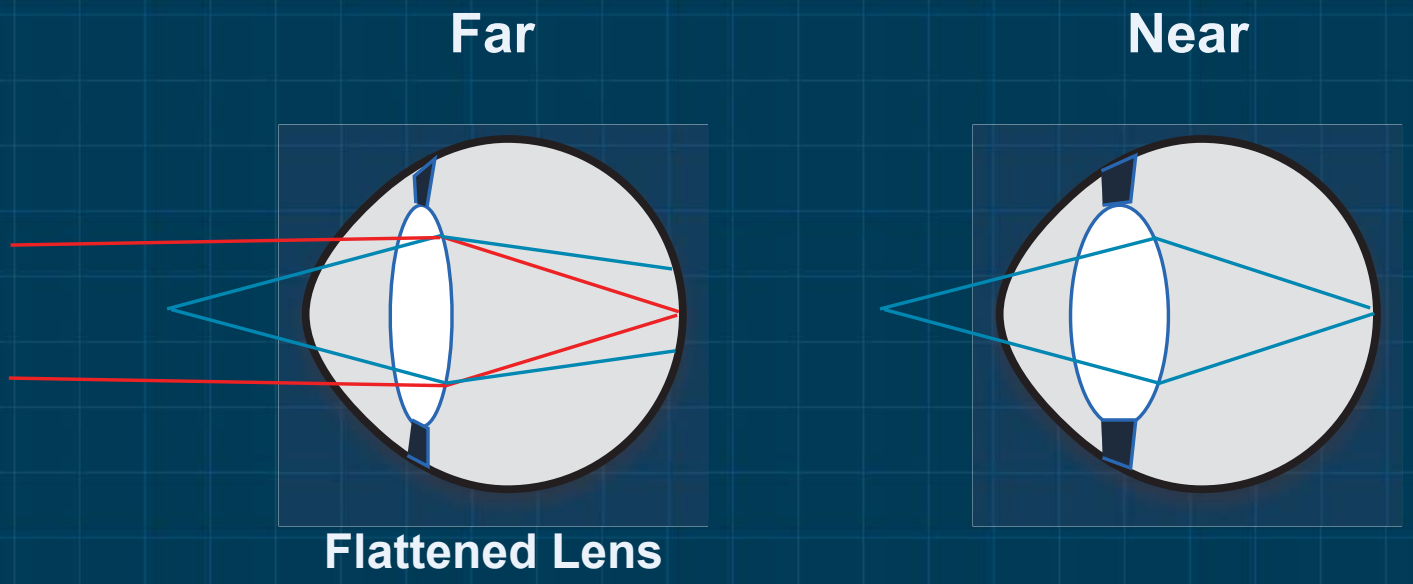
1. Accommodation weakness was a common problem control at near.

Part 2: Accommodation



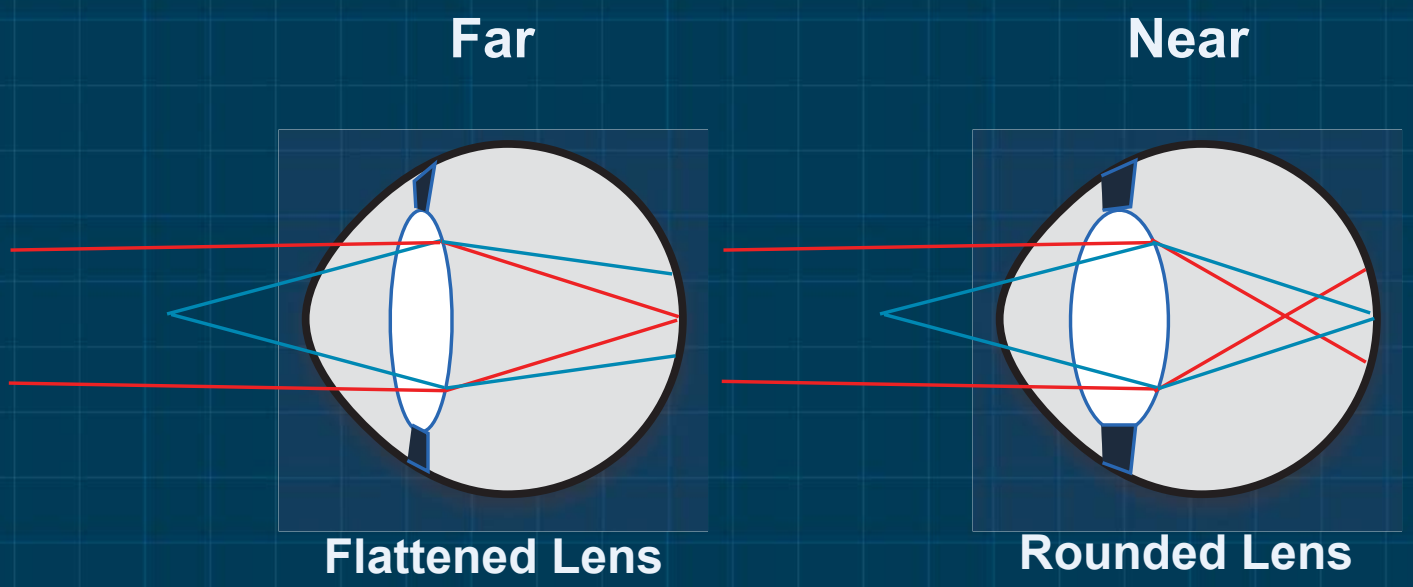
1. Accommodation weakness was a common problem control at near.

Part 2: Accommodation



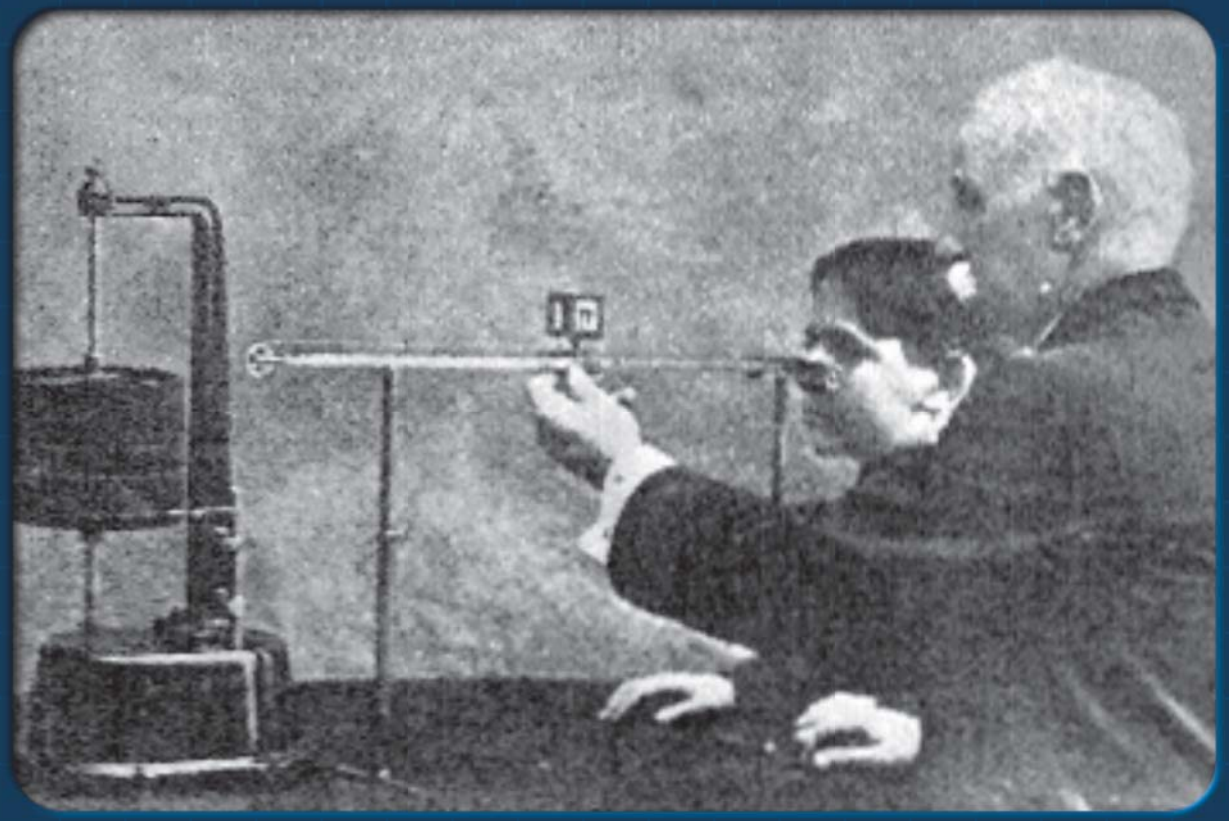
1. Accommodation weakness was a common problem control at near.

Part 2: Accommodation



1. Accommodation weakness was a common problem control at near.

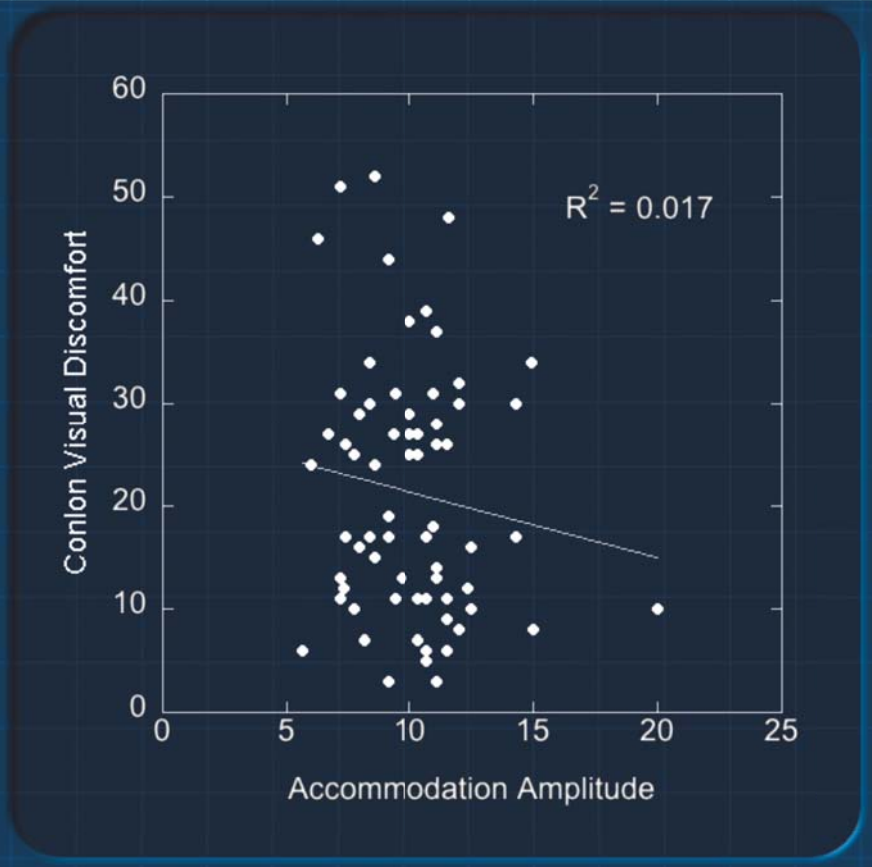
Hard to show accommodative dysfunction causes symptoms



From Berens & Stark 1932

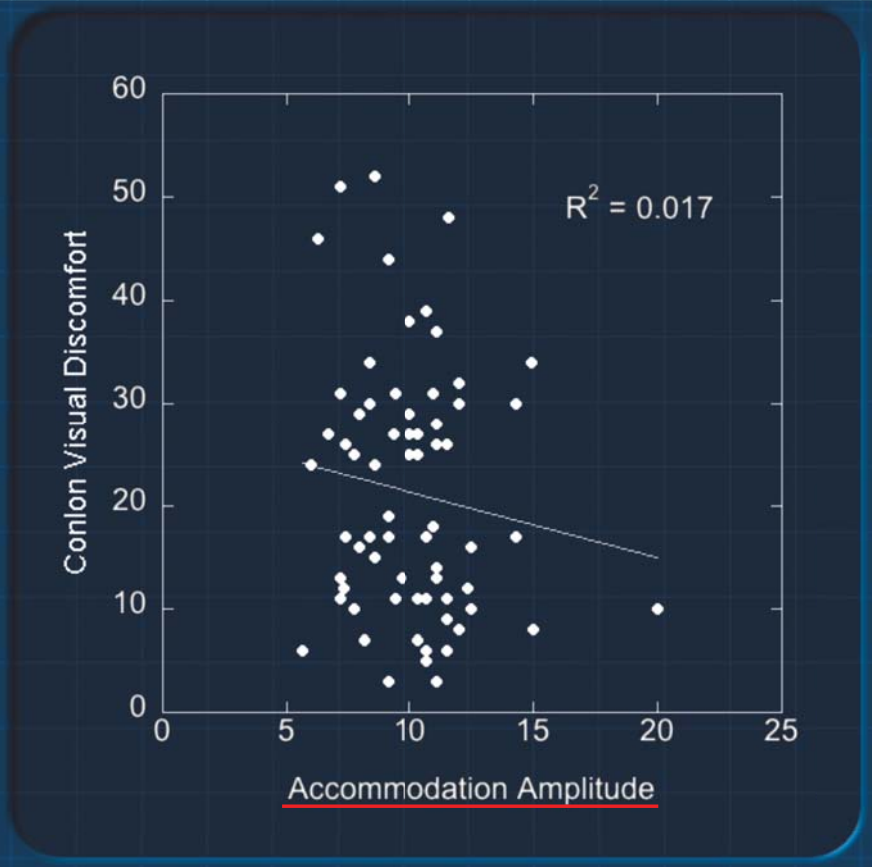
Lucien Howe - Buffalo, NY, Graduate of Bowdoin College, MD in 1871 at age of 22, Ophthalmologist at what was then the U of Buffalo, Built the first ergograph device for amplitude of accommodation (1912)

Accommodative amplitude is a poor predictor of symptoms



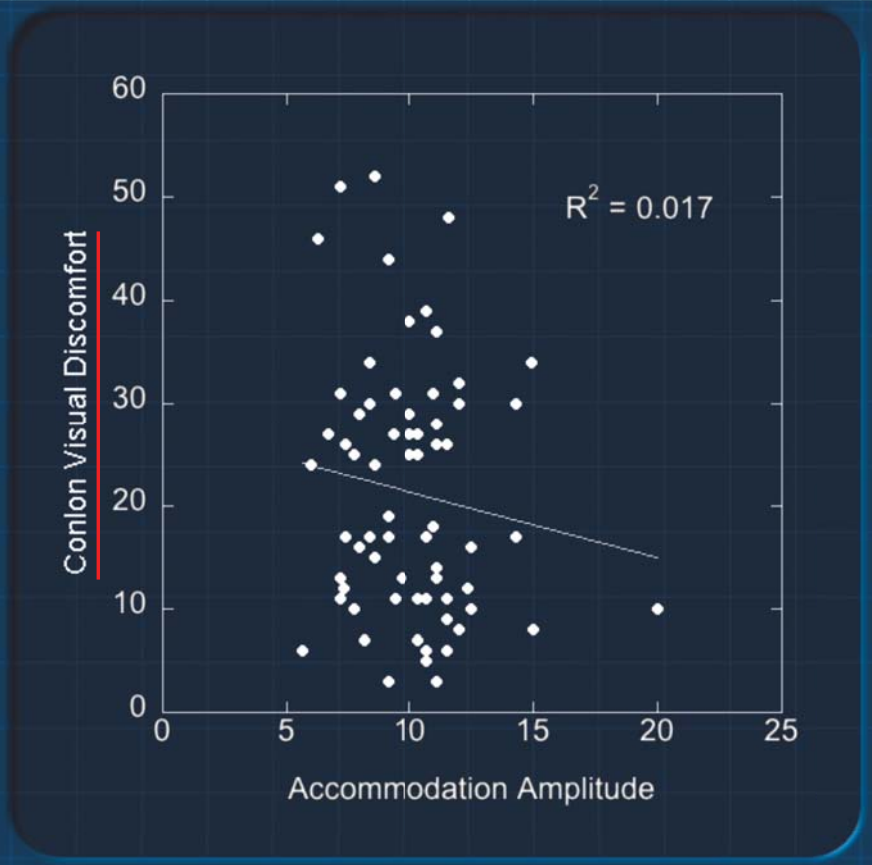
From Chase et al 2009

Accommodative amplitude is a poor predictor of symptoms



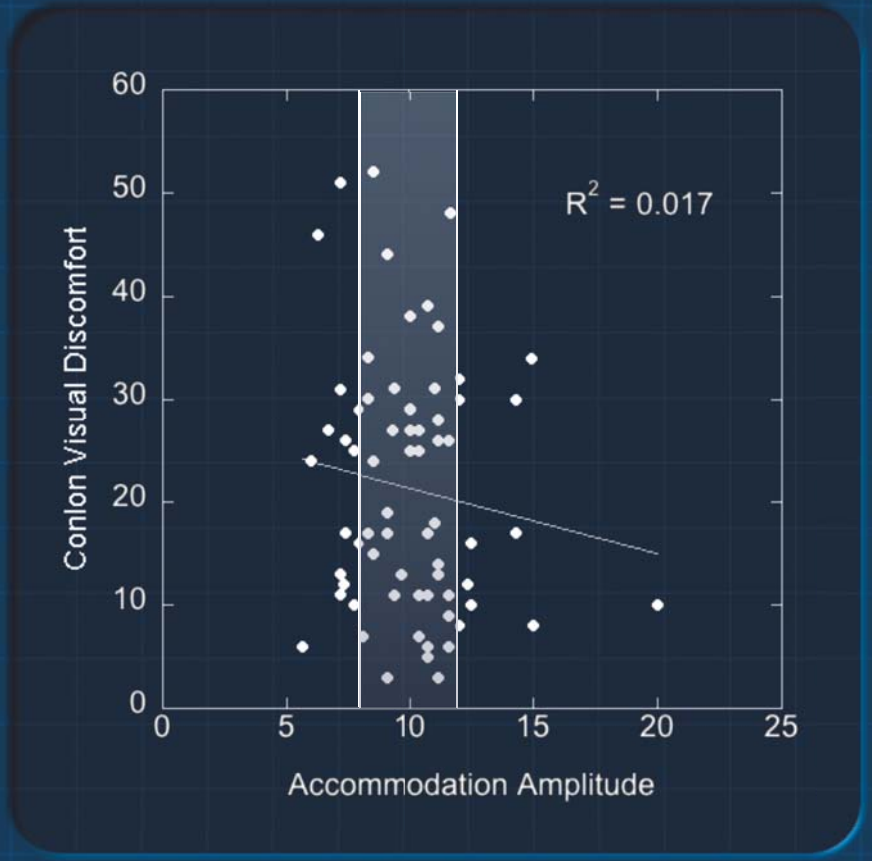
From Chase et al 2009

Accommodative amplitude is a poor predictor of symptoms



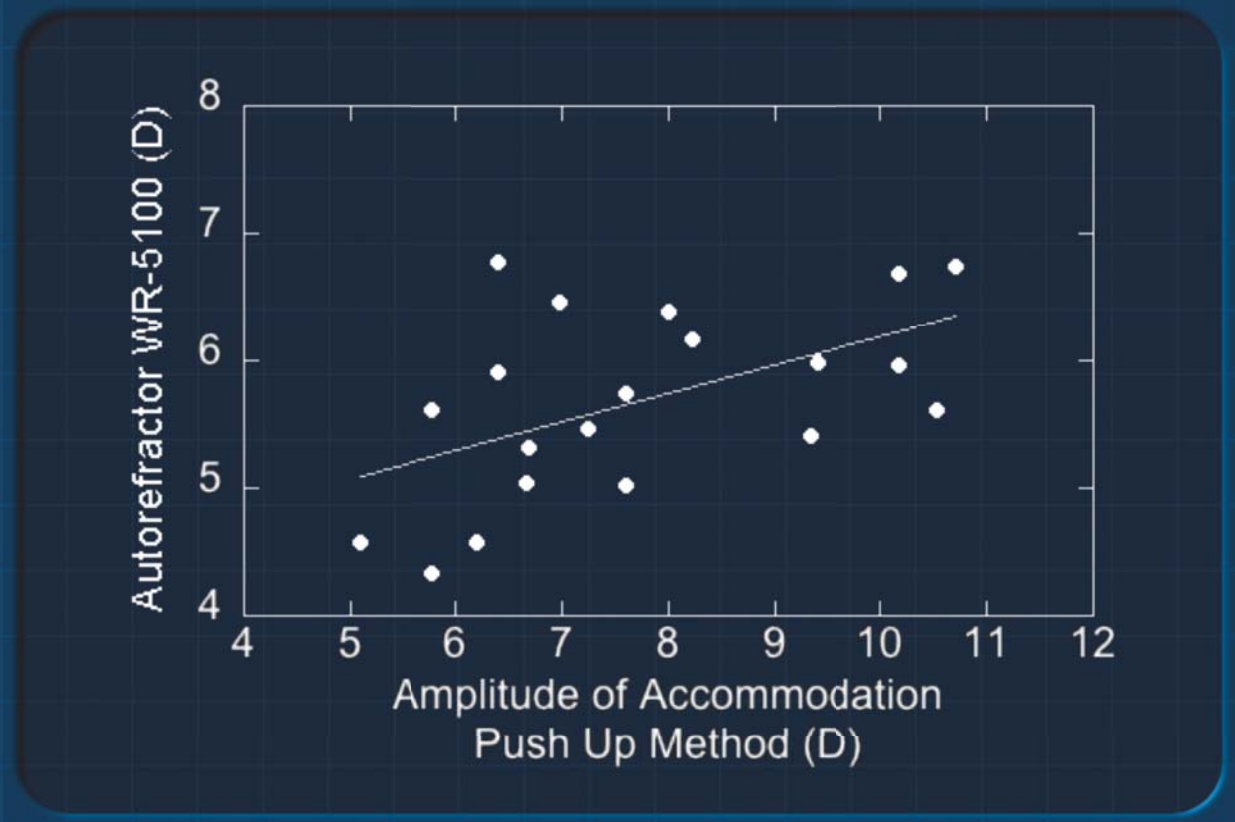
From Chase et al 2009

Accommodative amplitude is a poor predictor of symptoms



From Chase et al 2009

Clinical vs. Autorefraction



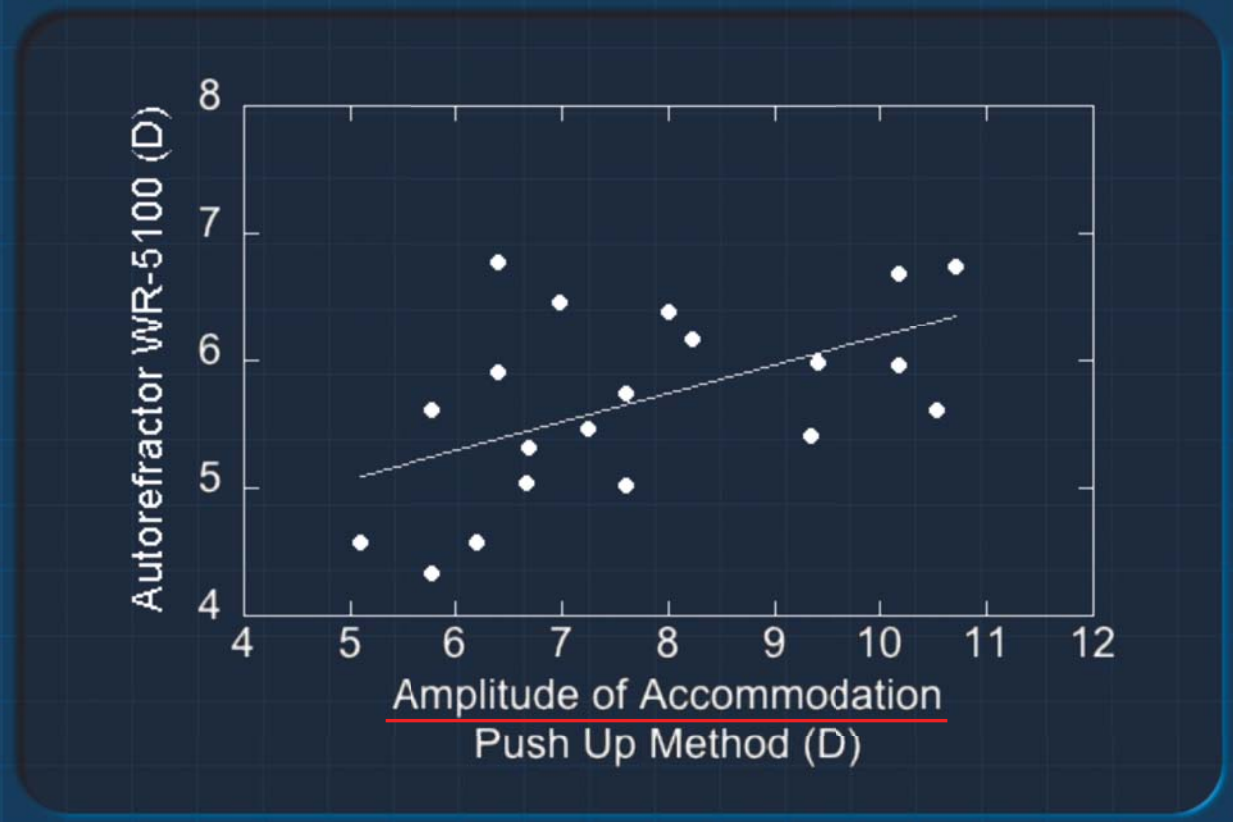
From Win-Hall et al. 2007

N=20. Ages 21-30. Positive but weak correlation (R2 = 0.28) between two measures of the same function.

Pushup (subjective) overestimates autorefractor (objective) by average of 2.1 D but as high as 5D. 95% overestimated amplitude by the push up method. Subjective judgment about the onset of blur. Blur detection is influenced by depth-of-field effects that are enhanced by accommodative pupil restriction; as the target is moved closer to the eye, the relative size of the target increases. An individual may still be able to identify the target even in the presence of a large defocus error.

Sustained viewing better than short measure lasting a few seconds. Can't measure fatigue by current clinical procedures.

Clinical vs. Autorefraction



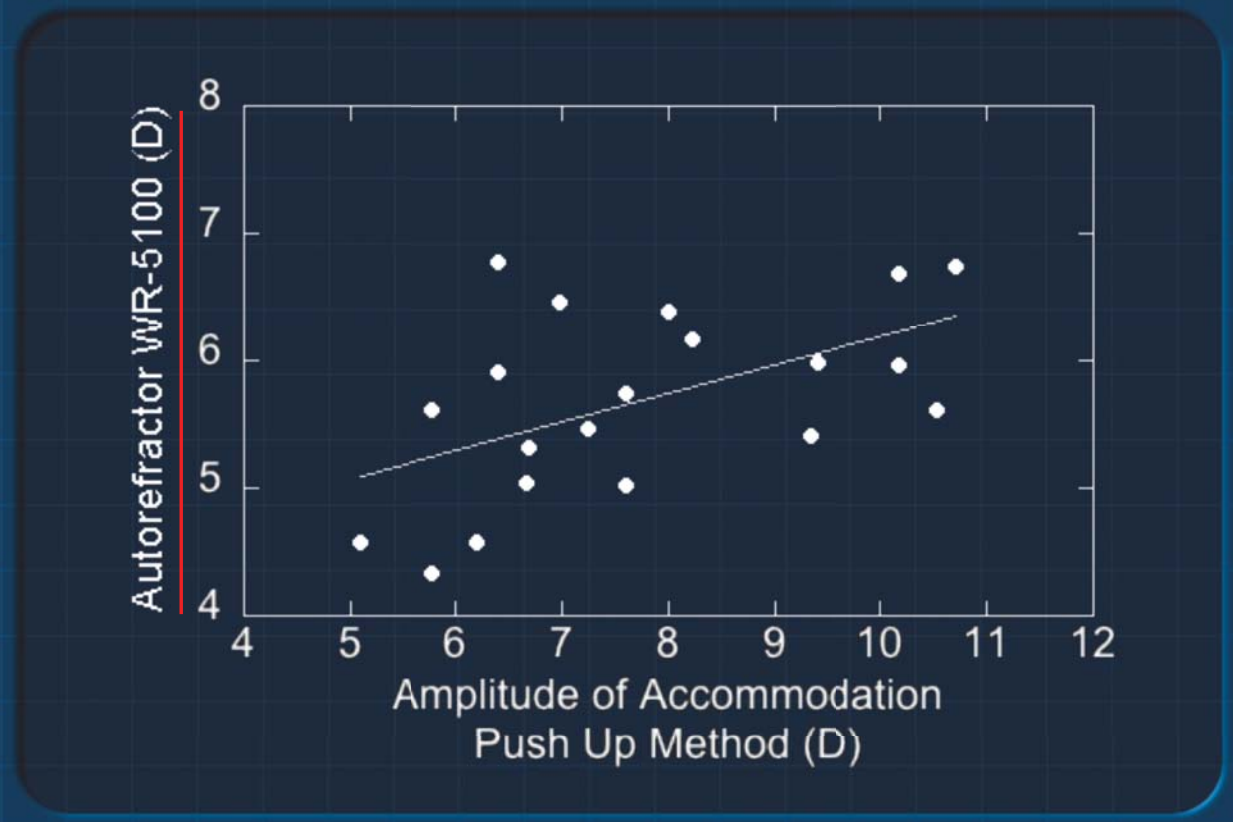
From Win-Hall et al. 2007

N=20. Ages 21-30. Positive but weak correlation (R2 = 0.28) between two measures of the same function.

Pushup (subjective) overestimates autorefractor (objective) by average of 2.1 D but as high as 5D. 95% overestimated amplitude by the push up method. Subjective judgment about the onset of blur. Blur detection is influenced by depth-of-field effects that are enhanced by accommodative pupil restriction; as the target is moved closer to the eye, the relative size of the target increases. An individual may still be able to identify the target even in the presence of a large defocus error.

Sustained viewing better than short measure lasting a few seconds. Can't measure fatigue by current clinical procedures.

Clinical vs. Autorefraction



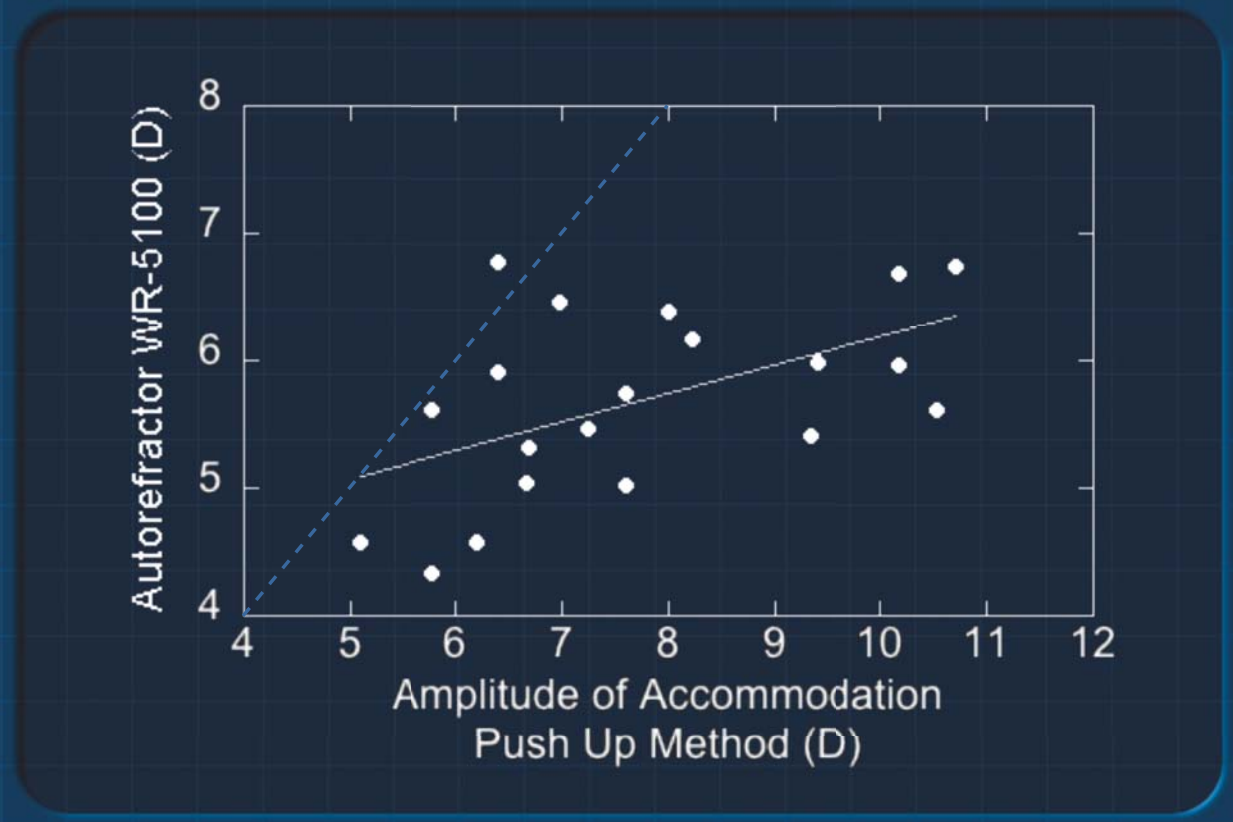
From Win-Hall et al. 2007

N=20. Ages 21-30. Positive but weak correlation (R2 = 0.28) between two measures of the same function.

Pushup (subjective) overestimates autorefractor (objective) by average of 2.1 D but as high as 5D. 95% overestimated amplitude by the push up method. Subjective judgment about the onset of blur. Blur detection is influenced by depth-of-field effects that are enhanced by accommodative pupil restriction; as the target is moved closer to the eye, the relative size of the target increases. An individual may still be able to identify the target even in the presence of a large defocus error.

Sustained viewing better than short measure lasting a few seconds. Can't measure fatigue by current clinical procedures.

Clinical vs. Autorefraction



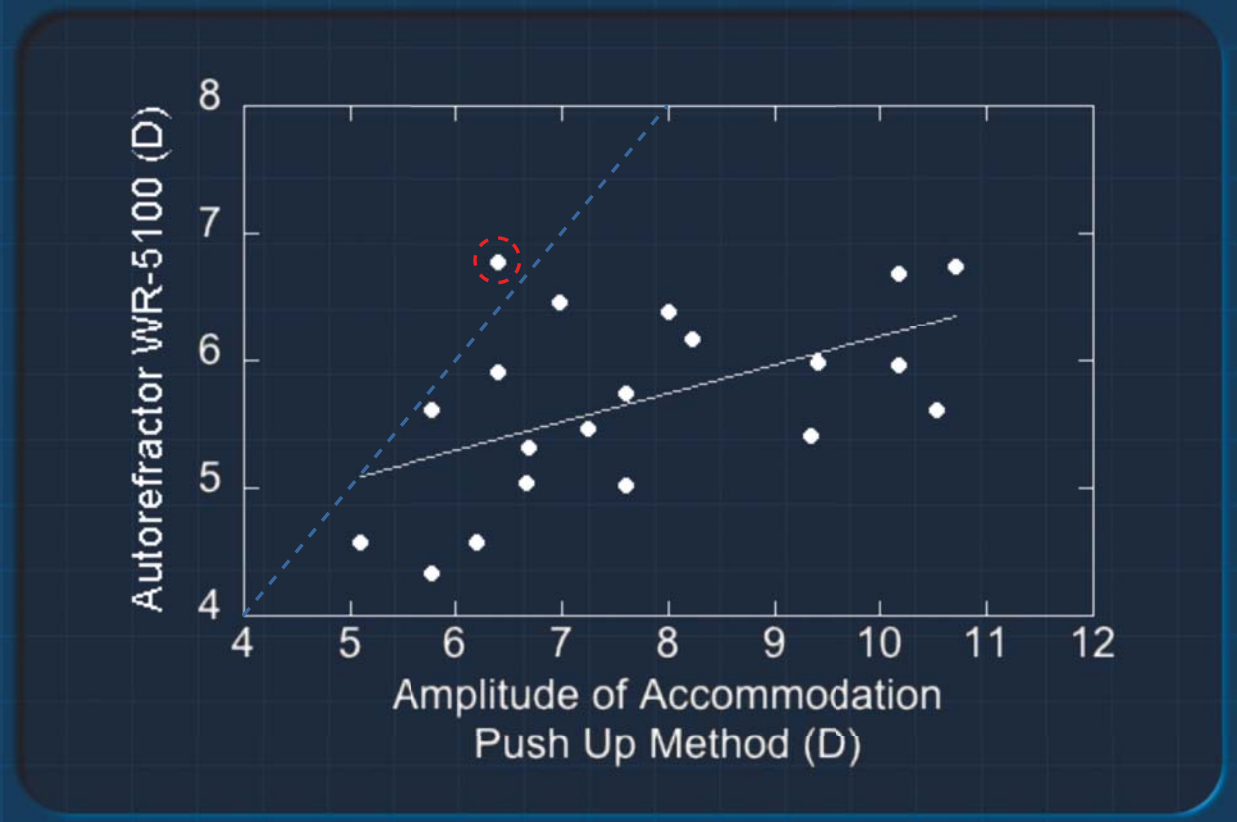
From Win-Hall et al. 2007

N=20. Ages 21-30. Positive but weak correlation (R2 = 0.28) between two measures of the same function.

Pushup (subjective) overestimates autorefractor (objective) by average of 2.1 D but as high as 5D. 95% overestimated amplitude by the push up method. Subjective judgment about the onset of blur. Blur detection is influenced by depth-of-field effects that are enhanced by accommodative pupil restriction; as the target is moved closer to the eye, the relative size of the target increases. An individual may still be able to identify the target even in the presence of a large defocus error.

Sustained viewing better than short measure lasting a few seconds. Can't measure fatigue by current clinical procedures.

Clinical vs. Autorefraction



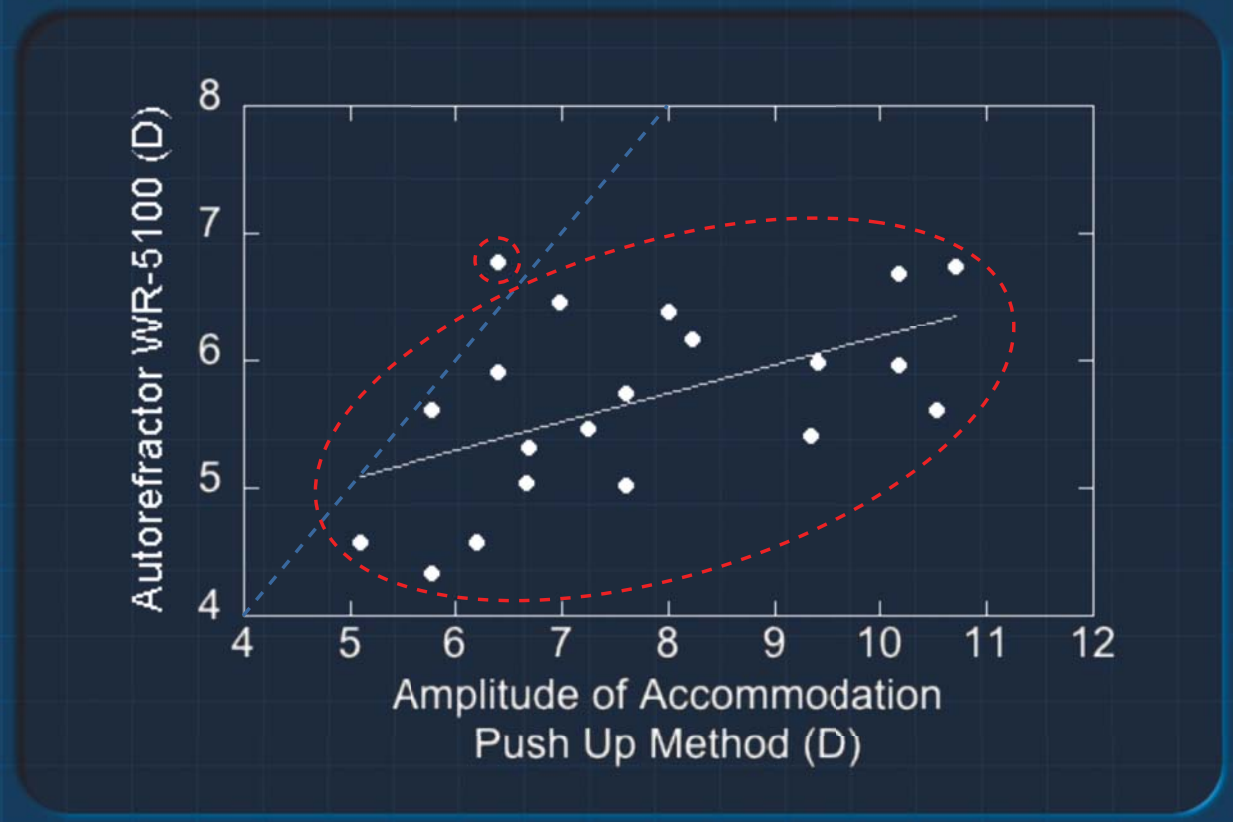
From Win-Hall et al. 2007

N=20. Ages 21-30. Positive but weak correlation (R2 = 0.28) between two measures of the same function.

Pushup (subjective) overestimates autorefractor (objective) by average of 2.1 D but as high as 5D. 95% overestimated amplitude by the push up method. Subjective judgment about the onset of blur. Blur detection is influenced by depth-of-field effects that are enhanced by accommodative pupil restriction; as the target is moved closer to the eye, the relative size of the target increases. An individual may still be able to identify the target even in the presence of a large defocus error.

Sustained viewing better than short measure lasting a few seconds. Can't measure fatigue by current clinical procedures.

Clinical vs. Autorefraction



From Win-Hall et al. 2007

N=20. Ages 21-30. Positive but weak correlation (R2 = 0.28) between two measures of the same function.

Pushup (subjective) overestimates autorefractor (objective) by average of 2.1 D but as high as 5D. 95% overestimated amplitude by the push up method. Subjective judgment about the onset of blur. Blur detection is influenced by depth-of-field effects that are enhanced by accommodative pupil restriction; as the target is moved closer to the eye, the relative size of the target increases. An individual may still be able to identify the target even in the presence of a large defocus error.

Sustained viewing better than short measure lasting a few seconds. Can't measure fatigue by current clinical procedures.

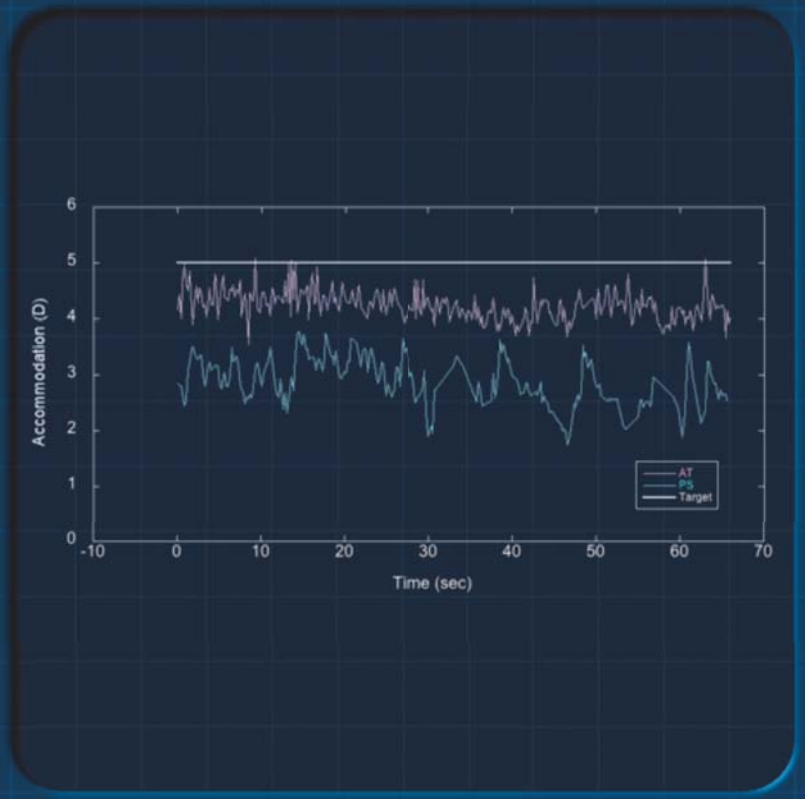

Grand Seiko Co.,Ltd.
AIT
CONY
SOCCER
FAR
SE-R
SE-L
P.Diam
PRINT
MODE
ACOM
IOL
Seiko Co.,Ltd.

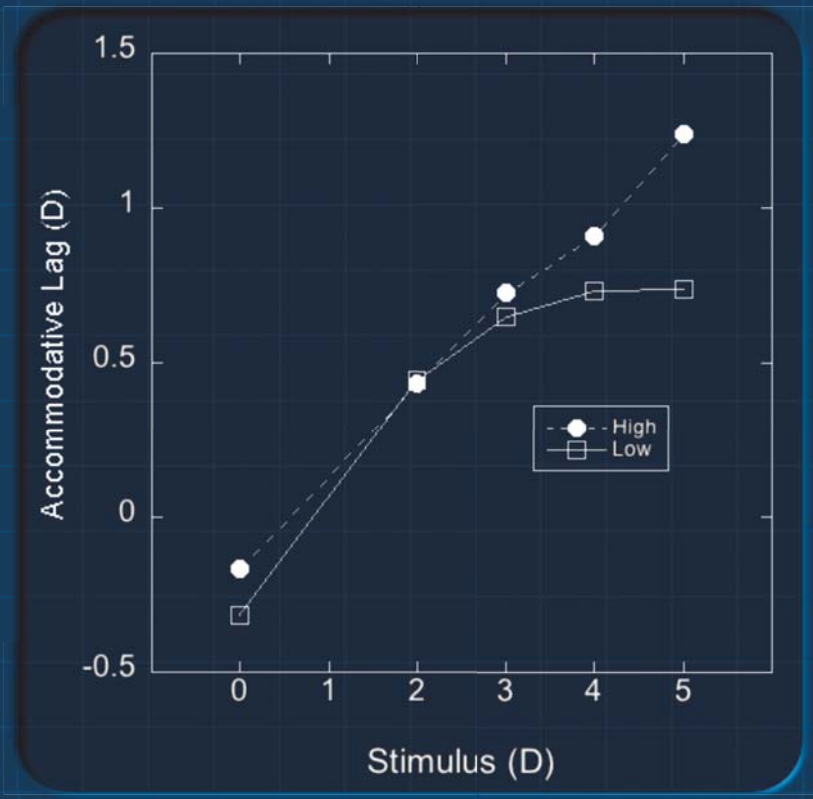
Autorefraction

- Open field
- Image-size Design
  - Analyzes IR ring projected onto retina
  - Myopic change increases diameter
  - Astigmatic change distorts shape elliptically
- Continuous recording

Monocular recordings to isolate accommodative function

Accommodation insufficiency is common in college students





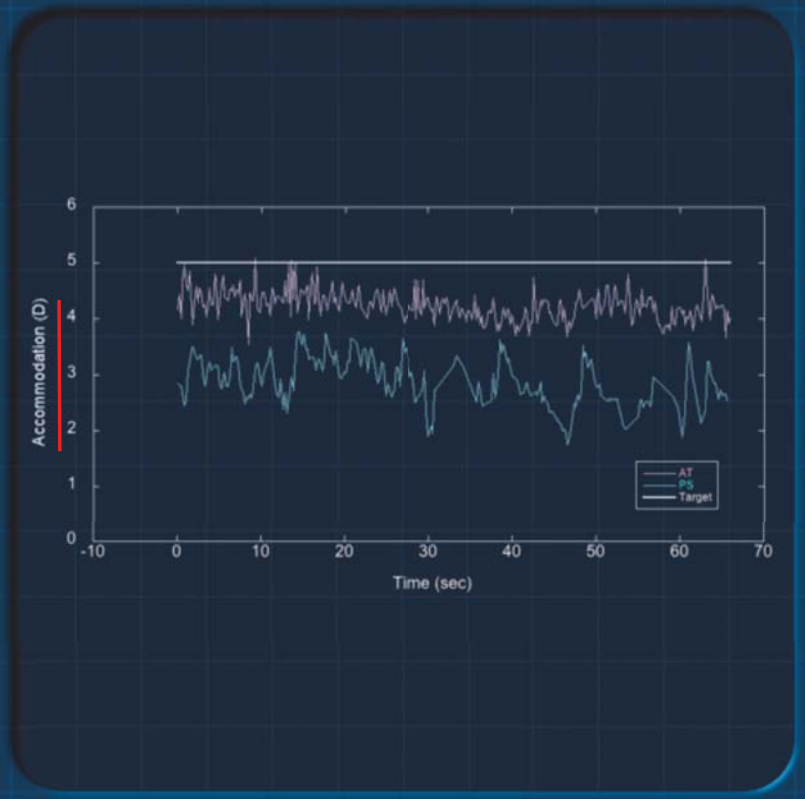
From Chase et al 2009

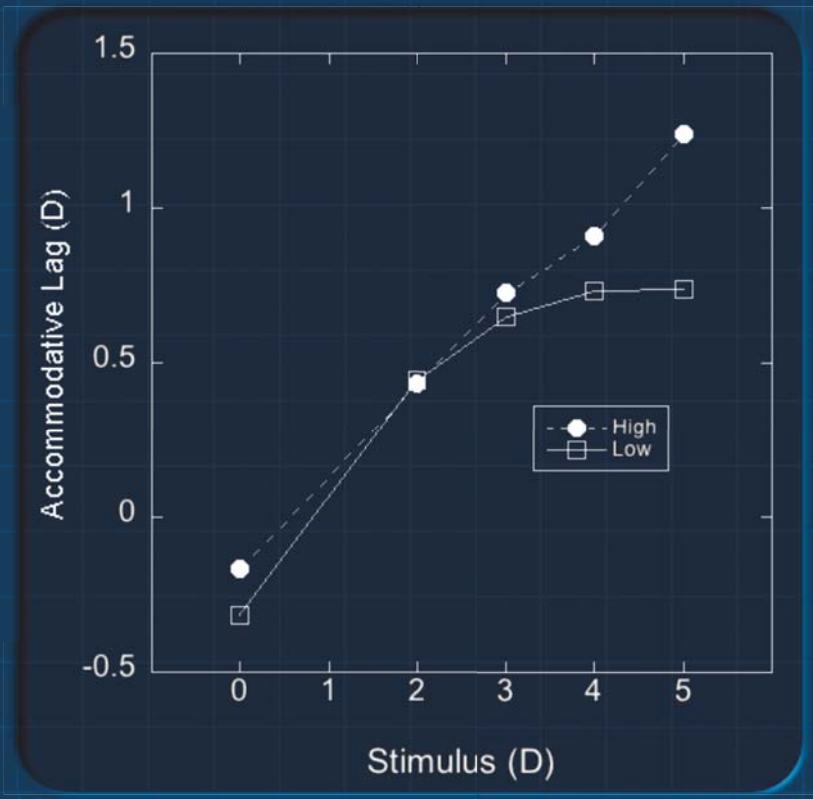
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





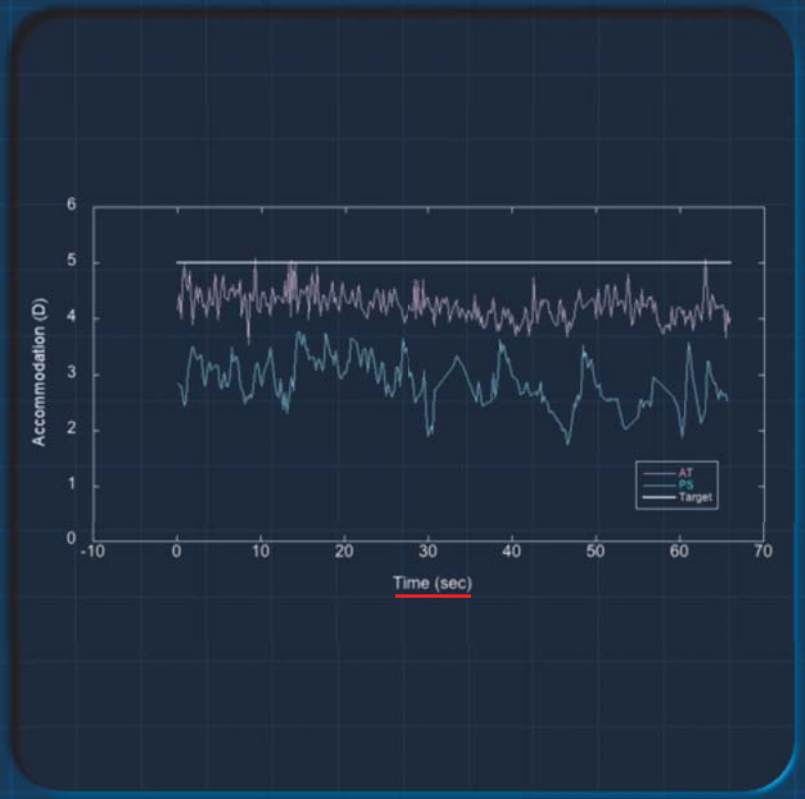
From Chase et al 2009

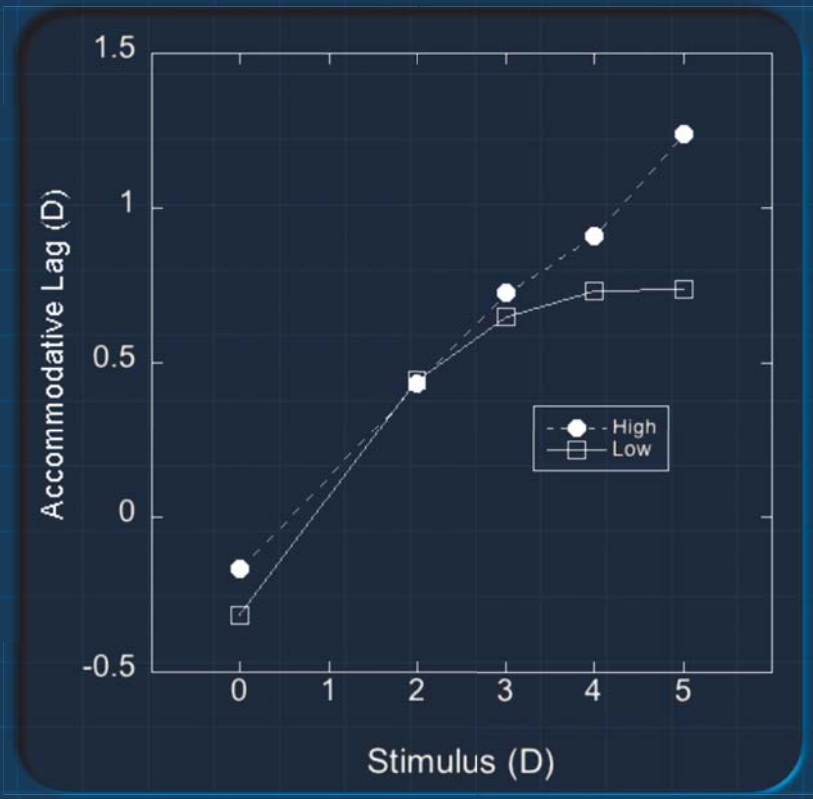
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





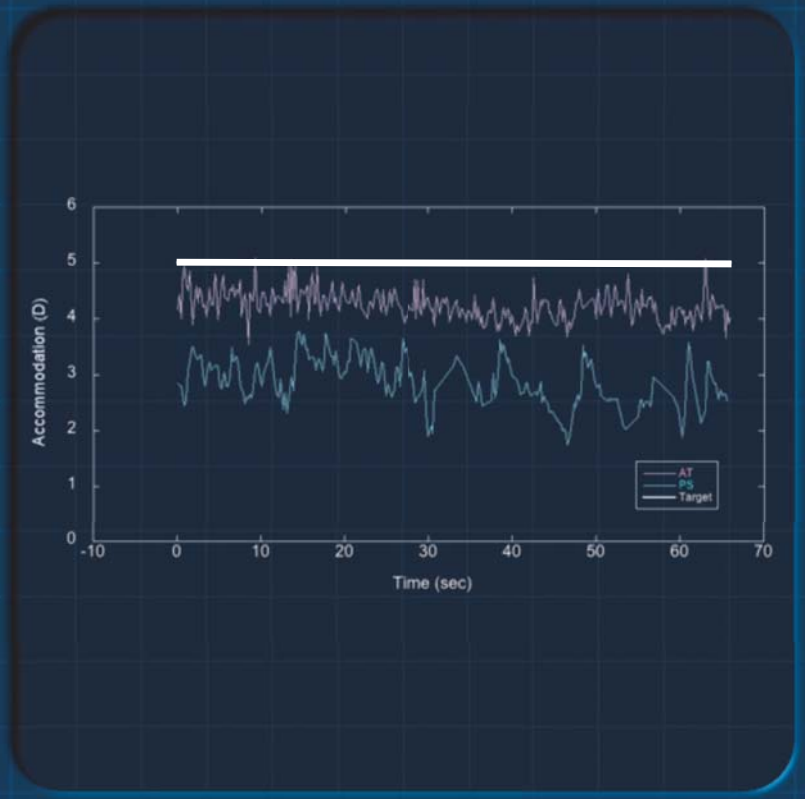
From Chase et al 2009

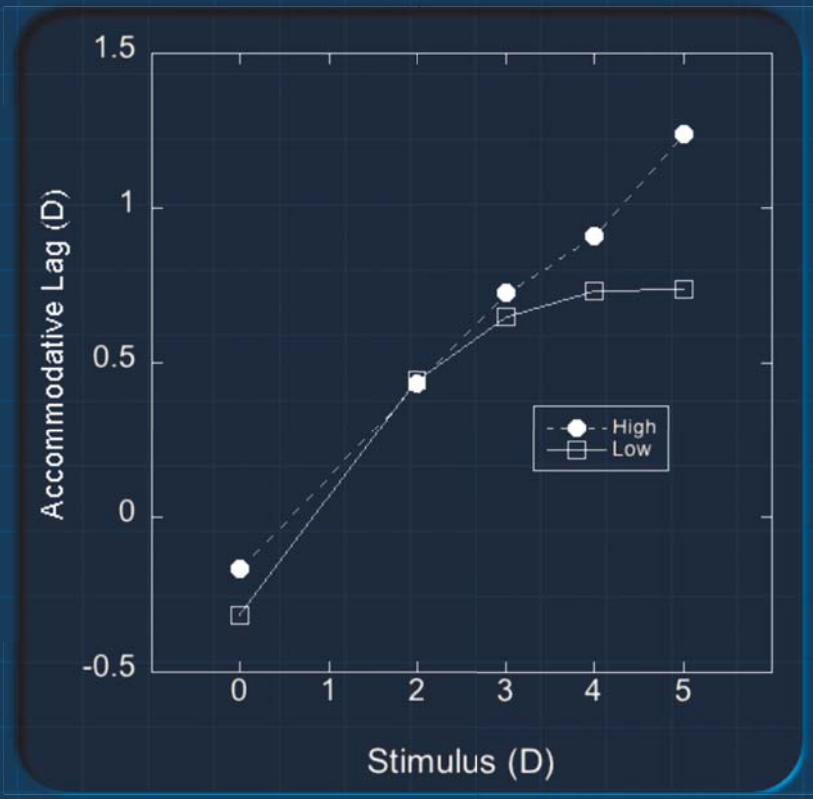
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





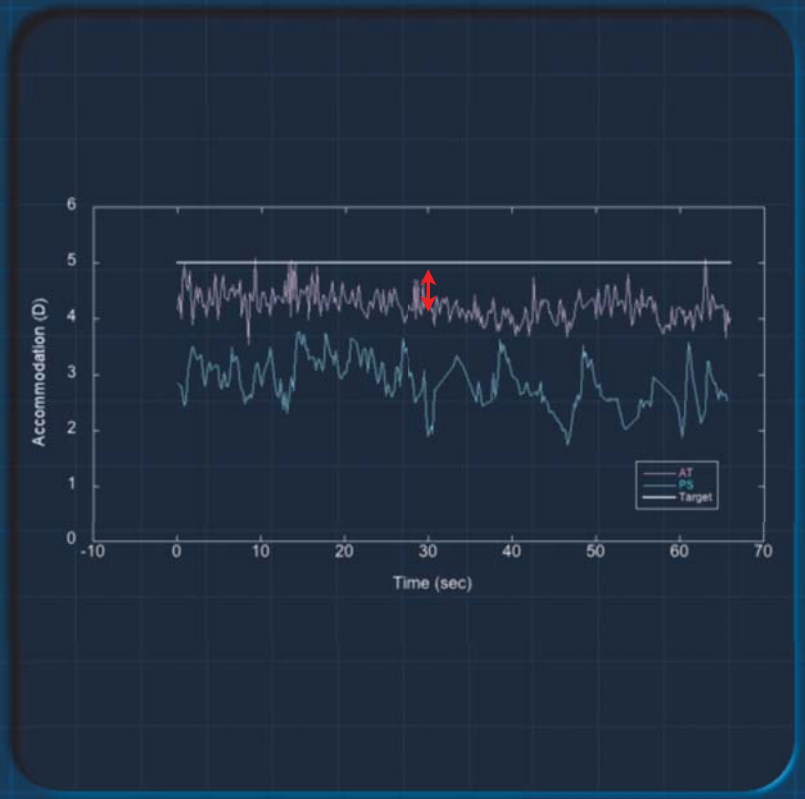
From Chase et al 2009

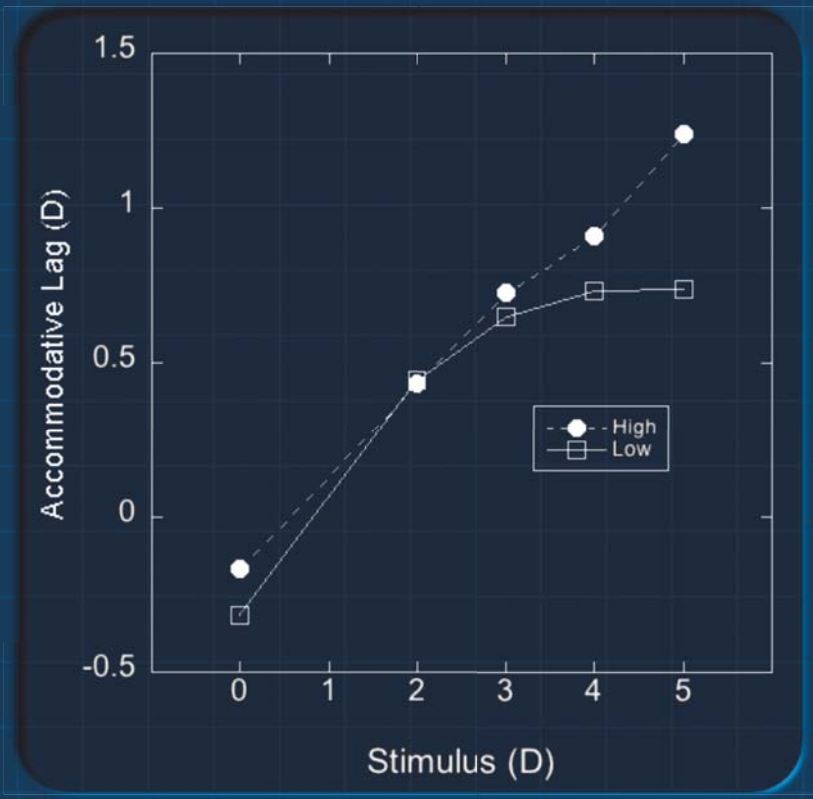
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





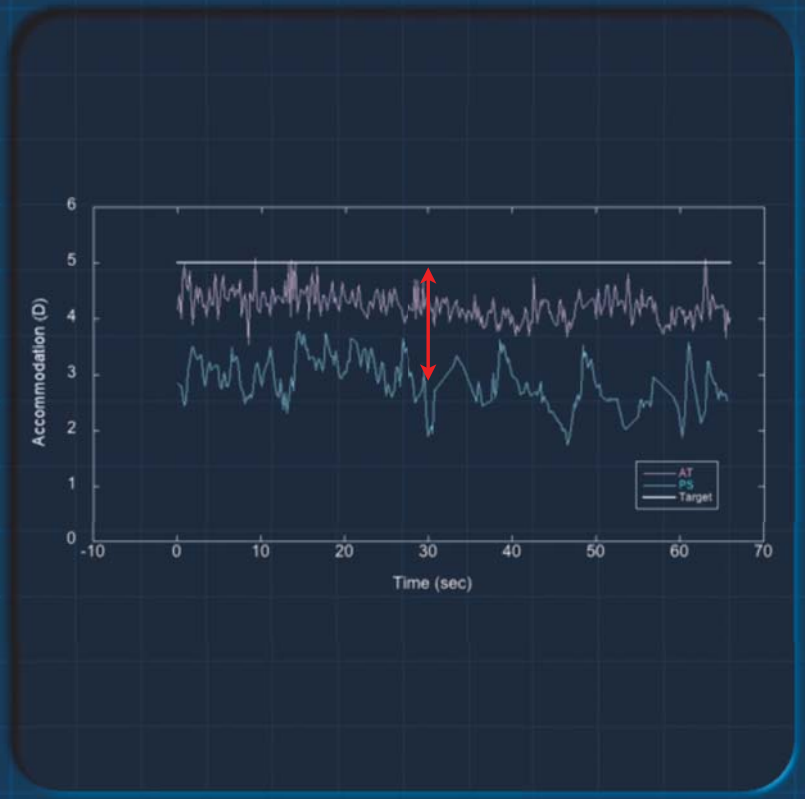
From Chase et al 2009

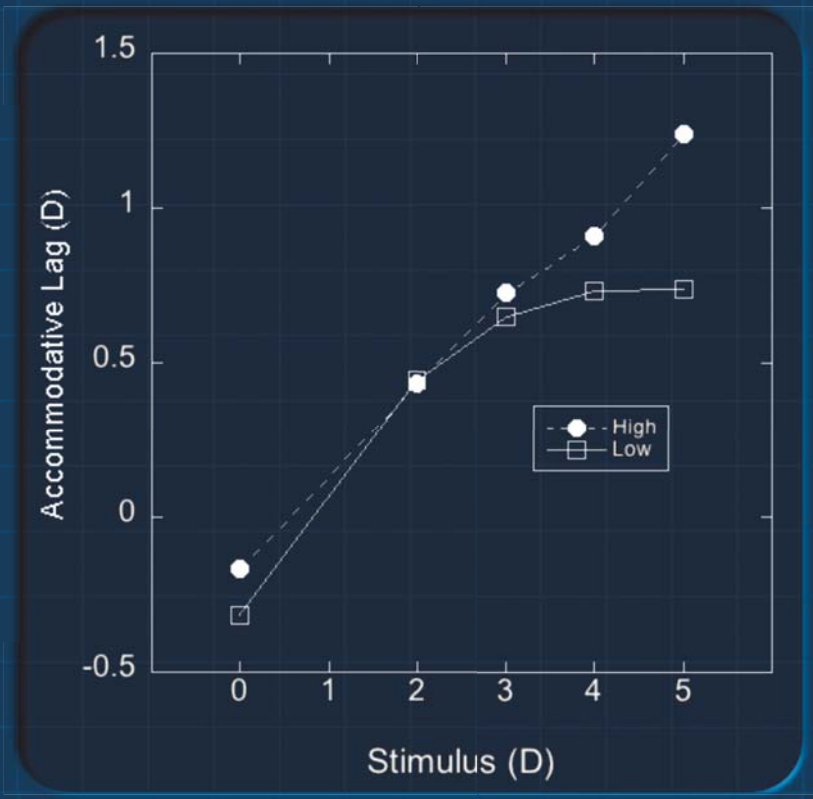
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





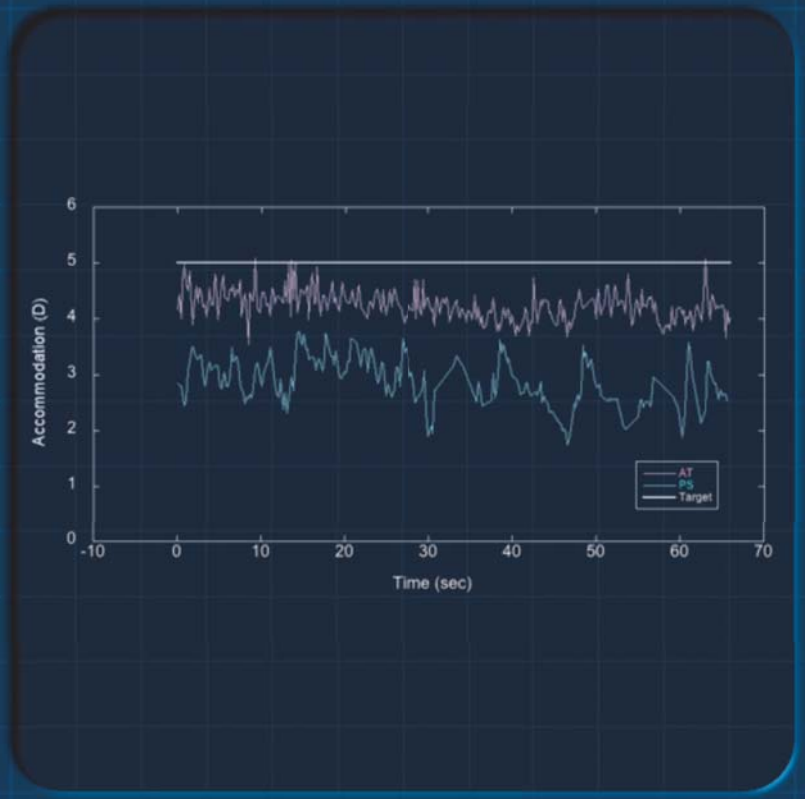
From Chase et al 2009

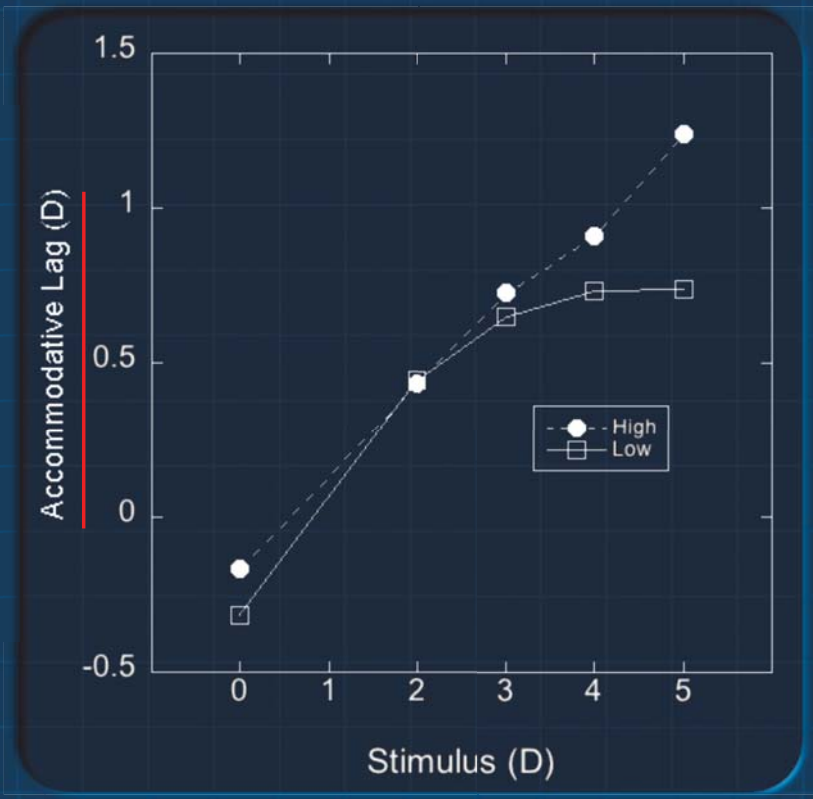
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





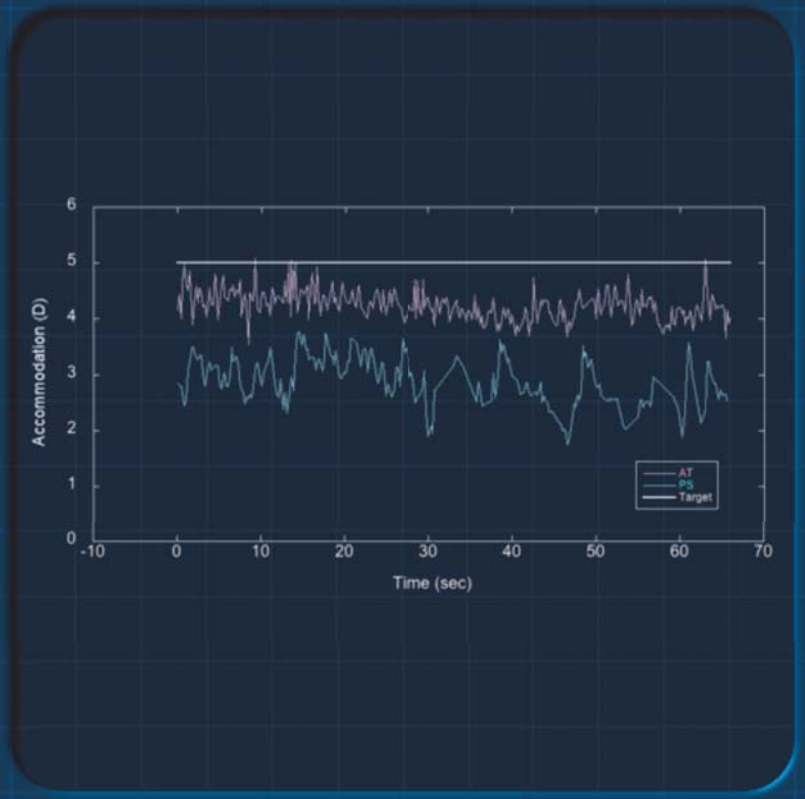
From Chase et al 2009

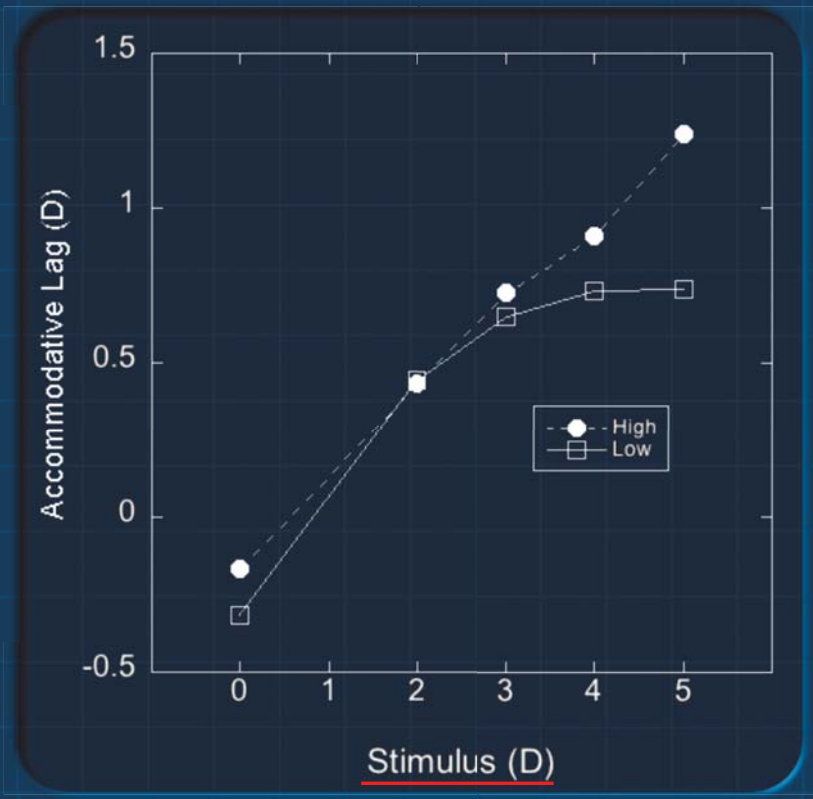
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





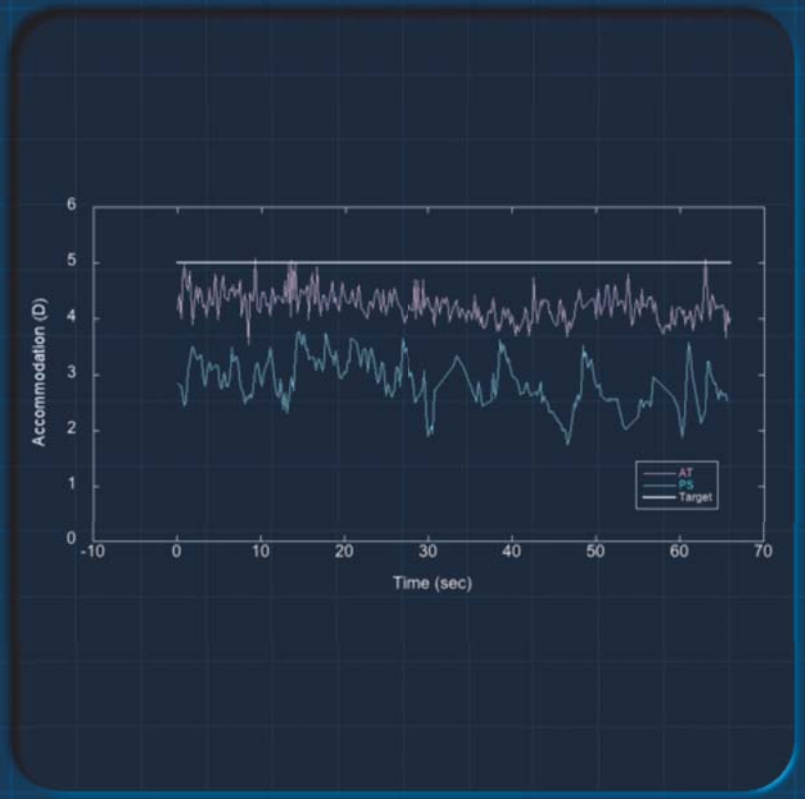
From Chase et al 2009

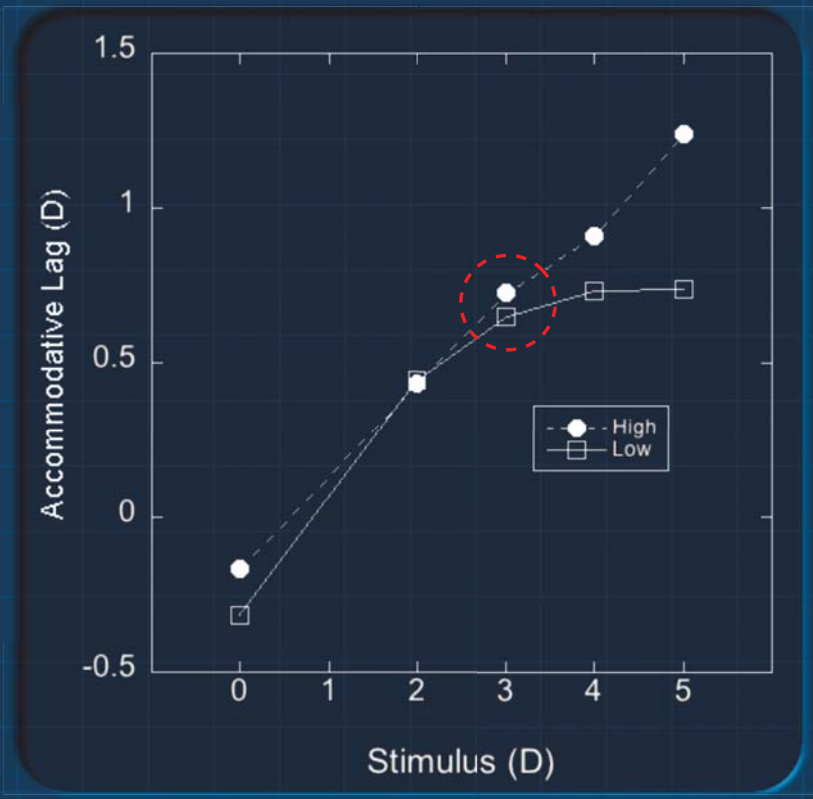
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





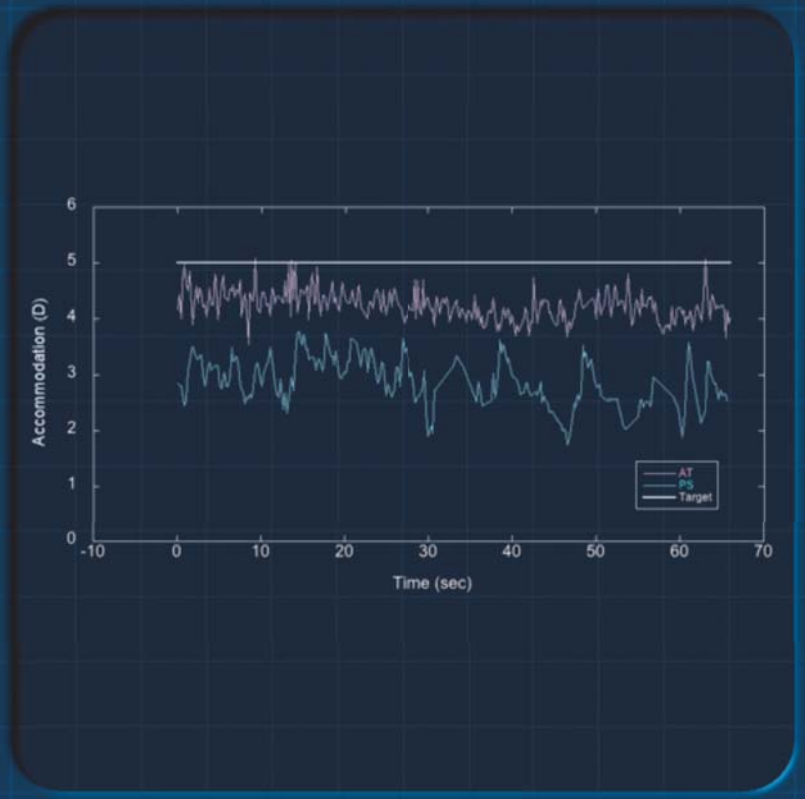
From Chase et al 2009

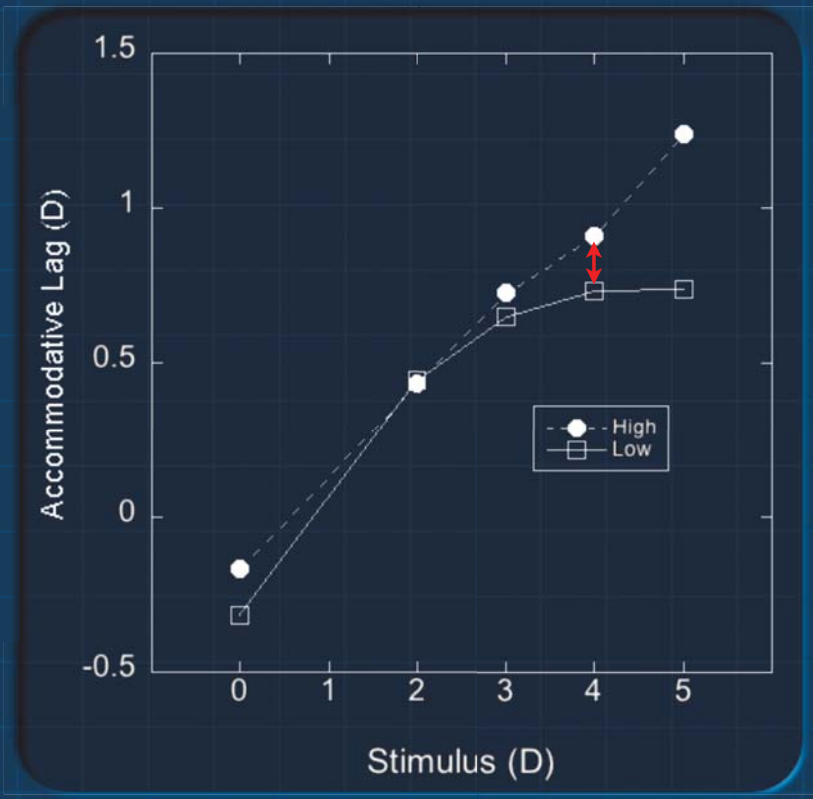
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





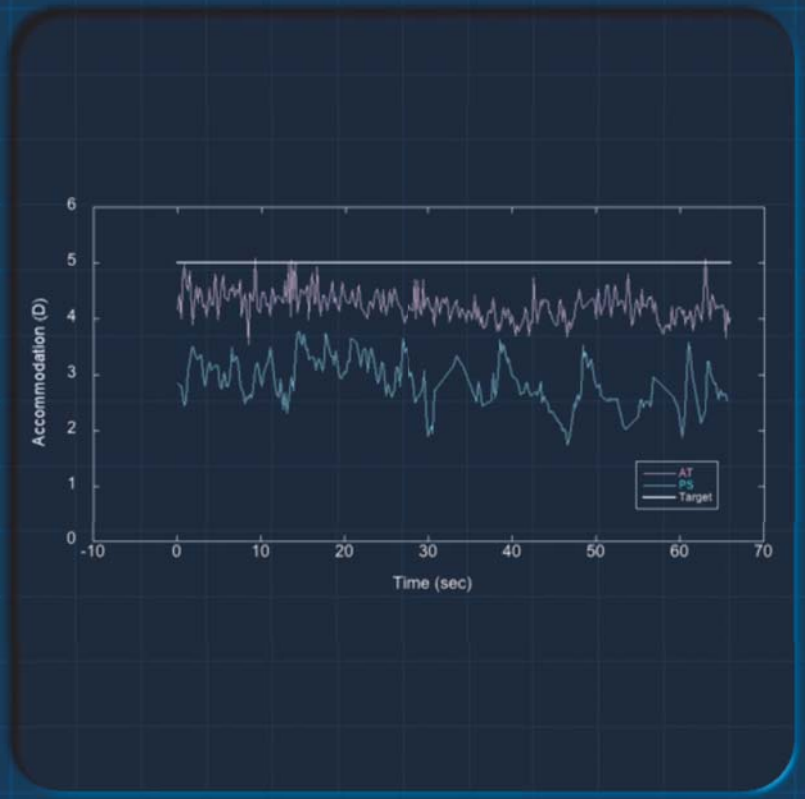
From Chase et al 2009

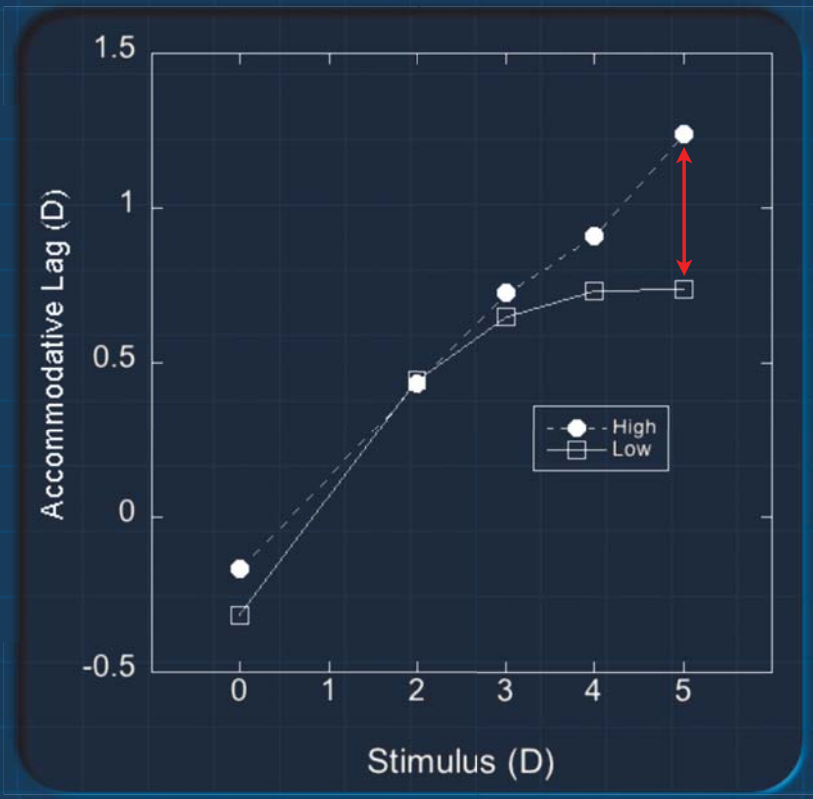
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation insufficiency is common in college students





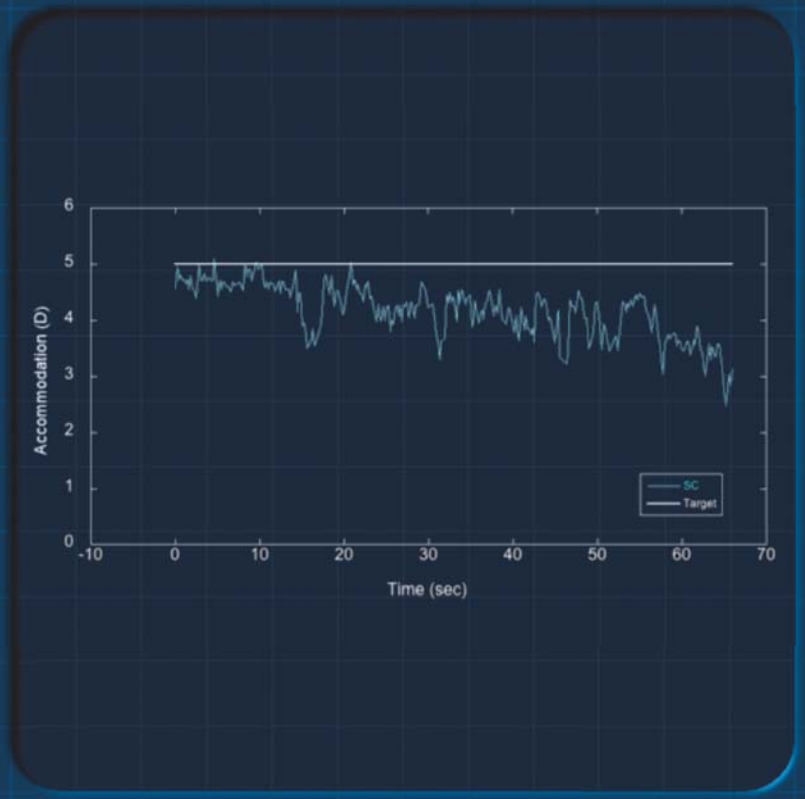
From Chase et al 2009

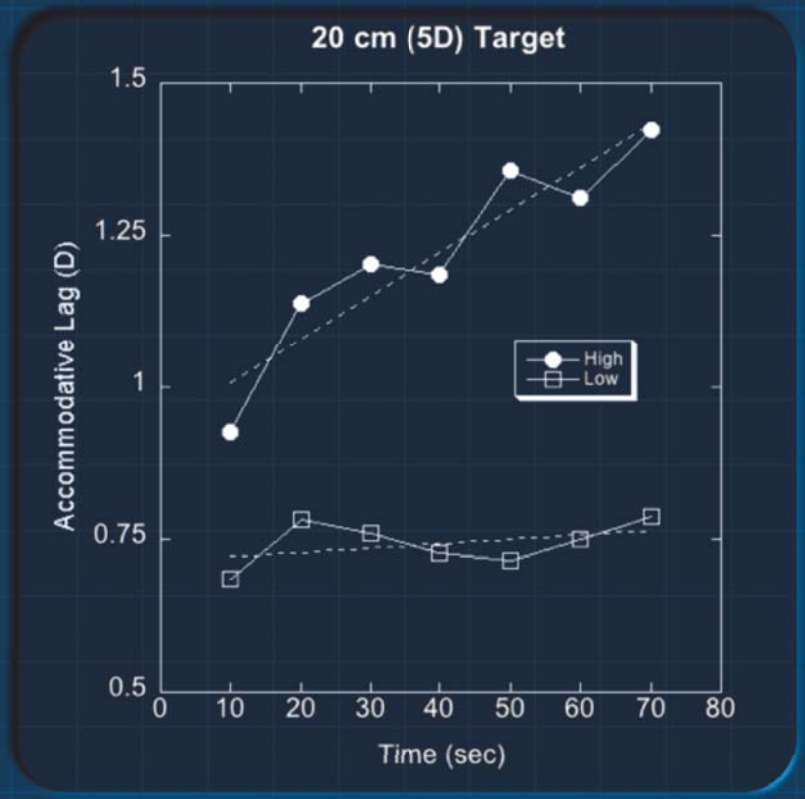
High group = 1 SD above mean, or Conlon >=25

N = 23 college students. PS Conlon = 34; AT Conlon = 11

Using depth of focus cut-off of 0.9D at 20 cm viewing distance, 10 students (43.5%) had insufficiency. Not the typical definition of insufficiency because recordings were based on average accommodative performance over 90 secs. They also had significantly more symptom complaints than those with lag < 0.9D.

Accommodation fatigue is associated with symptoms





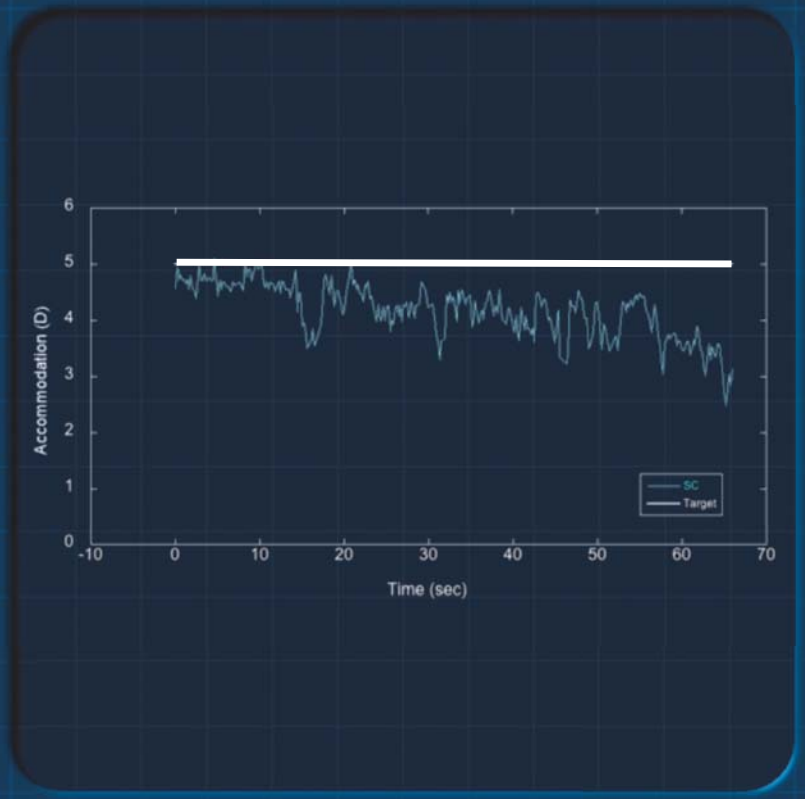
From Tosha et al 2009

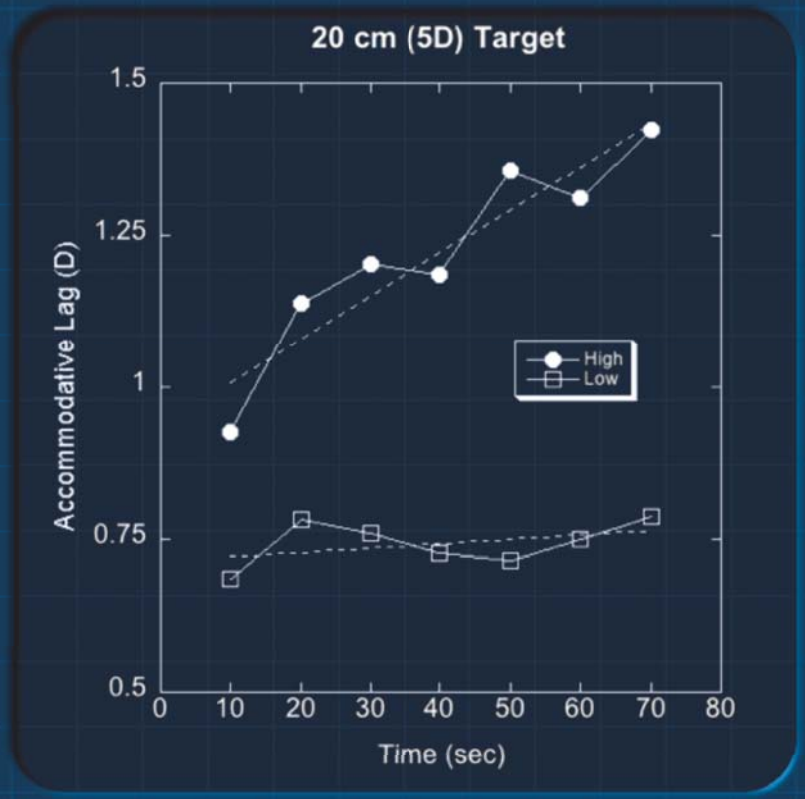
N = 31 college students (24 female). SC: Conlon = 27

Note the pattern of fatigue in the recording: stable for the first 10-15 sec, sudden drop, and then recovery from 15-20, trouble maintaining and instability, followed by short period of stabilization from 25-30 just at the edge of the field of focus. Then around 30 sec, another loss, greater instability from 30-50, and then more rapid deterioration.

Accommodation drift of about 0.4D per minute during this recording period. Don't know if they level off, over time.

Accommodation fatigue is associated with symptoms





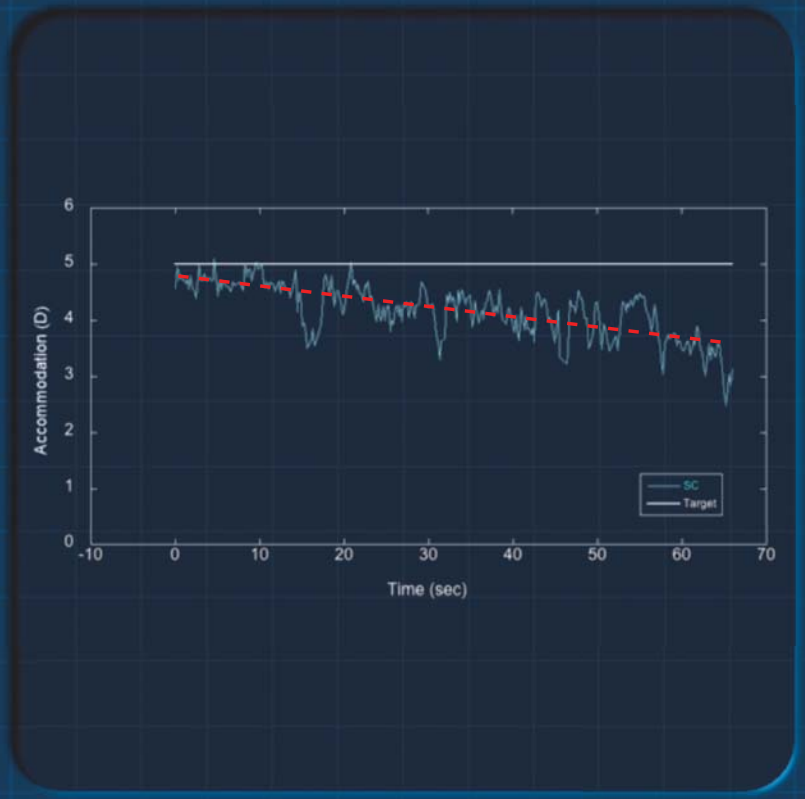
From Tosha et al 2009

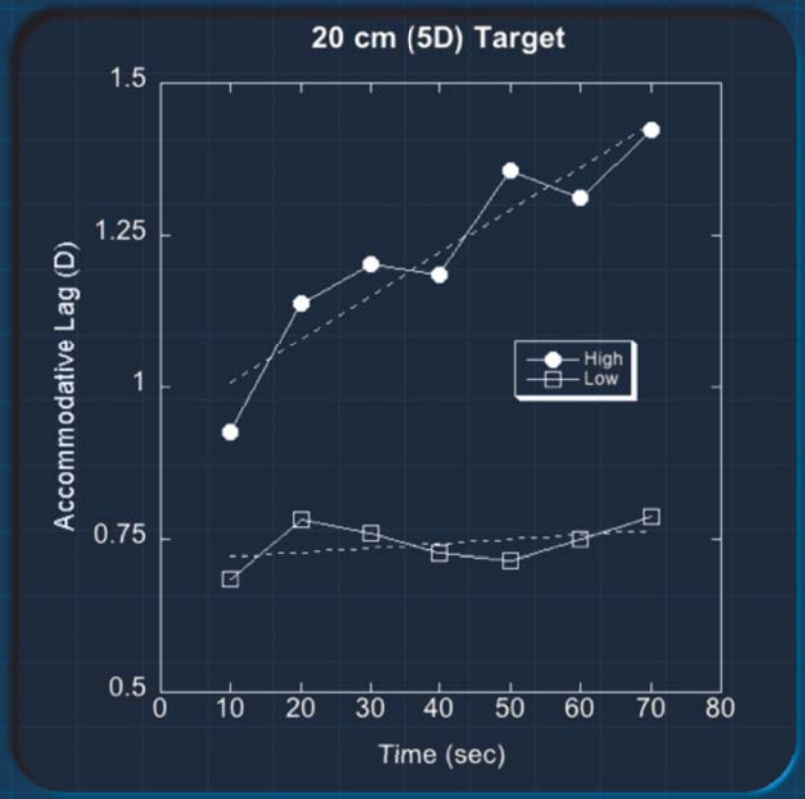
N = 31 college students (24 female). SC: Conlon = 27

Note the pattern of fatigue in the recording: stable for the first 10-15 sec, sudden drop, and then recovery from 15-20, trouble maintaining and instability, followed by short period of stabilization from 25-30 just at the edge of the field of focus. Then around 30 sec, another loss, greater instability from 30-50, and then more rapid deterioration.

Accommodation drift of about 0.4D per minute during this recording period. Don't know if they level off, over time.

Accommodation fatigue is associated with symptoms





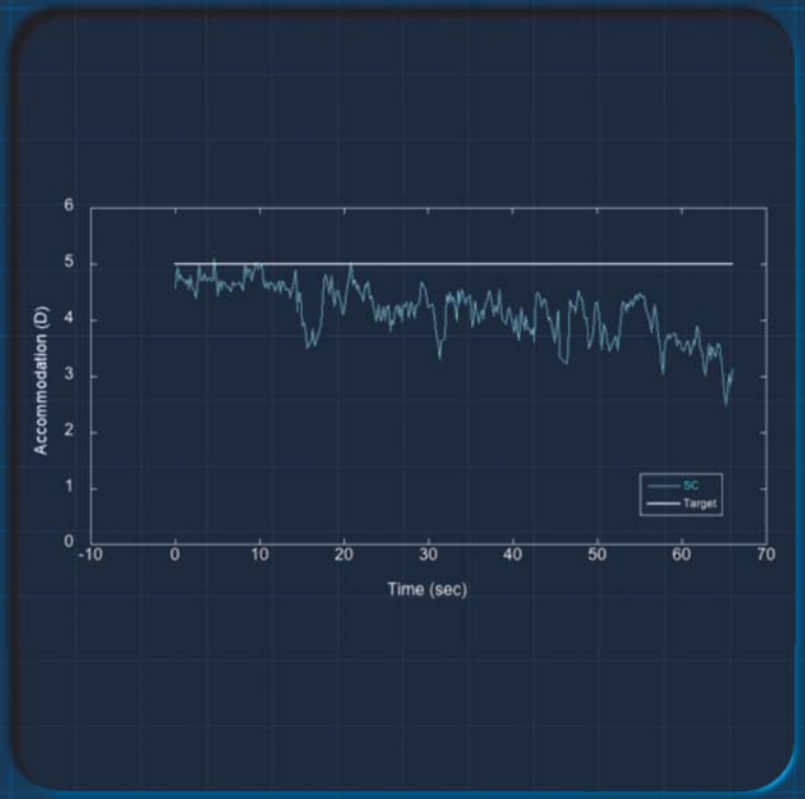
From Tosha et al 2009

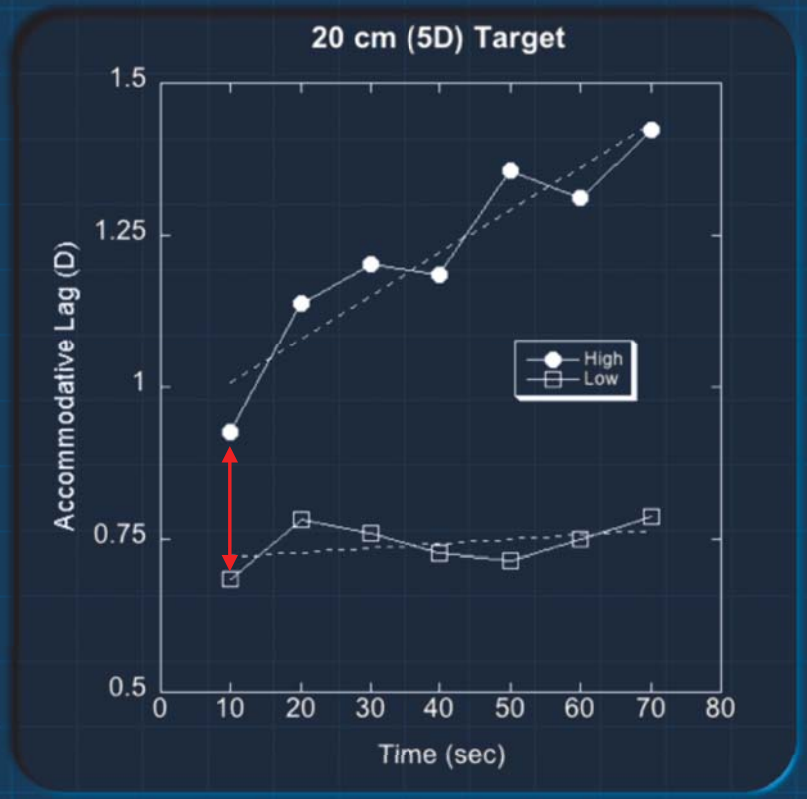
N = 31 college students (24 female). SC: Conlon = 27

Note the pattern of fatigue in the recording: stable for the first 10-15 sec, sudden drop, and then recovery from 15-20, trouble maintaining and instability, followed by short period of stabilization from 25-30 just at the edge of the field of focus. Then around 30 sec, another loss, greater instability from 30-50, and then more rapid deterioration.

Accommodation drift of about 0.4D per minute during this recording period. Don't know if they level off, over time.

Accommodation fatigue is associated with symptoms





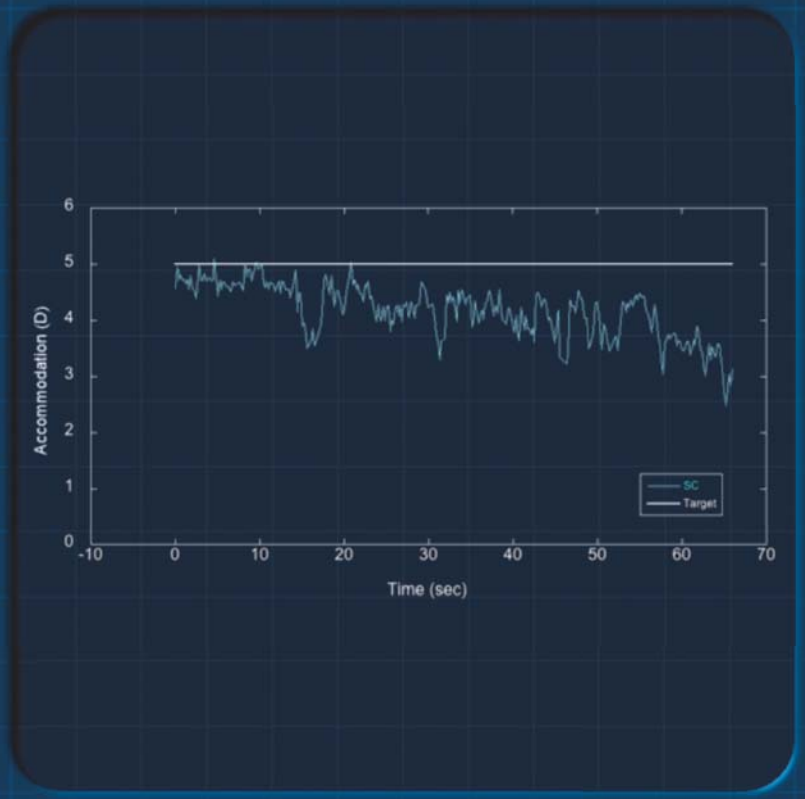
From Tosha et al 2009

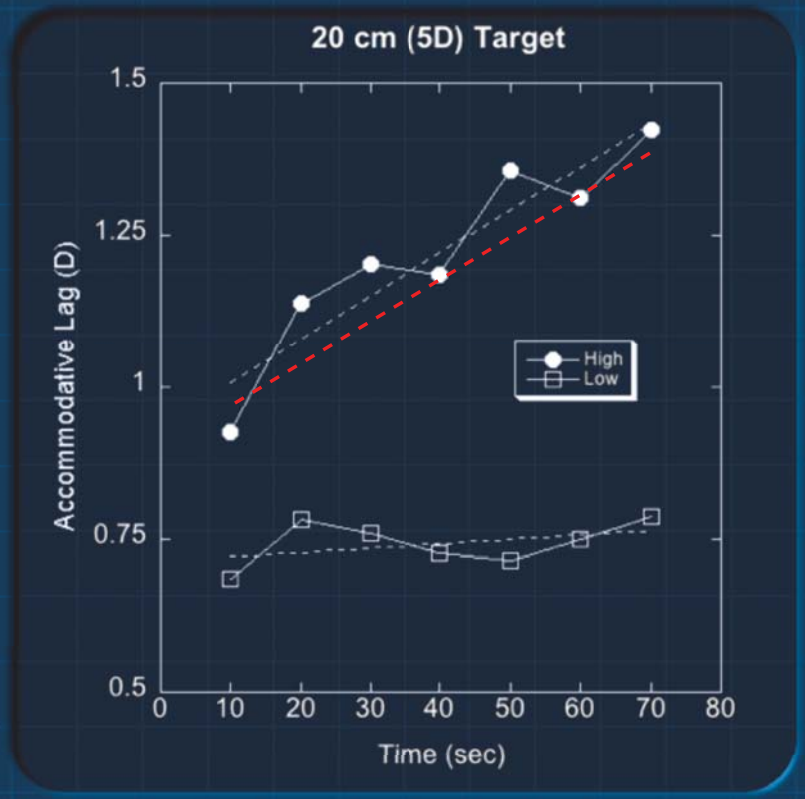
N = 31 college students (24 female). SC: Conlon = 27

Note the pattern of fatigue in the recording: stable for the first 10-15 sec, sudden drop, and then recovery from 15-20, trouble maintaining and instability, followed by short period of stabilization from 25-30 just at the edge of the field of focus. Then around 30 sec, another loss, greater instability from 30-50, and then more rapid deterioration.

Accommodation drift of about 0.4D per minute during this recording period. Don't know if they level off, over time.

Accommodation fatigue is associated with symptoms





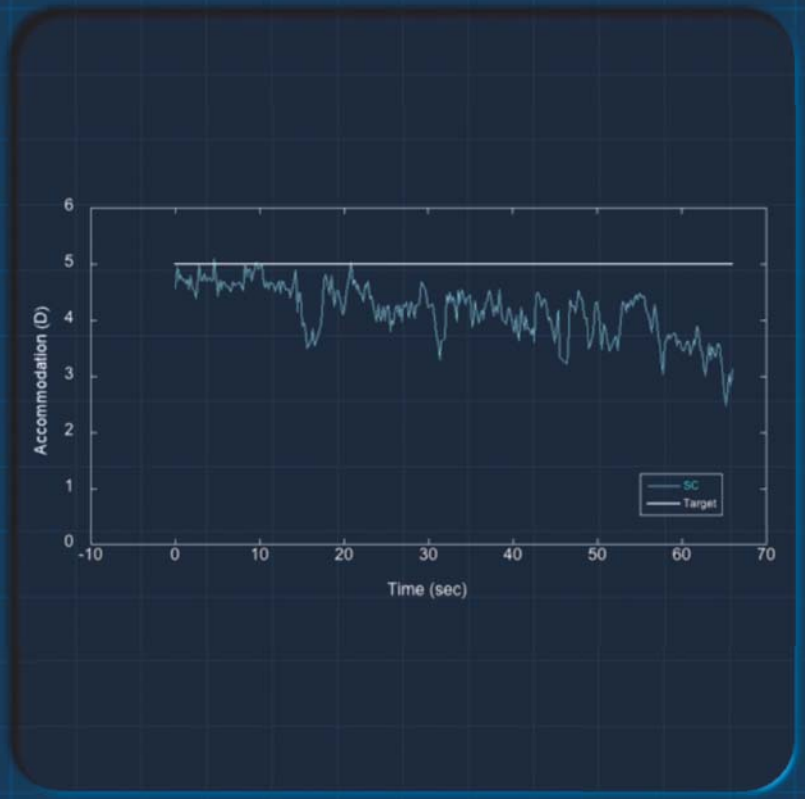
From Tosha et al 2009

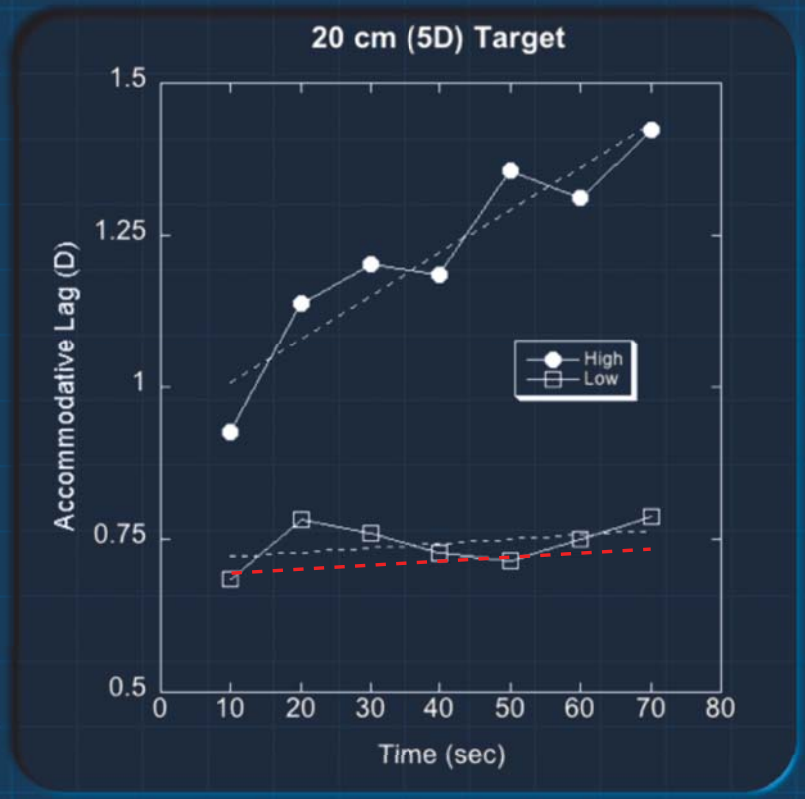
N = 31 college students (24 female). SC: Conlon = 27

Note the pattern of fatigue in the recording: stable for the first 10-15 sec, sudden drop, and then recovery from 15-20, trouble maintaining and instability, followed by short period of stabilization from 25-30 just at the edge of the field of focus. Then around 30 sec, another loss, greater instability from 30-50, and then more rapid deterioration.

Accommodation drift of about 0.4D per minute during this recording period. Don't know if they level off, over time.

Accommodation fatigue is associated with symptoms





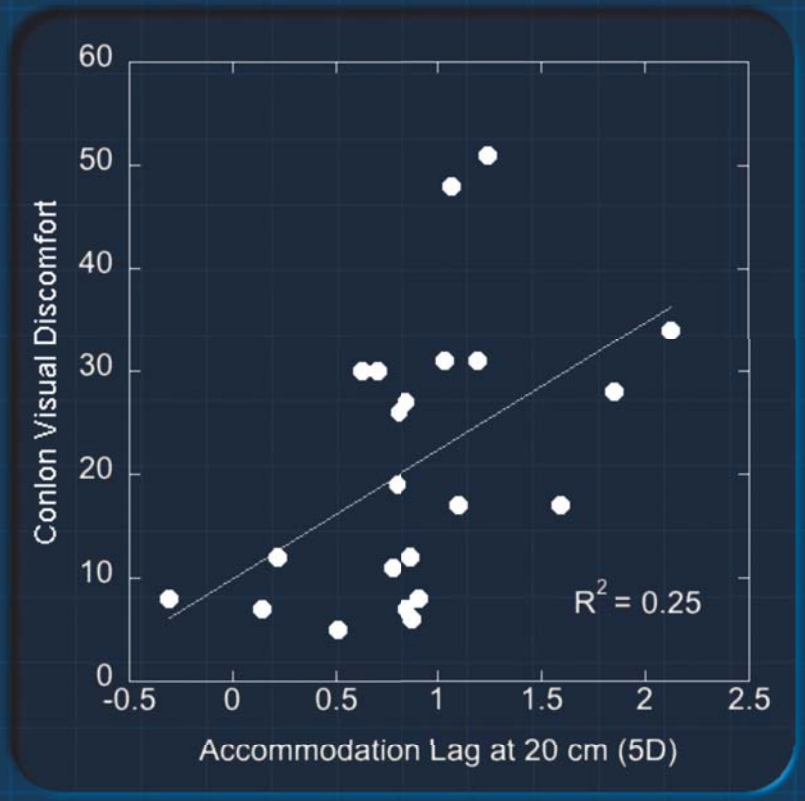
From Tosha et al 2009

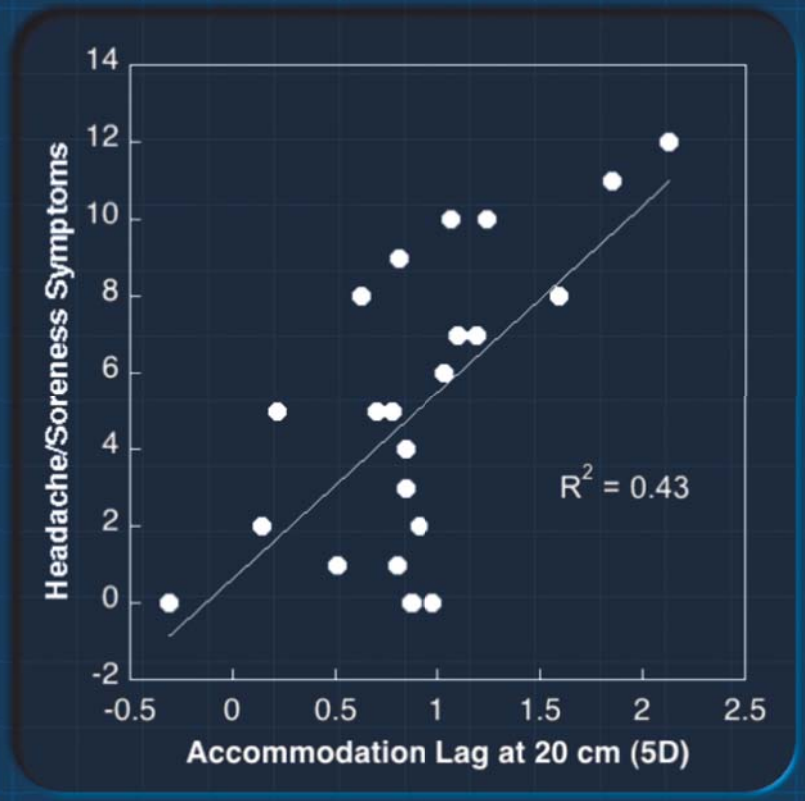
N = 31 college students (24 female). SC: Conlon = 27

Note the pattern of fatigue in the recording: stable for the first 10-15 sec, sudden drop, and then recovery from 15-20, trouble maintaining and instability, followed by short period of stabilization from 25-30 just at the edge of the field of focus. Then around 30 sec, another loss, greater instability from 30-50, and then more rapid deterioration.

Accommodation drift of about 0.4D per minute during this recording period. Don't know if they level off, over time.

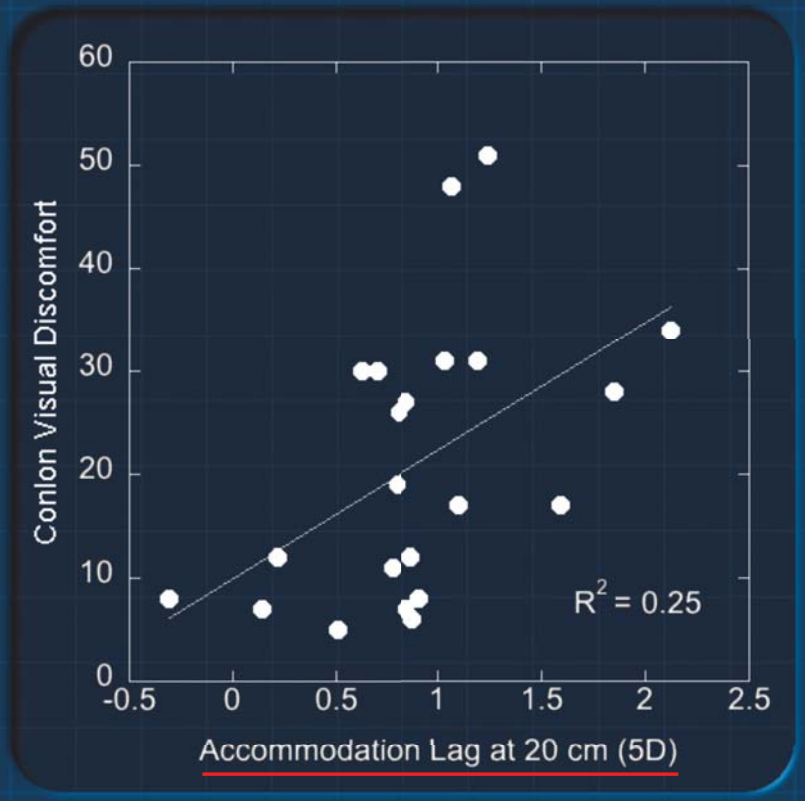
Accommodation lag predicts symptom severity

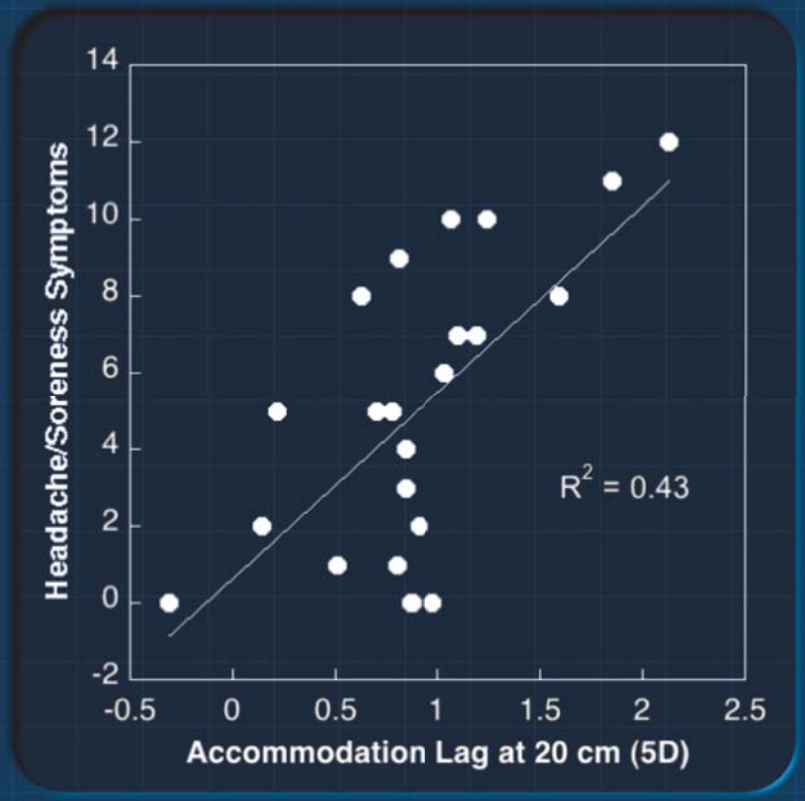




From Chase et al 2009

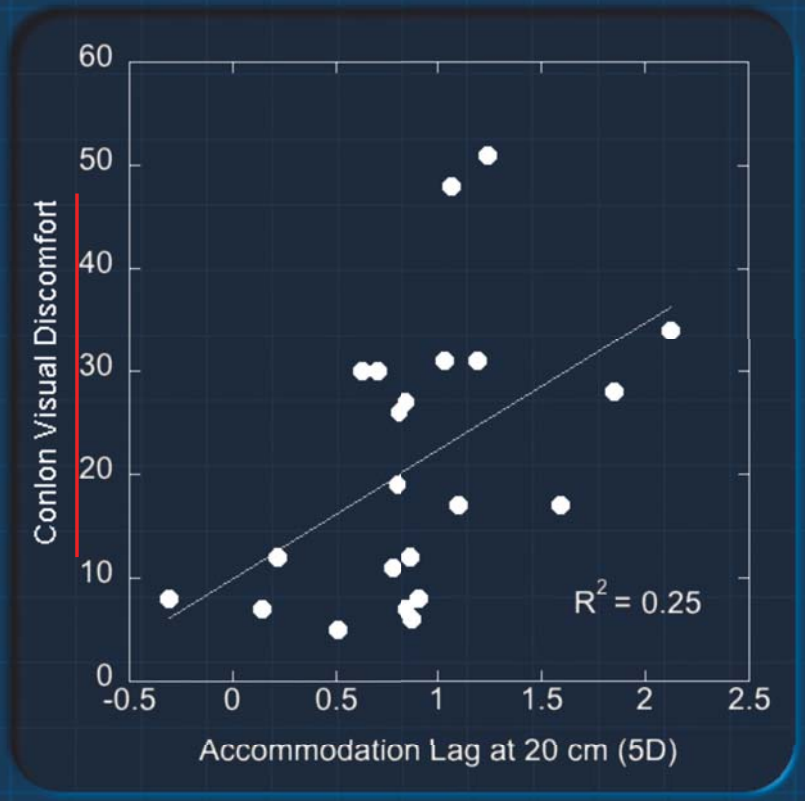
Accommodation lag predicts symptom severity

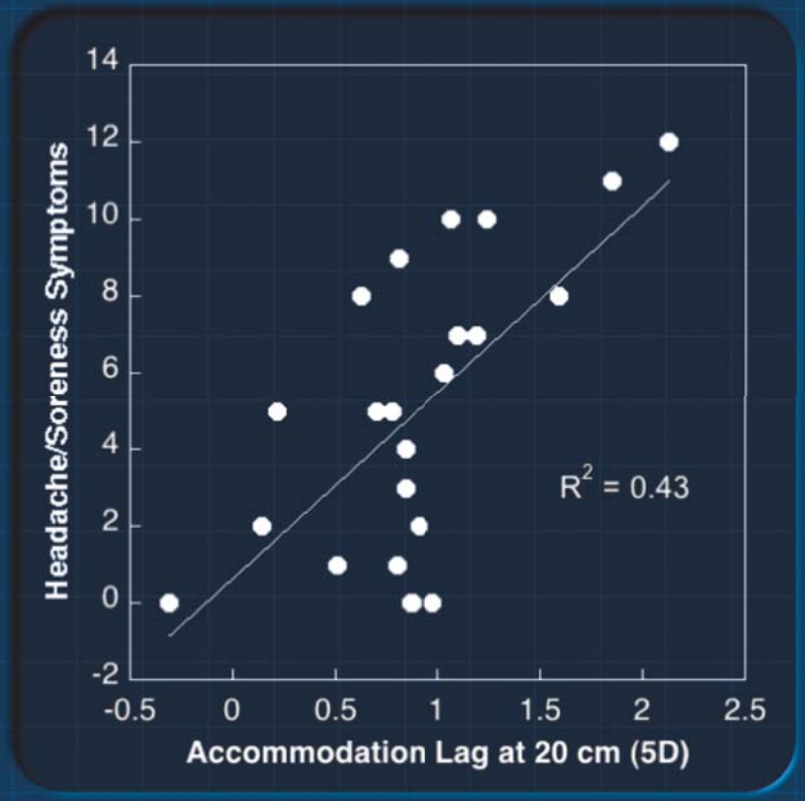




From Chase et al 2009

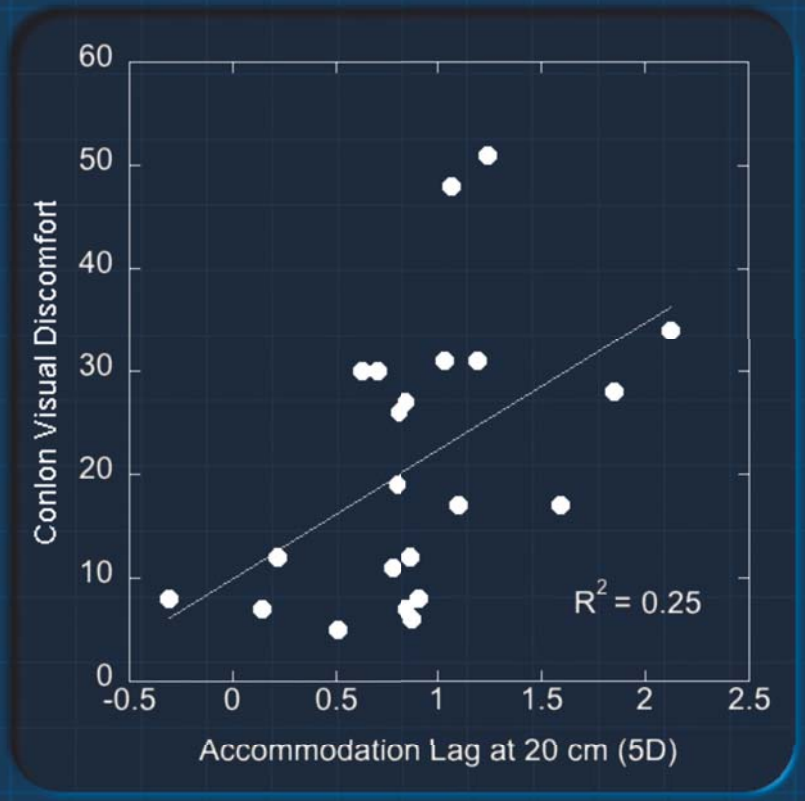
Accommodation lag predicts symptom severity

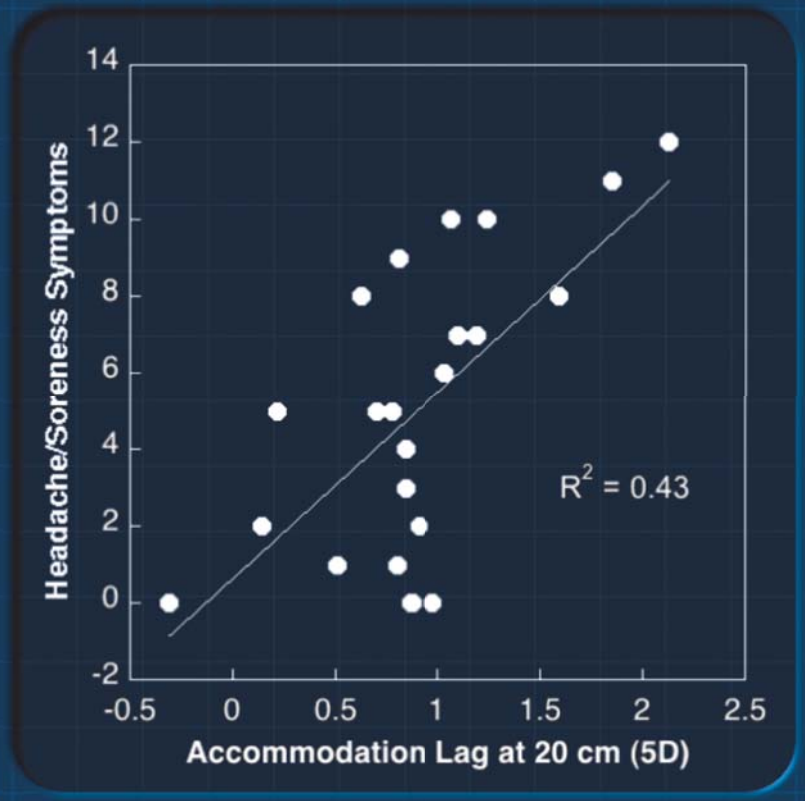




From Chase et al 2009

Accommodation lag predicts symptom severity



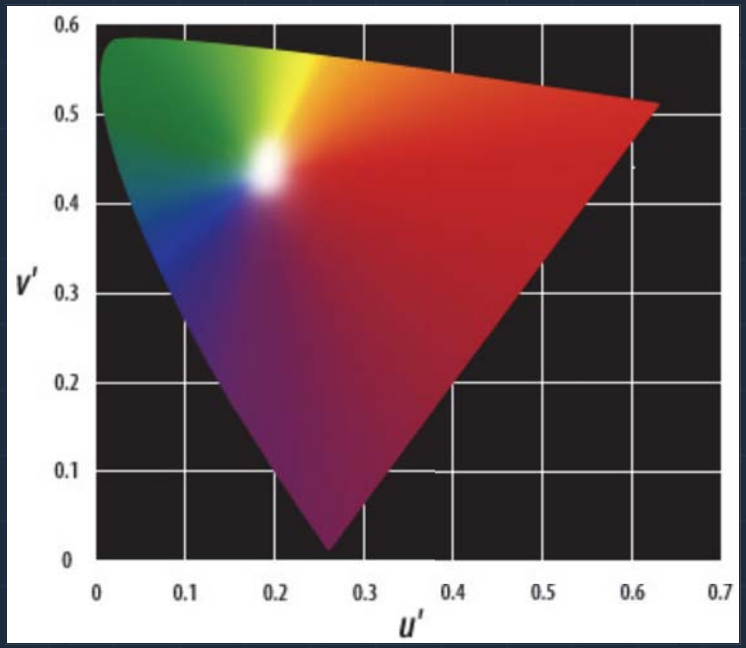


From Chase et al 2009

Accommodation summary

- Accommodative insufficiency.
  - Significant lag at 25 cm (4D) and closer.
- Accommodative fatigue.
  - Lag increased at rate of 0.4D per minute.
- Accommodative lag positively correlates with symptoms.

Part 3: Color and reading



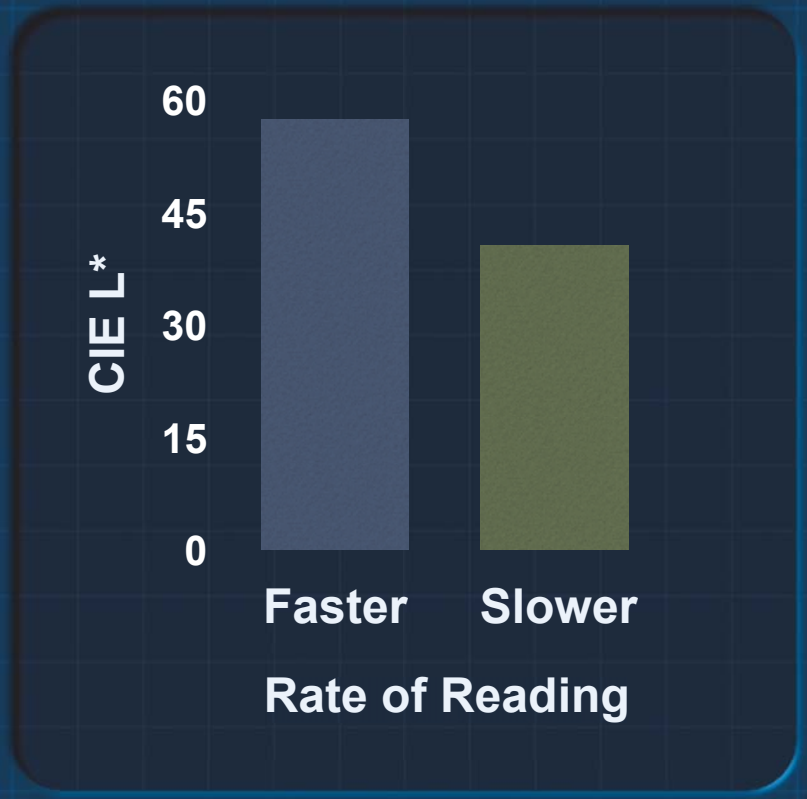
1. There is another scale for luminance intensity CIE L* not shown here.
2. Results from two color studies.

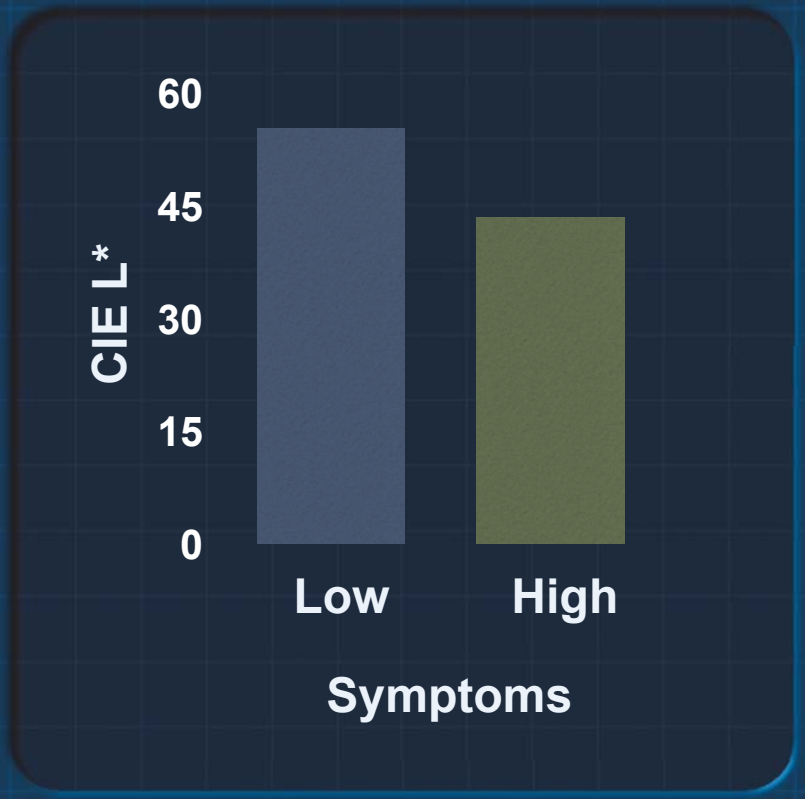
Color was used to treat eyestrain over 150 years ago

"On the supposition that the retina was in some measure implicated in the affection, Böhm and Reute thought it 'rational' to recommend that the convex glasses should be blue."

Donders, 1964 *Accommodation and Refraction of the Eye, p 275.*

Slower, more symptomatic readers prefer less luminance

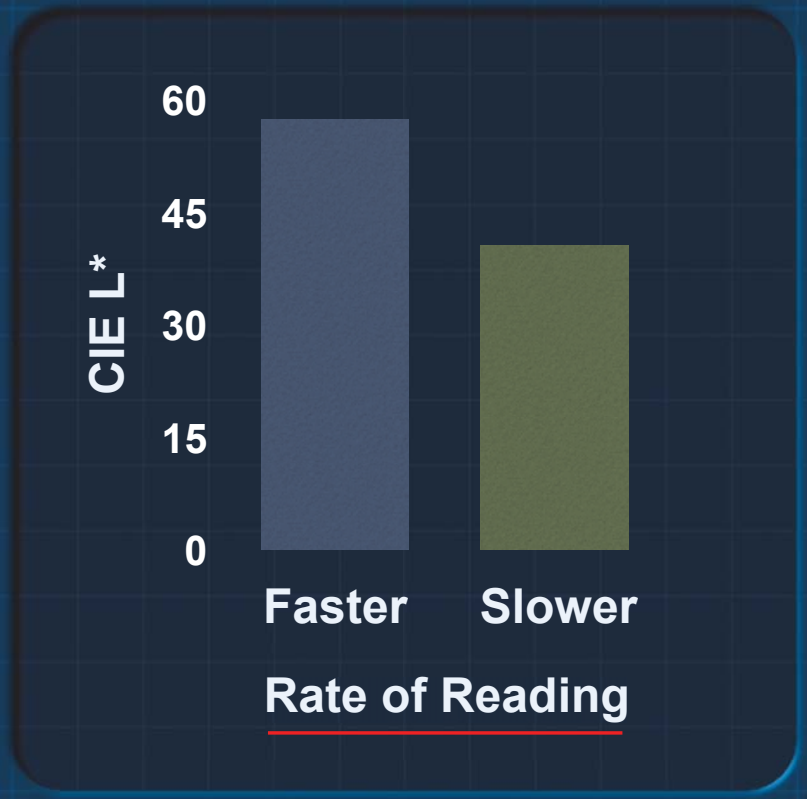


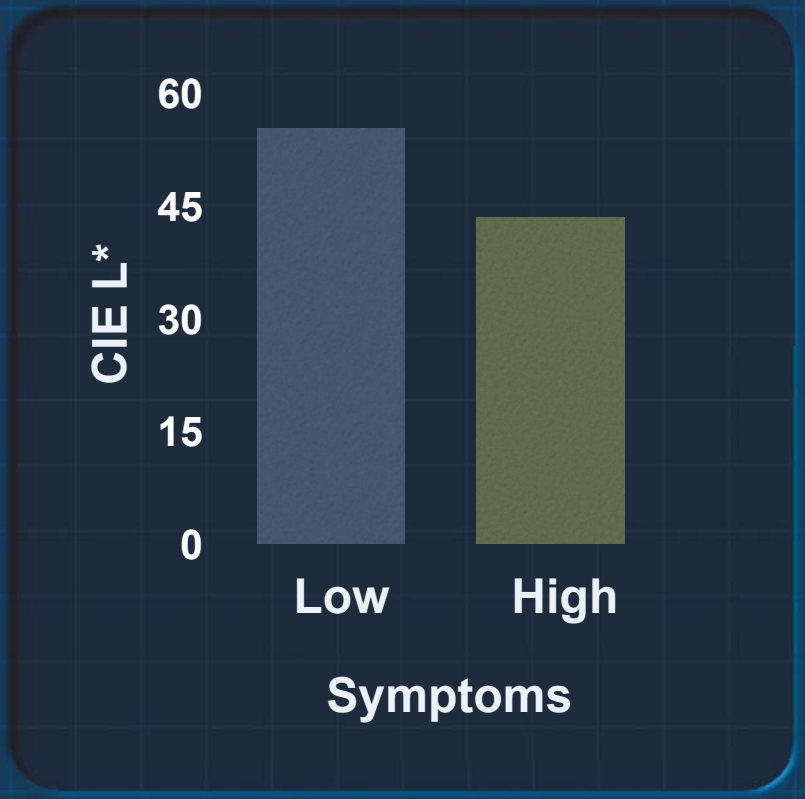


t(58) = 2.85, p = .003

t(59) = 2.00, p = .025

Slower, more symptomatic readers prefer less luminance

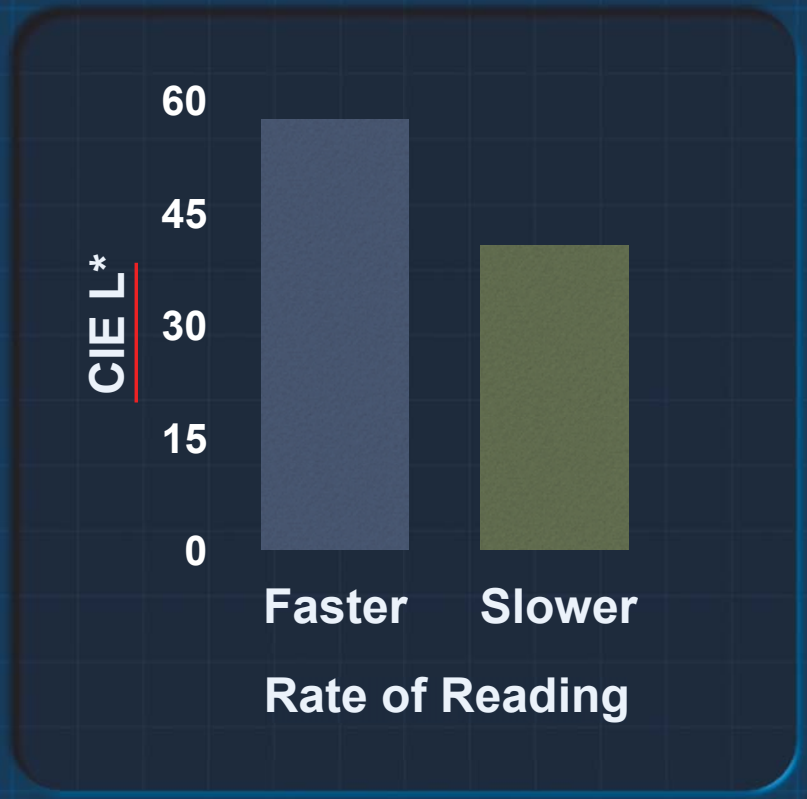


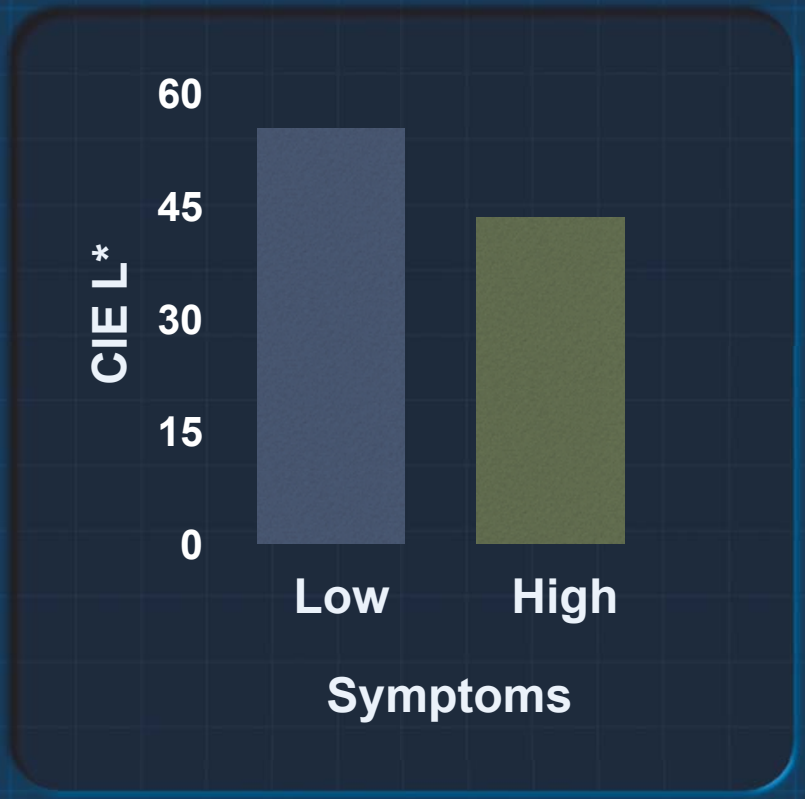


t(58) = 2.85, p = .003

t(59) = 2.00, p = .025

Slower, more symptomatic readers prefer less luminance

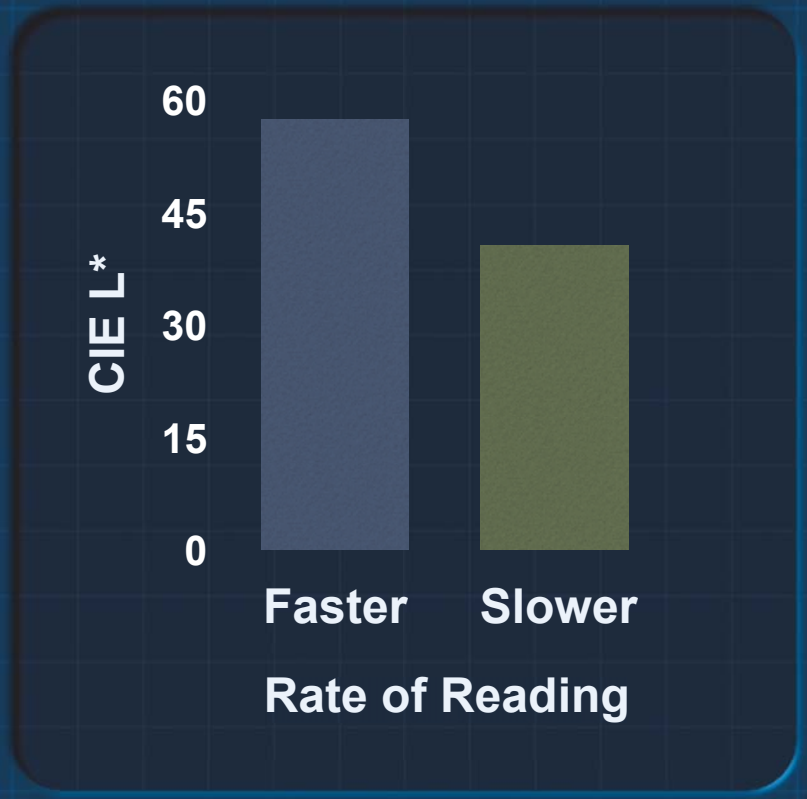


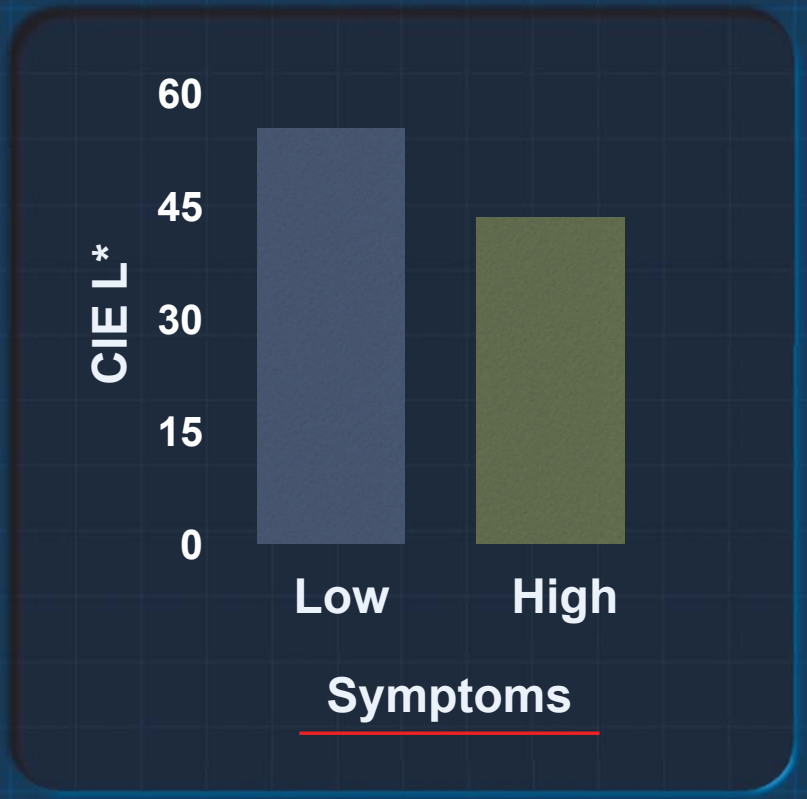


t(58) = 2.85, p = .003

t(59) = 2.00, p = .025

Slower, more symptomatic readers prefer less luminance

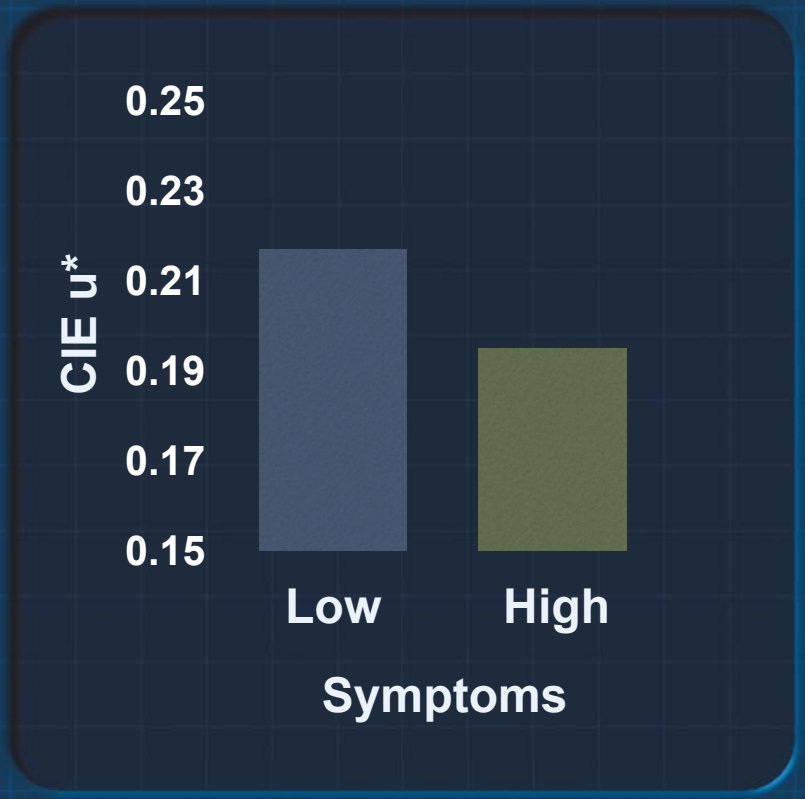


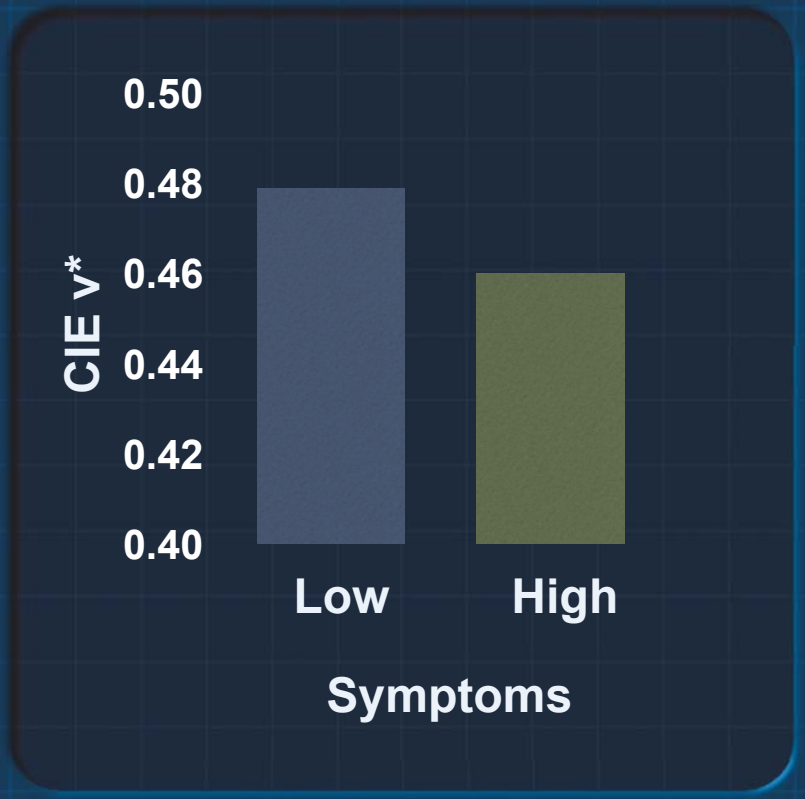


t(58) = 2.85, p = .003

t(59) = 2.00, p = .025

Symptomatic students prefer lower CIE u* & CIE v* colors



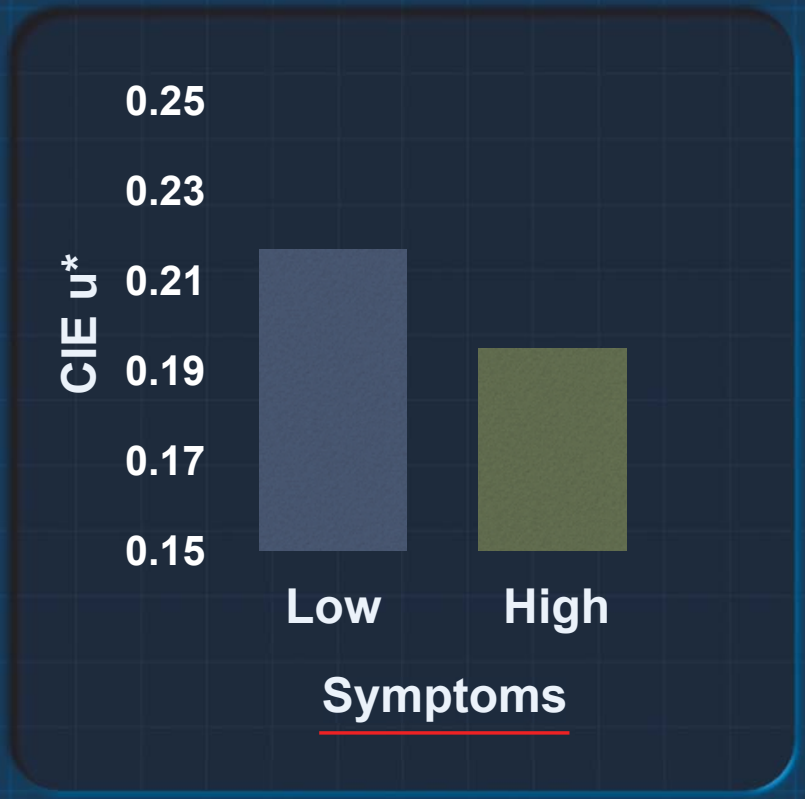


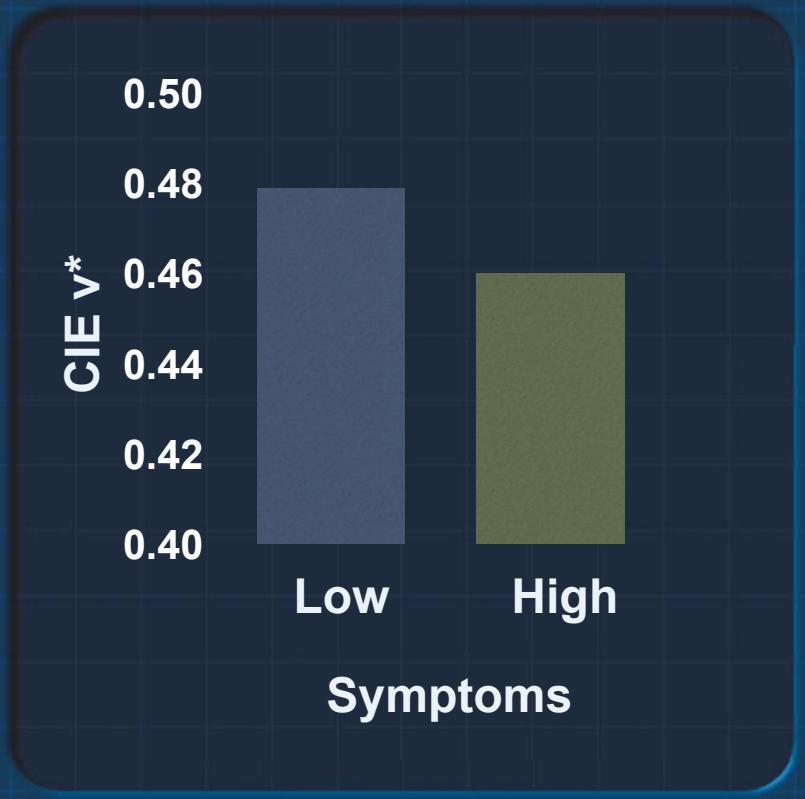
t(59) = 2.21, p = .02

t(59) = 1.90, p = .03

1. High group significantly different from no filter u=0.21 or v=0.474, but low group not different from no filter condition.
2. Groups meet criteria for visual stress:
   a. symptomatic/asymptomatic
   b. prefer/don't prefer color to reduce symptoms

Symptomatic students prefer lower CIE u* & CIE v* colors



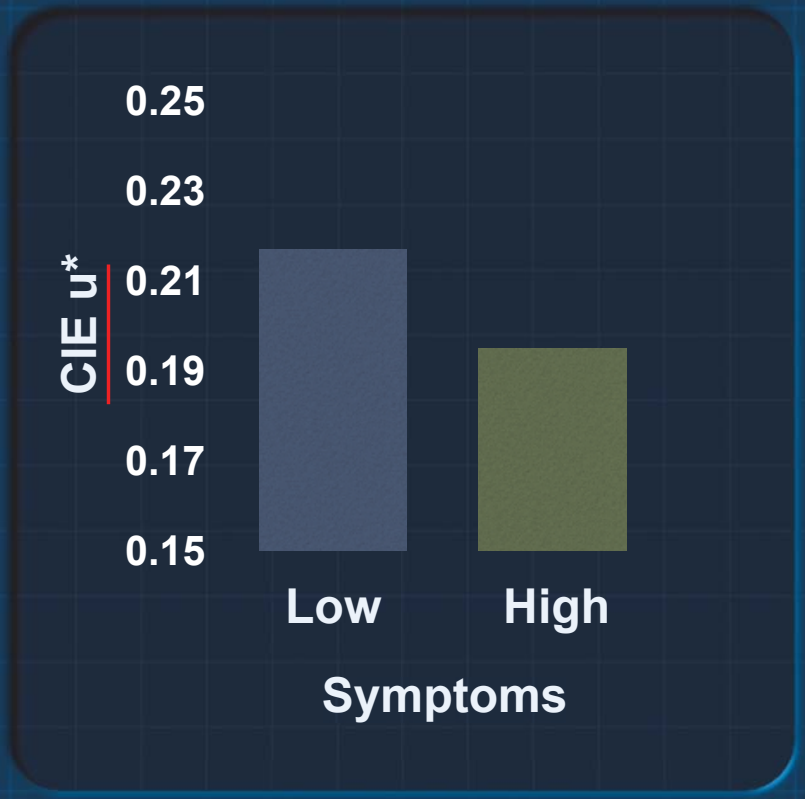


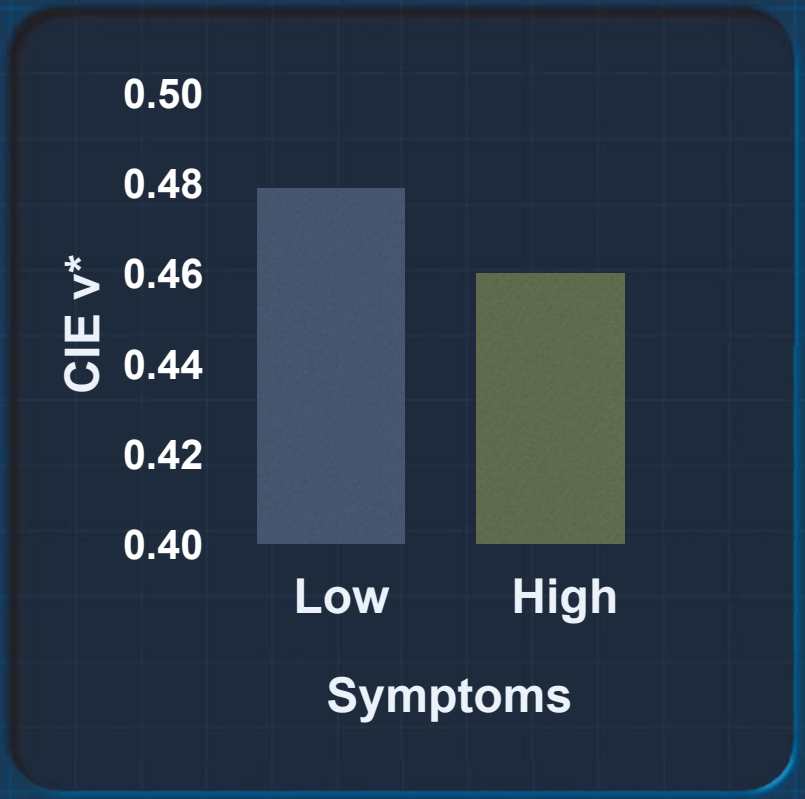
t(59) = 2.21, p = .02

t(59) = 1.90, p = .03

1. High group significantly different from no filter u=0.21 or v=0.474, but low group not different from no filter condition.
2. Groups meet criteria for visual stress:
   a. symptomatic/asymptomatic
   b. prefer/don't prefer color to reduce symptoms

Symptomatic students prefer lower CIE u* & CIE v* colors



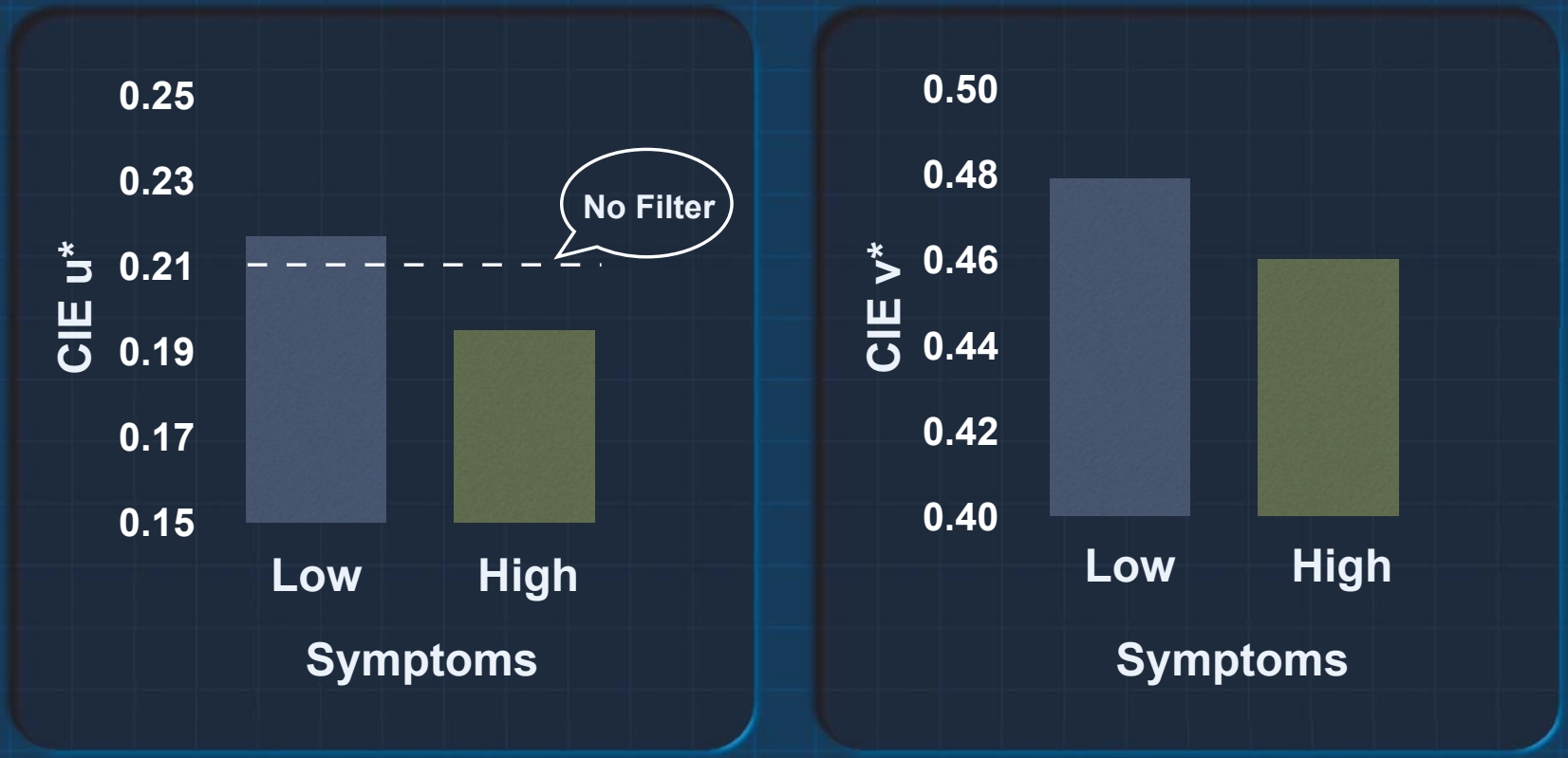


t(59) = 2.21, p = .02

t(59) = 1.90, p = .03

1. High group significantly different from no filter u=0.21 or v=0.474, but low group not different from no filter condition.
2. Groups meet criteria for visual stress:
   a. symptomatic/asymptomatic
   b. prefer/don't prefer color to reduce symptoms

Symptomatic students prefer lower CIE u* & CIE v* colors

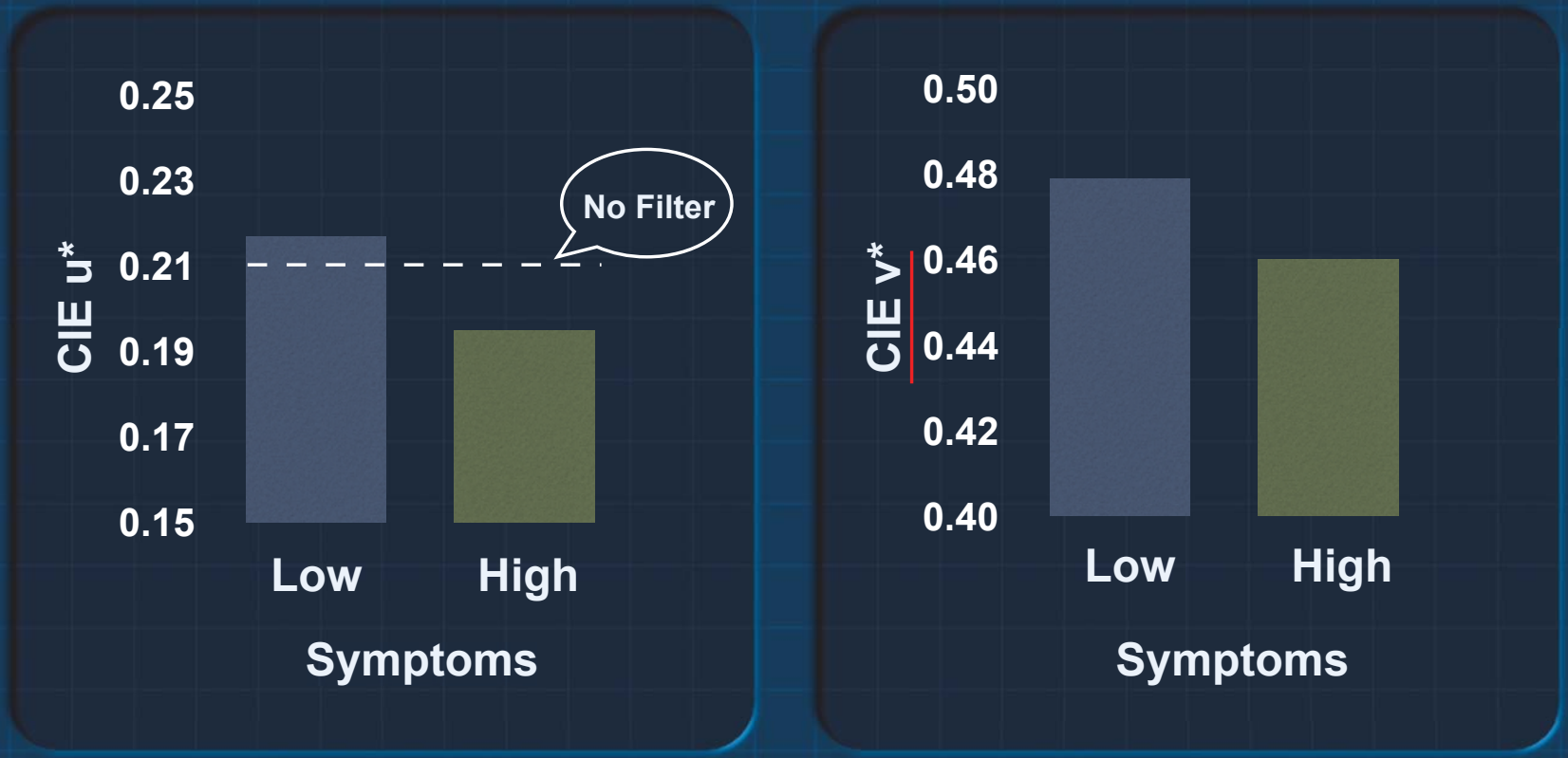


t(59) = 2.21, p = .02

t(59) = 1.90, p = .03

1. High group significantly different from no filter u=0.21 or v=0.474, but low group not different from no filter condition.
2. Groups meet criteria for visual stress:
   a. symptomatic/asymptomatic
   b. prefer/don't prefer color to reduce symptoms

Symptomatic students prefer lower CIE u* & CIE v* colors

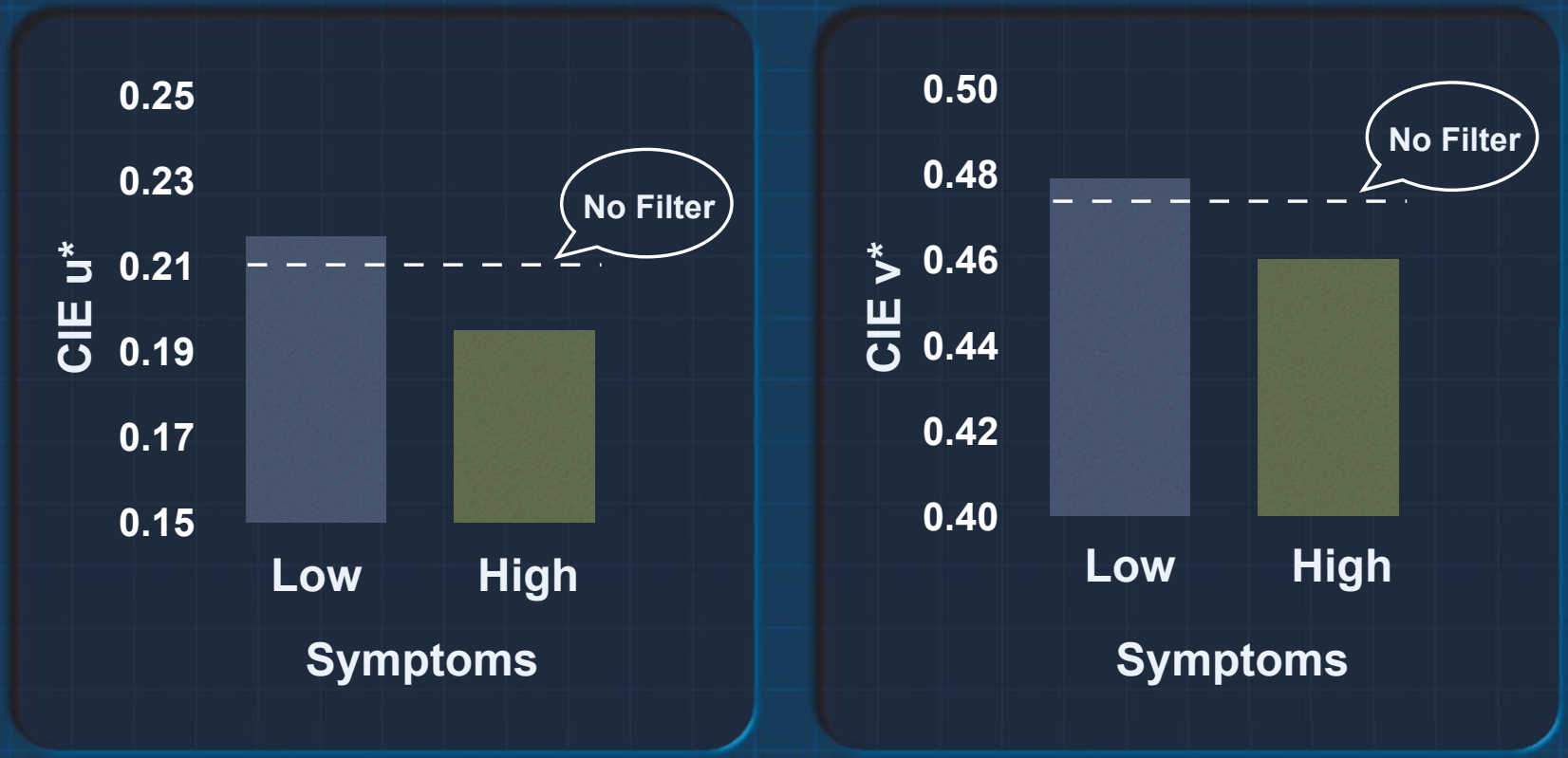


t(59) = 2.21, p = .02

t(59) = 1.90, p = .03

1. High group significantly different from no filter u=0.21 or v=0.474, but low group not different from no filter condition.
2. Groups meet criteria for visual stress:
   a. symptomatic/asymptomatic
   b. prefer/don't prefer color to reduce symptoms

Symptomatic students prefer lower CIE u* & CIE v* colors

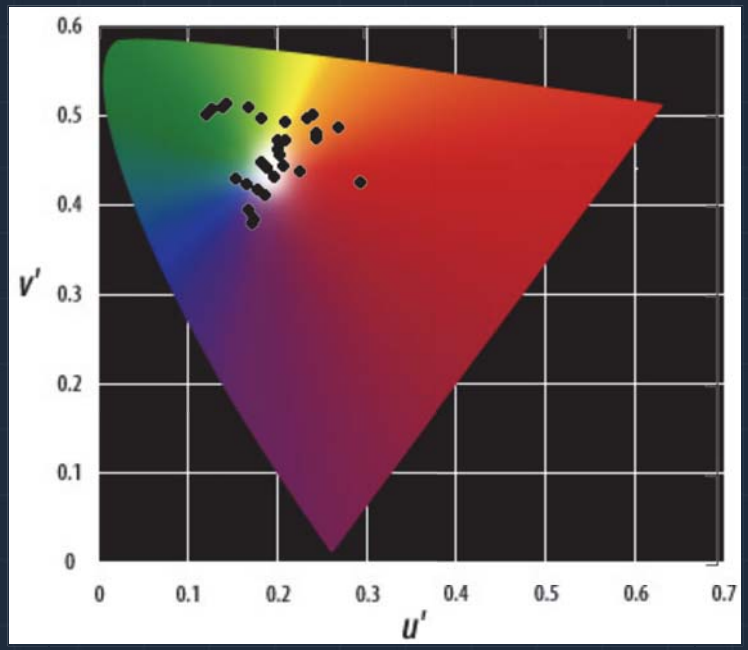


t(59) = 2.21, p = .02

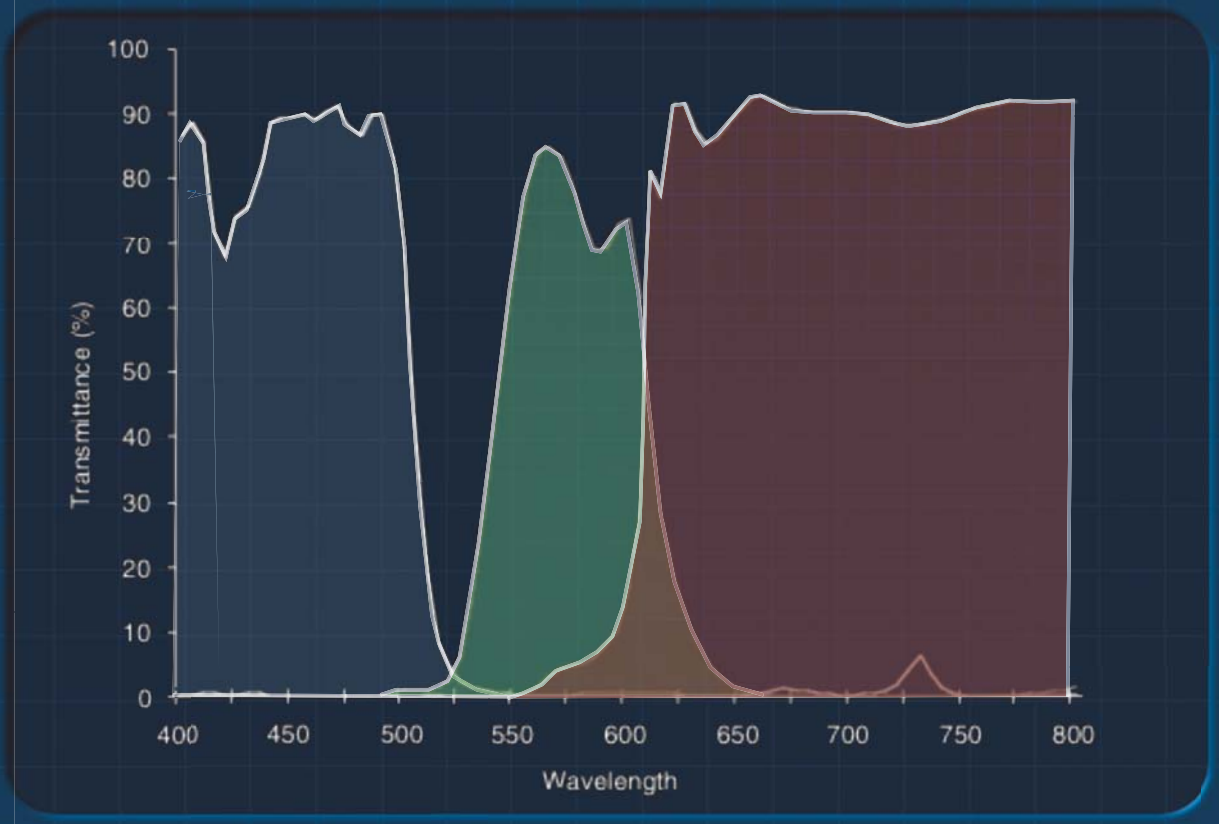
t(59) = 1.90, p = .03

1. High group significantly different from no filter u=0.21 or v=0.474, but low group not different from no filter condition.
2. Groups meet criteria for visual stress:
   a. symptomatic/asymptomatic
   b. prefer/don't prefer color to reduce symptoms

Symptomatic students preferred blues and greens



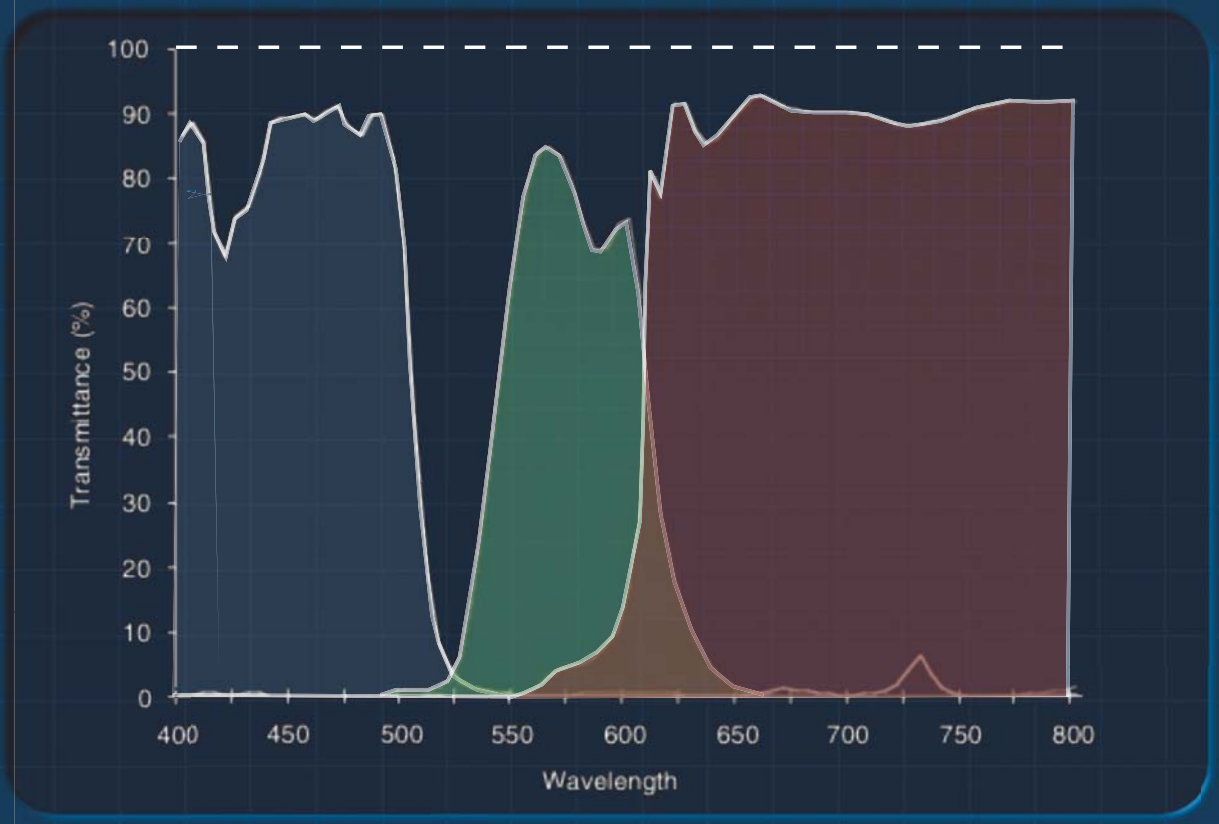
Are some colors better for reading than others?



From Chase et al 2003

1. Reducing luminance cuts down the transmittance of all wavelengths. But perhaps some colors are worse for reading.
2.This study looked at dichroic filtered reading.
3. Conditions matched for luminance and contrast.

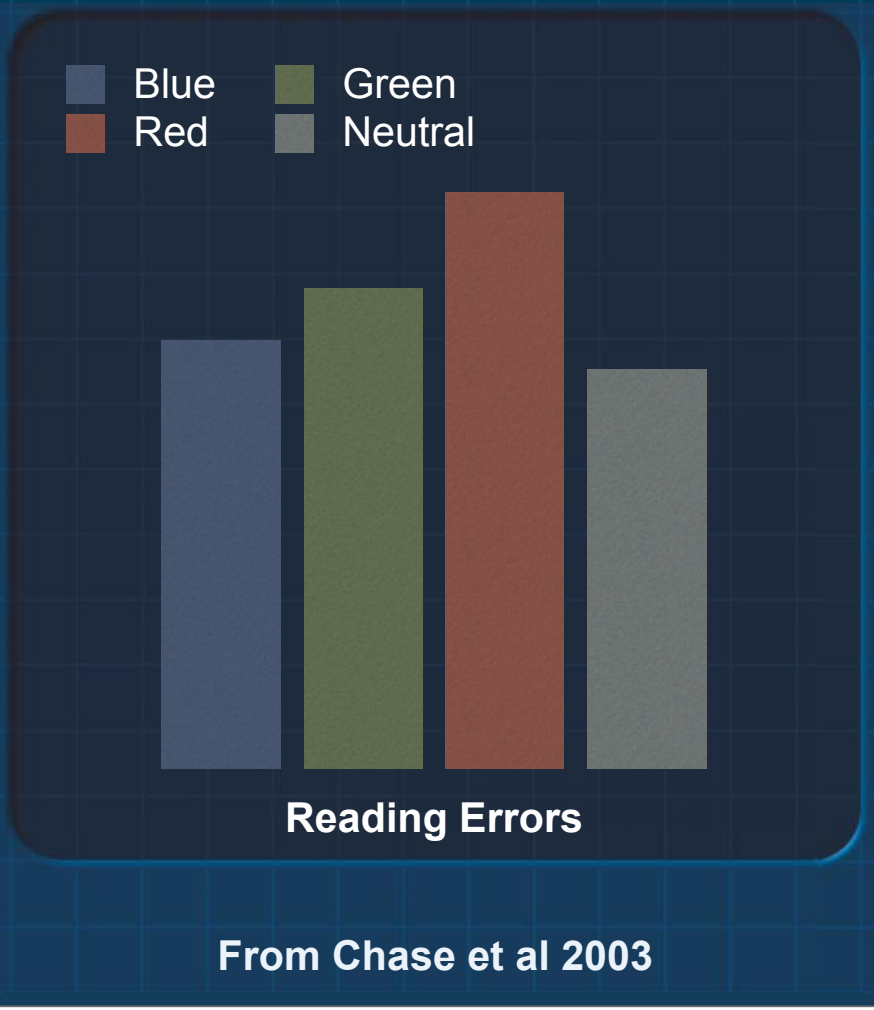
Are some colors better for reading than others?



From Chase et al 2003

1. Reducing luminance cuts down the transmittance of all wavelengths. But perhaps some colors are worse for reading.
2.This study looked at dichroic filtered reading.
3. Conditions matched for luminance and contrast.

Red is worse



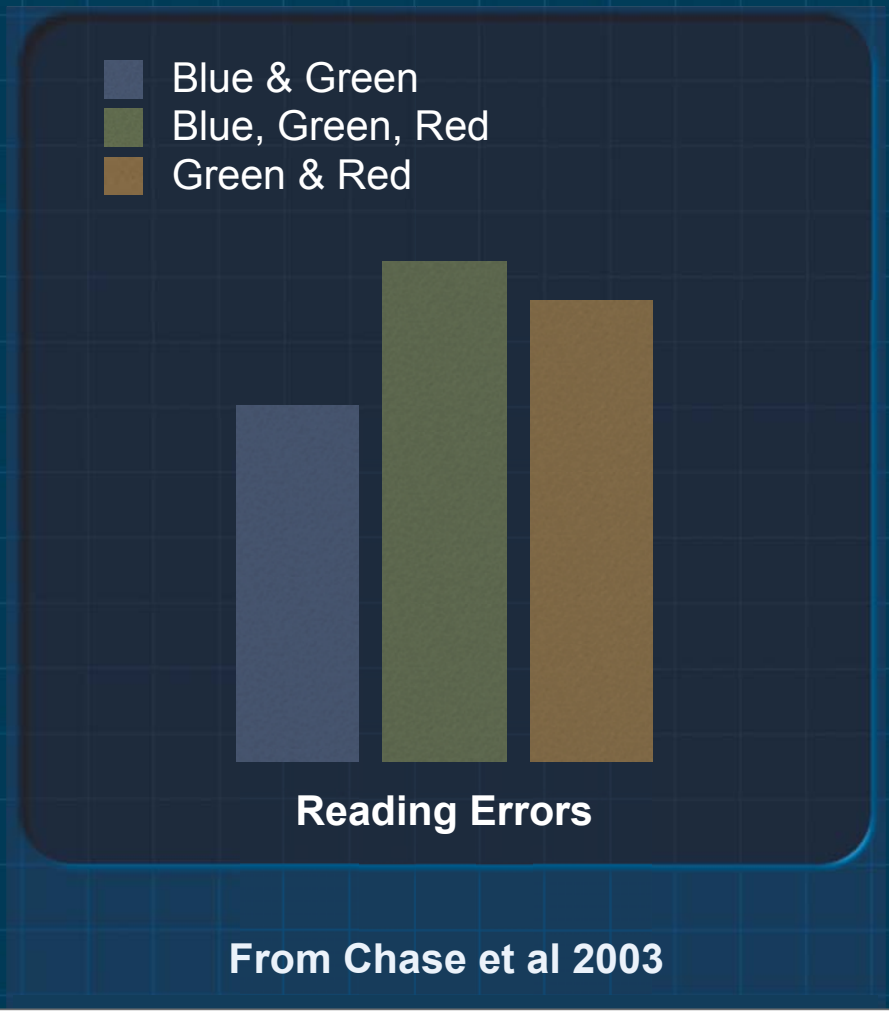
1. N=24 college students with normal acuity, no LD, and normal color perception.
2. Added Neutral condition and matched luminance for all three colors with neutral.
3. Blue, Green, Neutral not different from each other but Blue and Neutral different from Red.

Too much red or not enough blue?

From Chase et al 2003

1. Designed a second study to sort out this question. Here are the predictions.

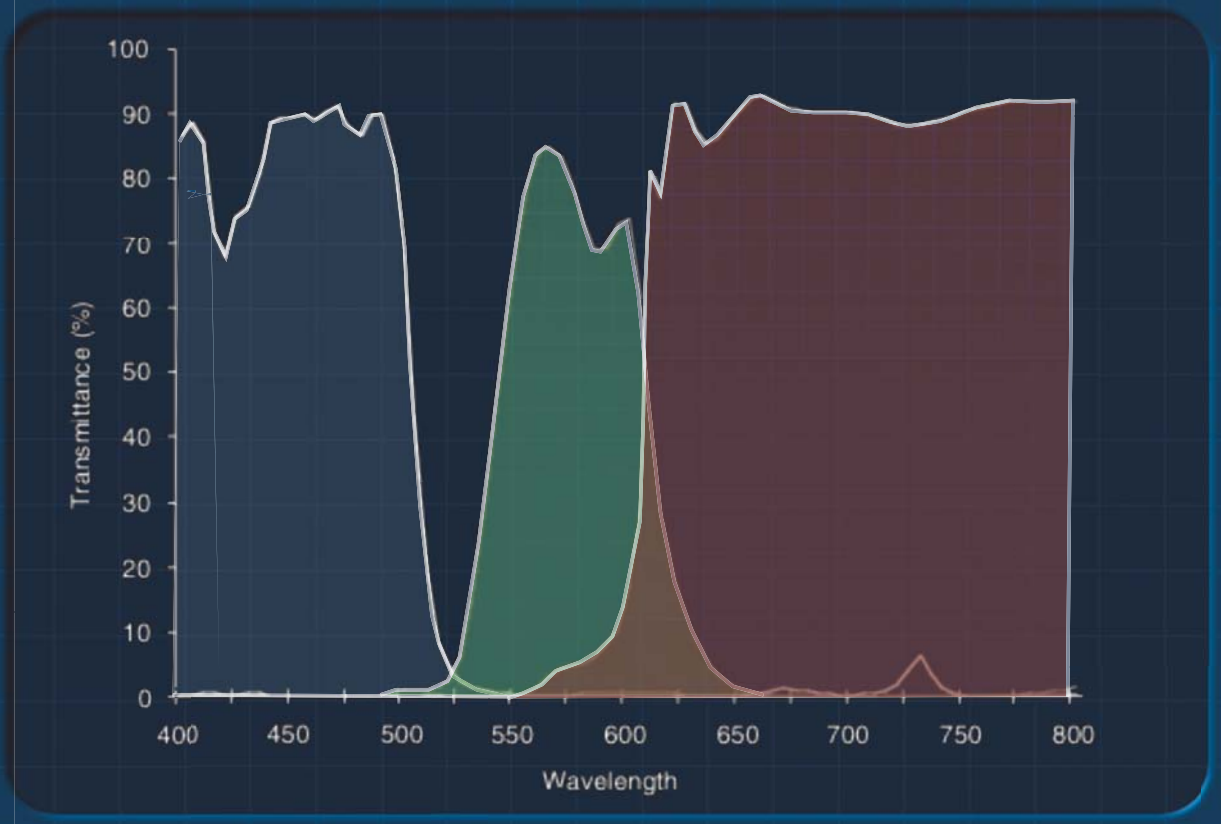
Red is worse



From Chase et al 2003

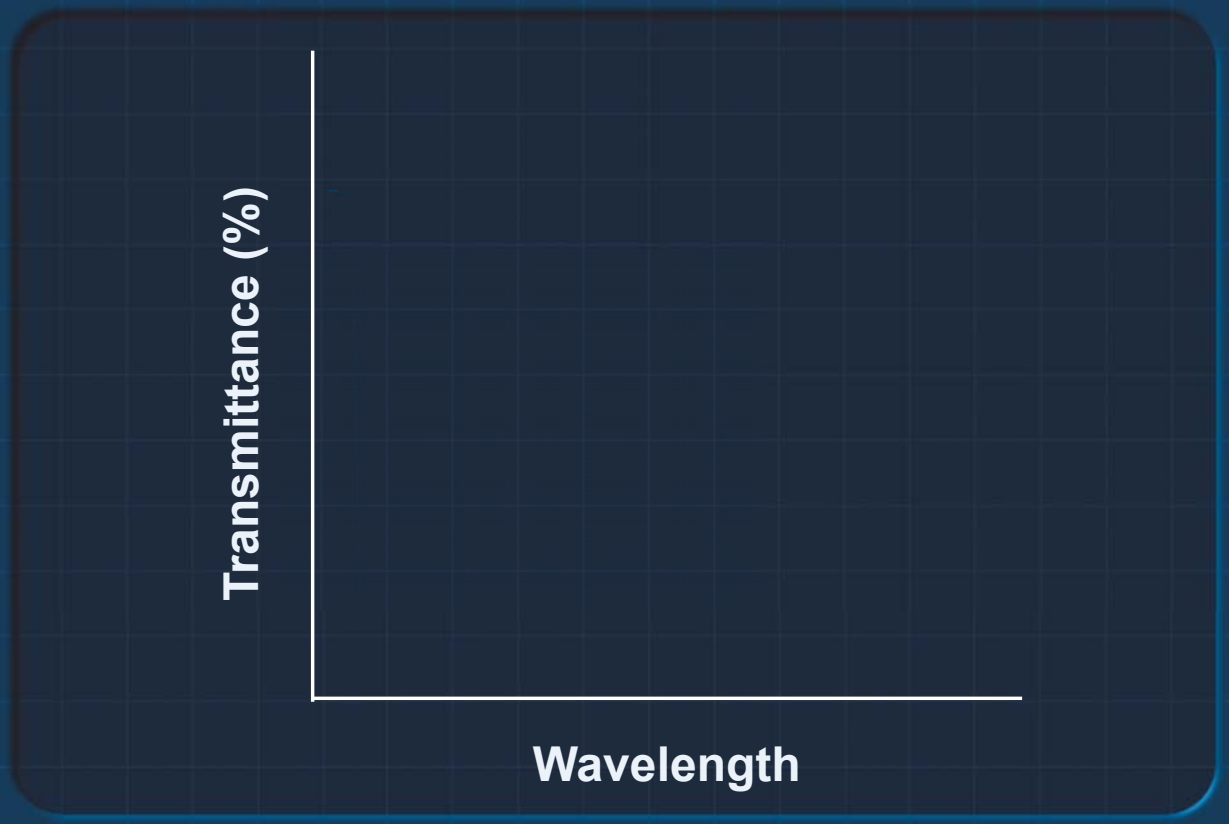
1. N = 18 college students.
2. The two circled conditions not different from each other but both different from Blue & Green.

What is the red filter transmitting?



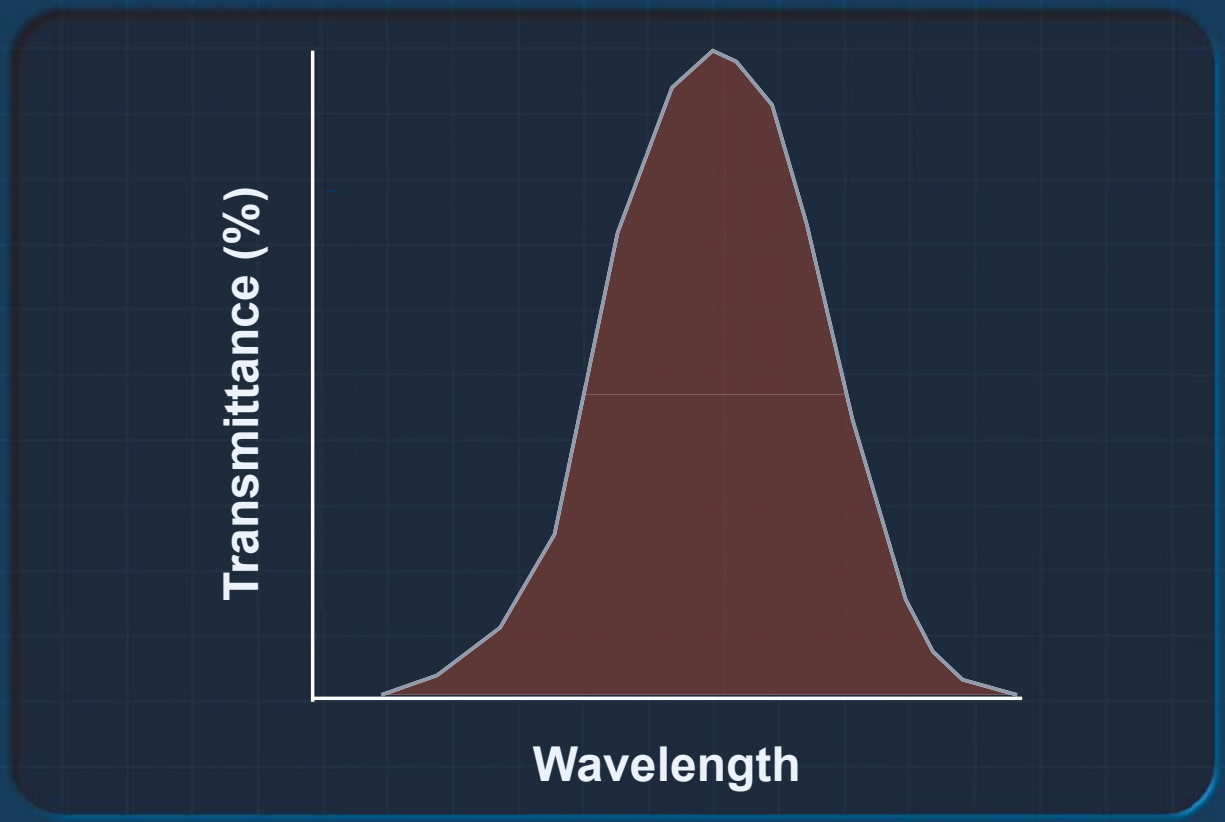
1. Transmitting wavelengths that activate cones. To understand which cones requires a short review about cone types and their wavelength sensitivities.

L- and M-cone signals normally are balanced



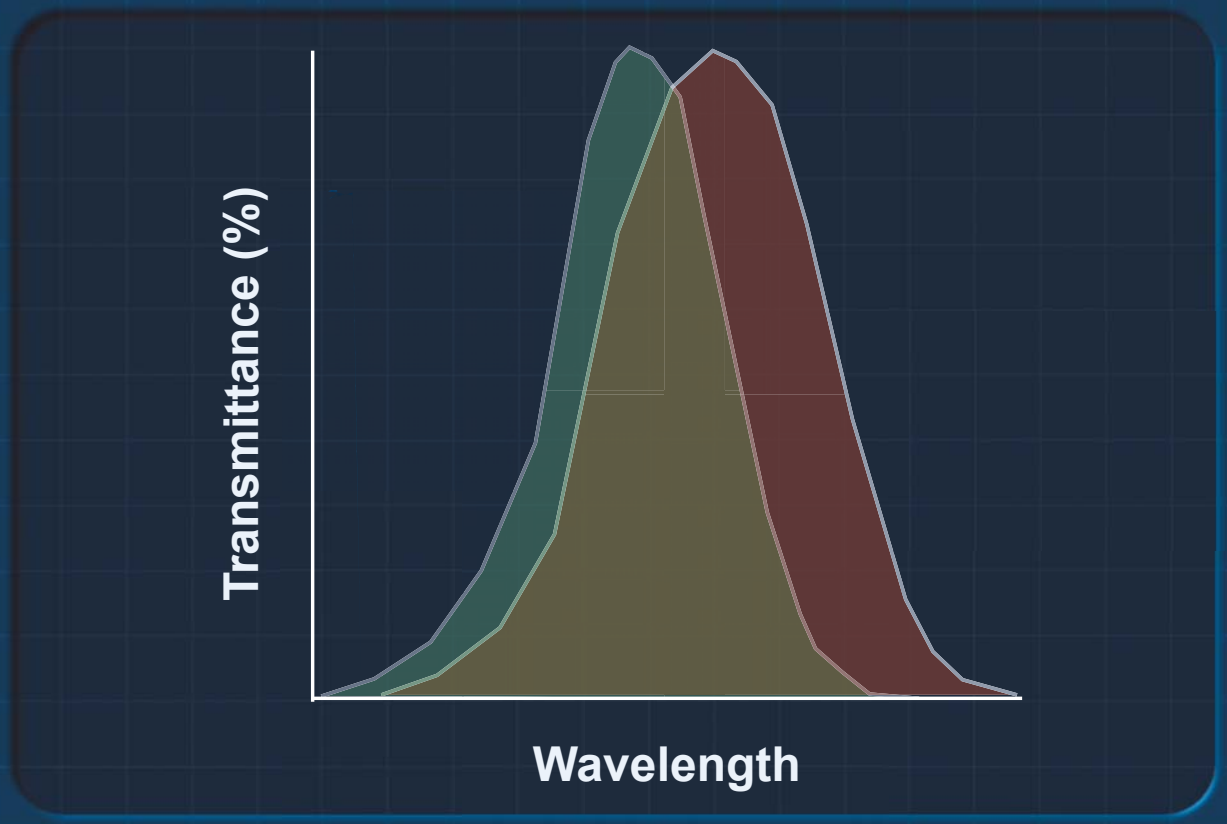
1. We are interested in L- and M-cones. We have far more of them than S-cones, and they are primarily responsible for luminance contrast and used in reading.
2. Balance between L- and M-cone activation with a slight advantage going to L-cone.
3. Note this is with a broad spectrum light source and doesn't account for biological variation including effects from: chromatic aberration, cone absorption and contrast gain, relative cone frequency, and macular pigment.

L- and M-cone signals normally are balanced



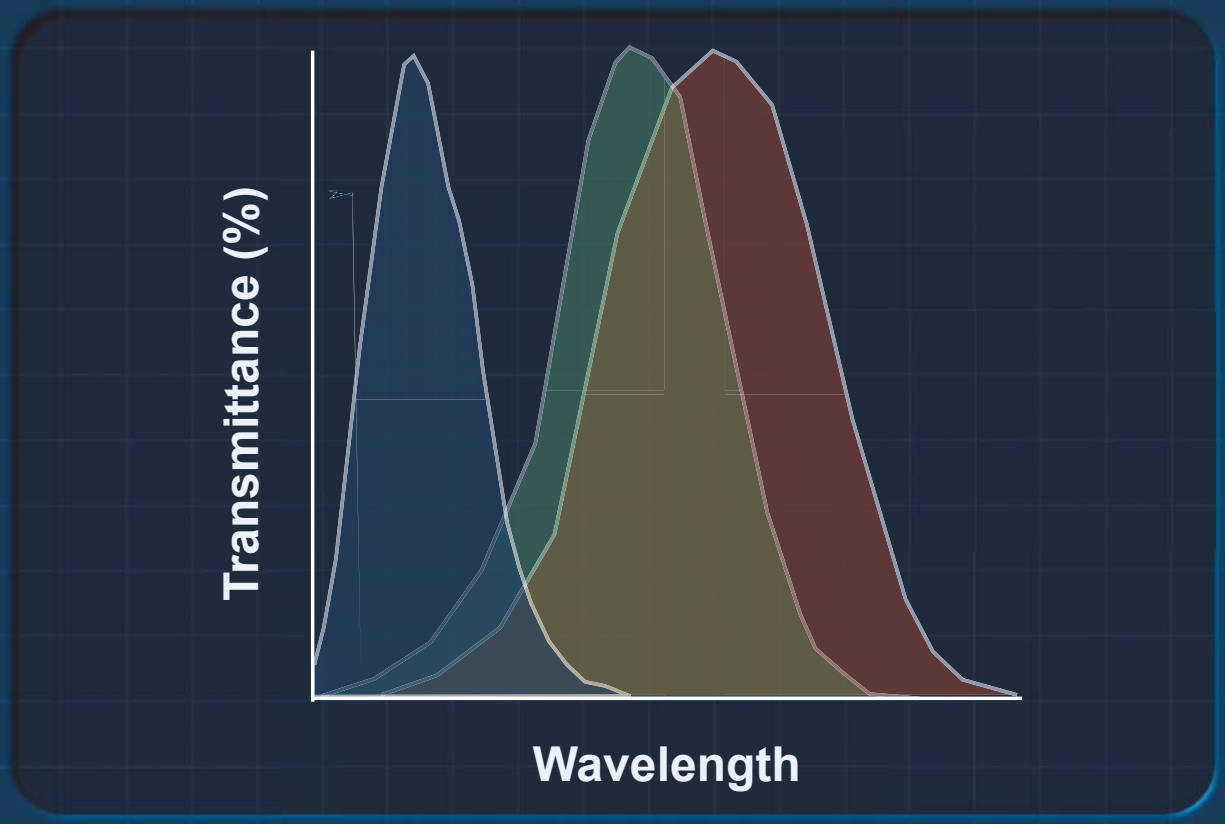
1. We are interested in L- and M-cones. We have far more of them than S-cones, and they are primarily responsible for luminance contrast and used in reading.
2. Balance between L- and M-cone activation with a slight advantage going to L-cone.
3. Note this is with a broad spectrum light source and doesn't account for biological variation including effects from: chromatic aberration, cone absorption and contrast gain, relative cone frequency, and macular pigment.

L- and M-cone signals normally are balanced



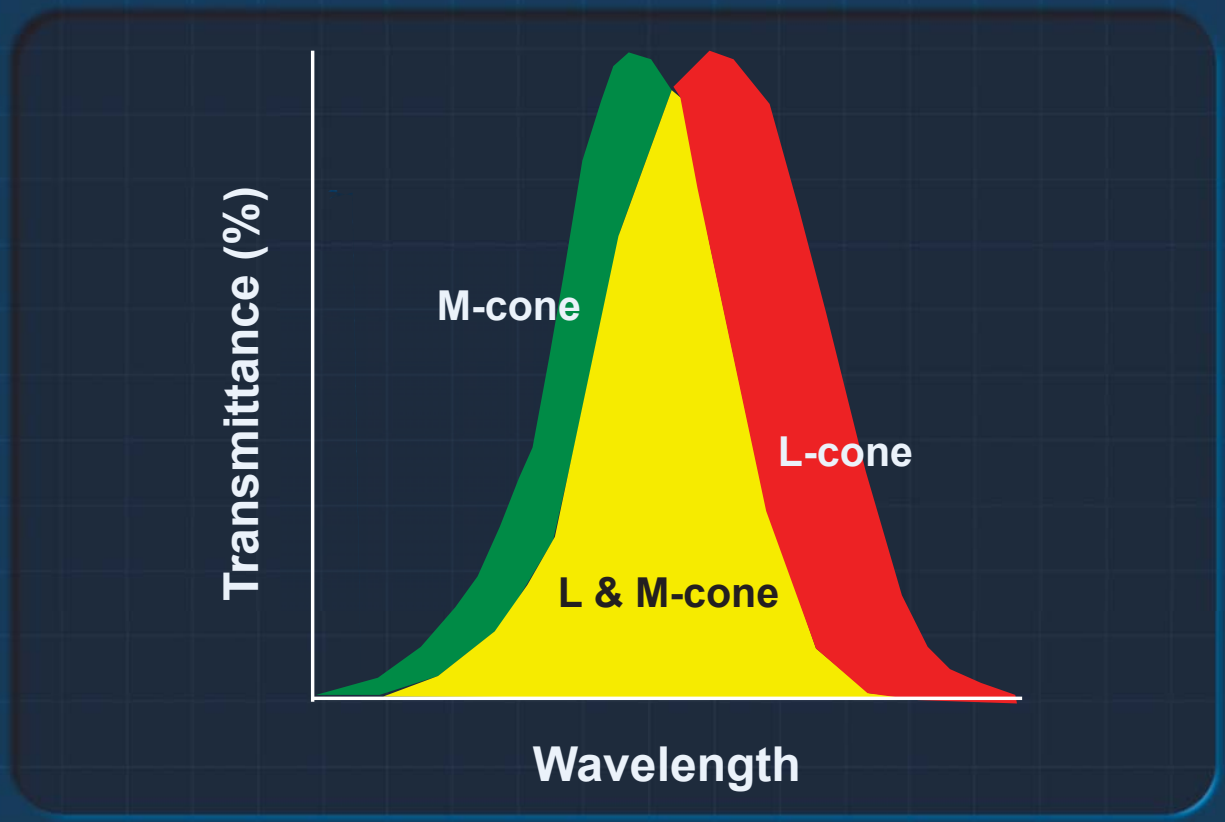
1. We are interested in L- and M-cones. We have far more of them than S-cones, and they are primarily responsible for luminance contrast and used in reading.
2. Balance between L- and M-cone activation with a slight advantage going to L-cone.
3. Note this is with a broad spectrum light source and doesn't account for biological variation including effects from: chromatic aberration, cone absorption and contrast gain, relative cone frequency, and macular pigment.

L- and M-cone signals normally are balanced



1. We are interested in L- and M-cones. We have far more of them than S-cones, and they are primarily responsible for luminance contrast and used in reading.
2. Balance between L- and M-cone activation with a slight advantage going to L-cone.
3. Note this is with a broad spectrum light source and doesn't account for biological variation including effects from: chromatic aberration, cone absorption and contrast gain, relative cone frequency, and macular pigment.

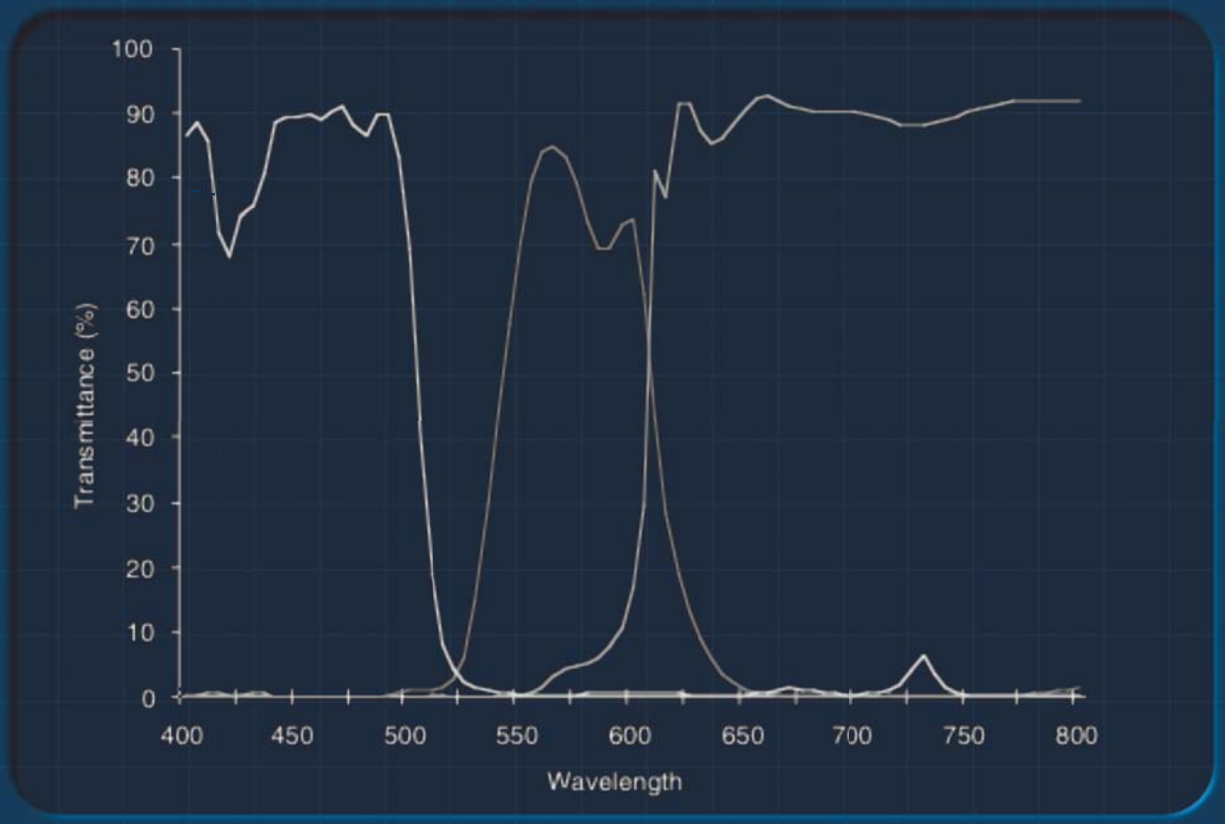
L- and M-cone signals normally are balanced



L/M ratio = 1.22 for equal energy source

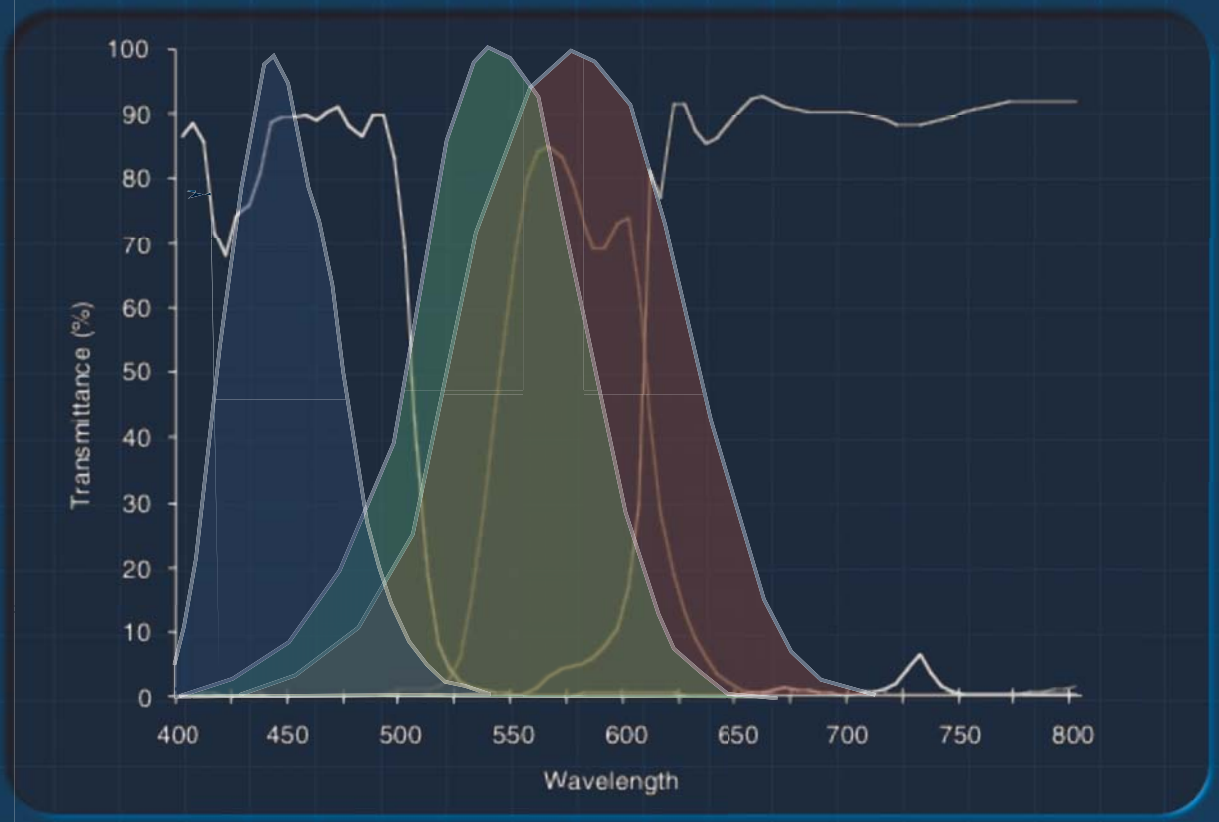
1. We are interested in L- and M-cones. We have far more of them than S-cones, and they are primarily responsible for luminance contrast and used in reading.
2. Balance between L- and M-cone activation with a slight advantage going to L-cone.
3. Note this is with a broad spectrum light source and doesn't account for biological variation including effects from: chromatic aberration, cone absorption and contrast gain, relative cone frequency, and macular pigment.

Red filter is increasing the L/M cone contrast ratio



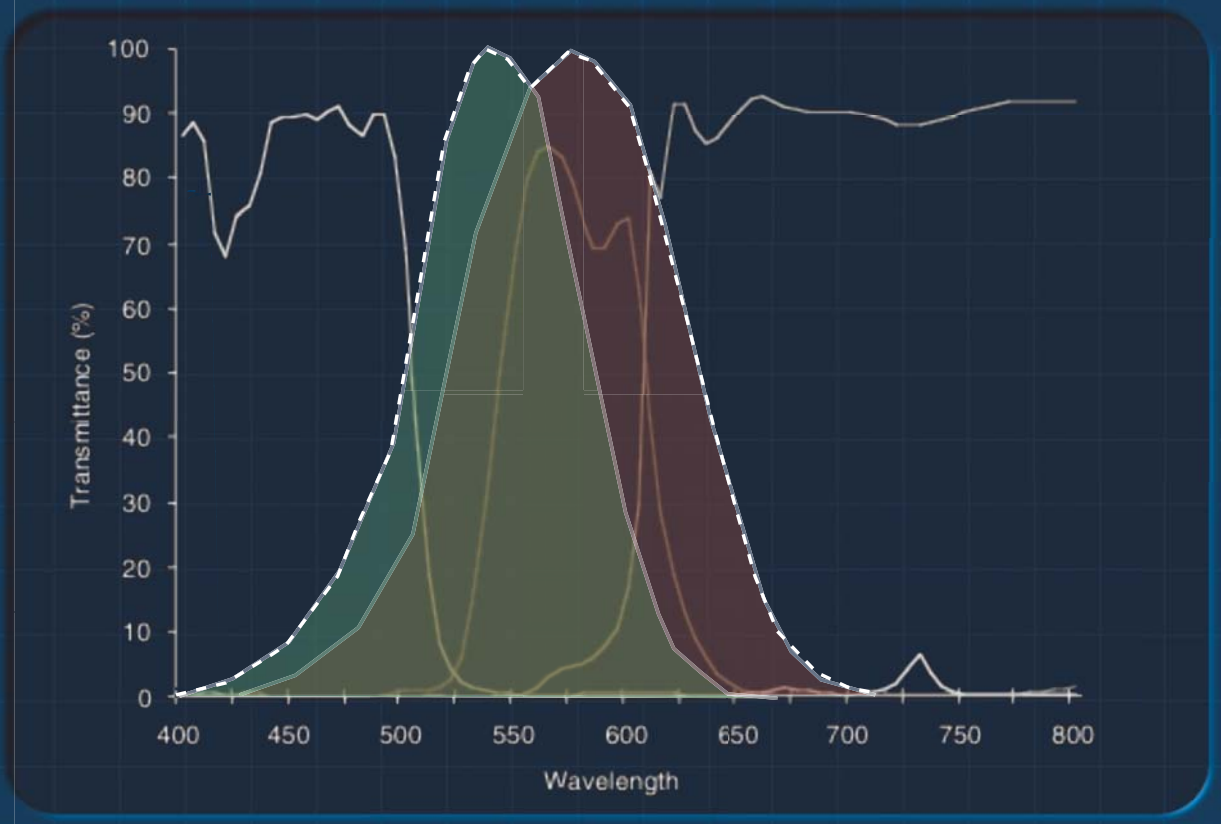
1. The red dichroic filter changes that balance, creating a strong L-cone bias and increasing the L/M ratio.

Red filter is increasing the L/M cone contrast ratio



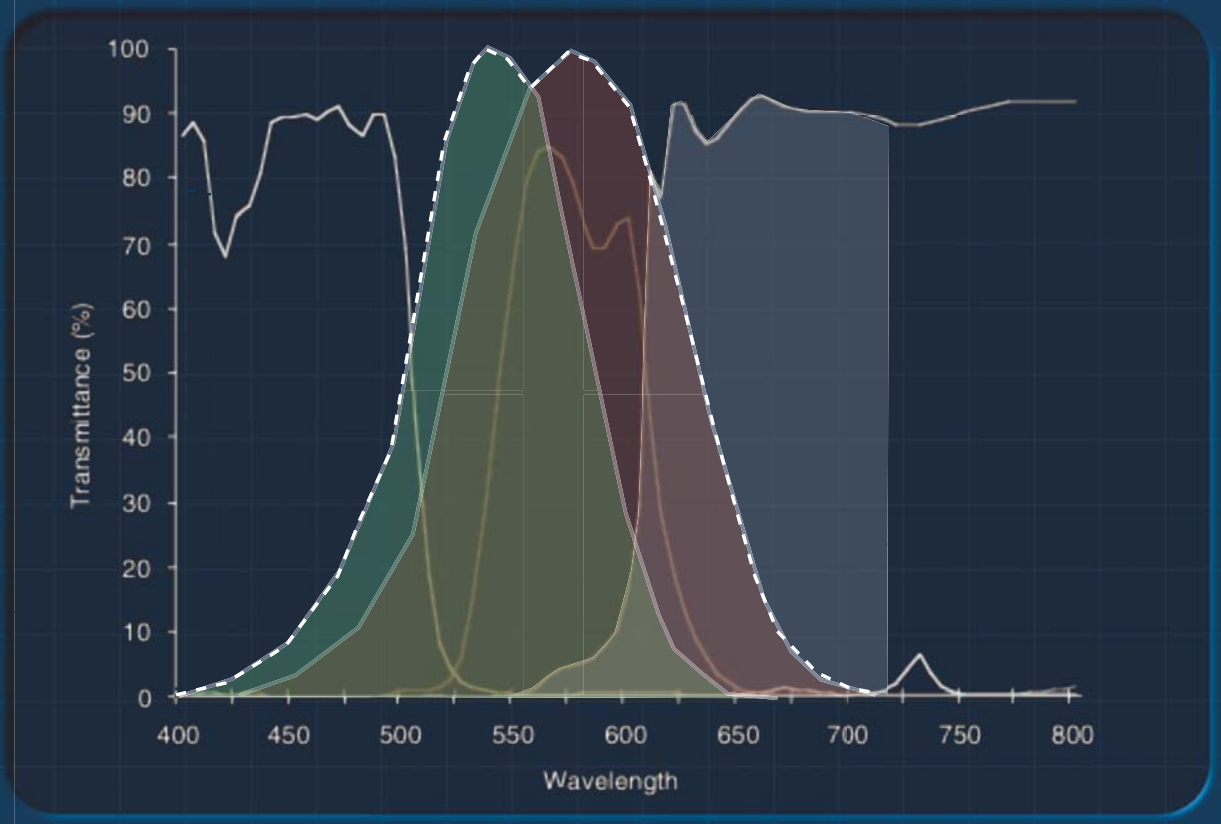
1. The red dichroic filter changes that balance, creating a strong L-cone bias and increasing the L/M ratio.

Red filter is increasing the L/M cone contrast ratio



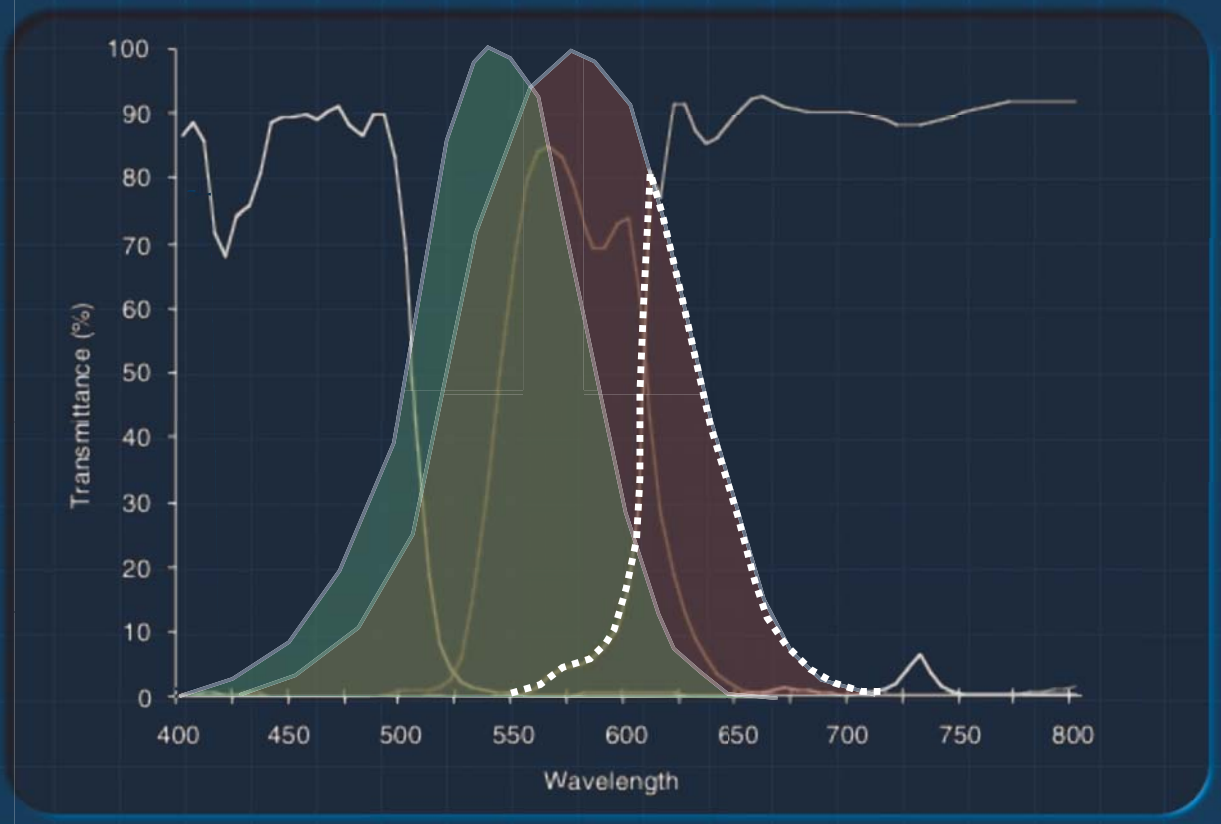
1. The red dichroic filter changes that balance, creating a strong L-cone bias and increasing the L/M ratio.

Red filter is increasing the L/M cone contrast ratio



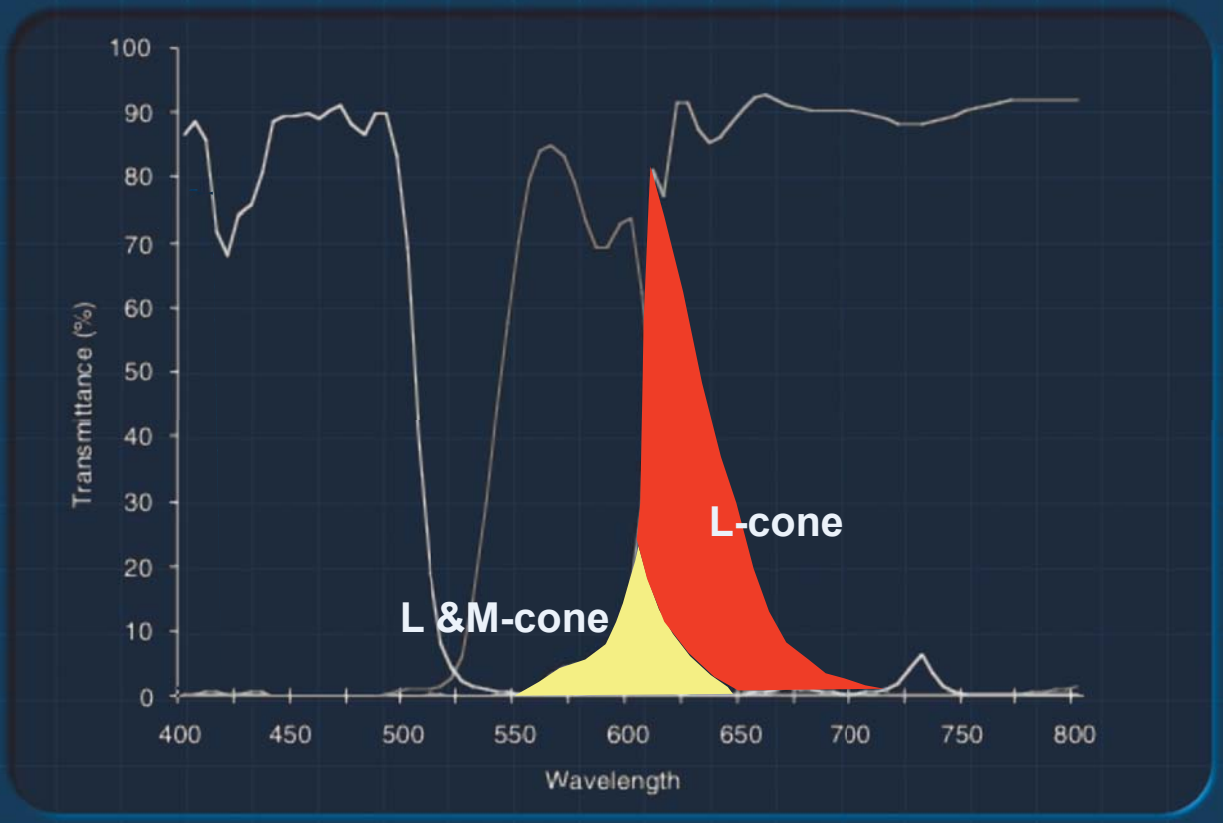
1. The red dichroic filter changes that balance, creating a strong L-cone bias and increasing the L/M ratio.

Red filter is increasing the L/M cone contrast ratio



1. The red dichroic filter changes that balance, creating a strong L-cone bias and increasing the L/M ratio.

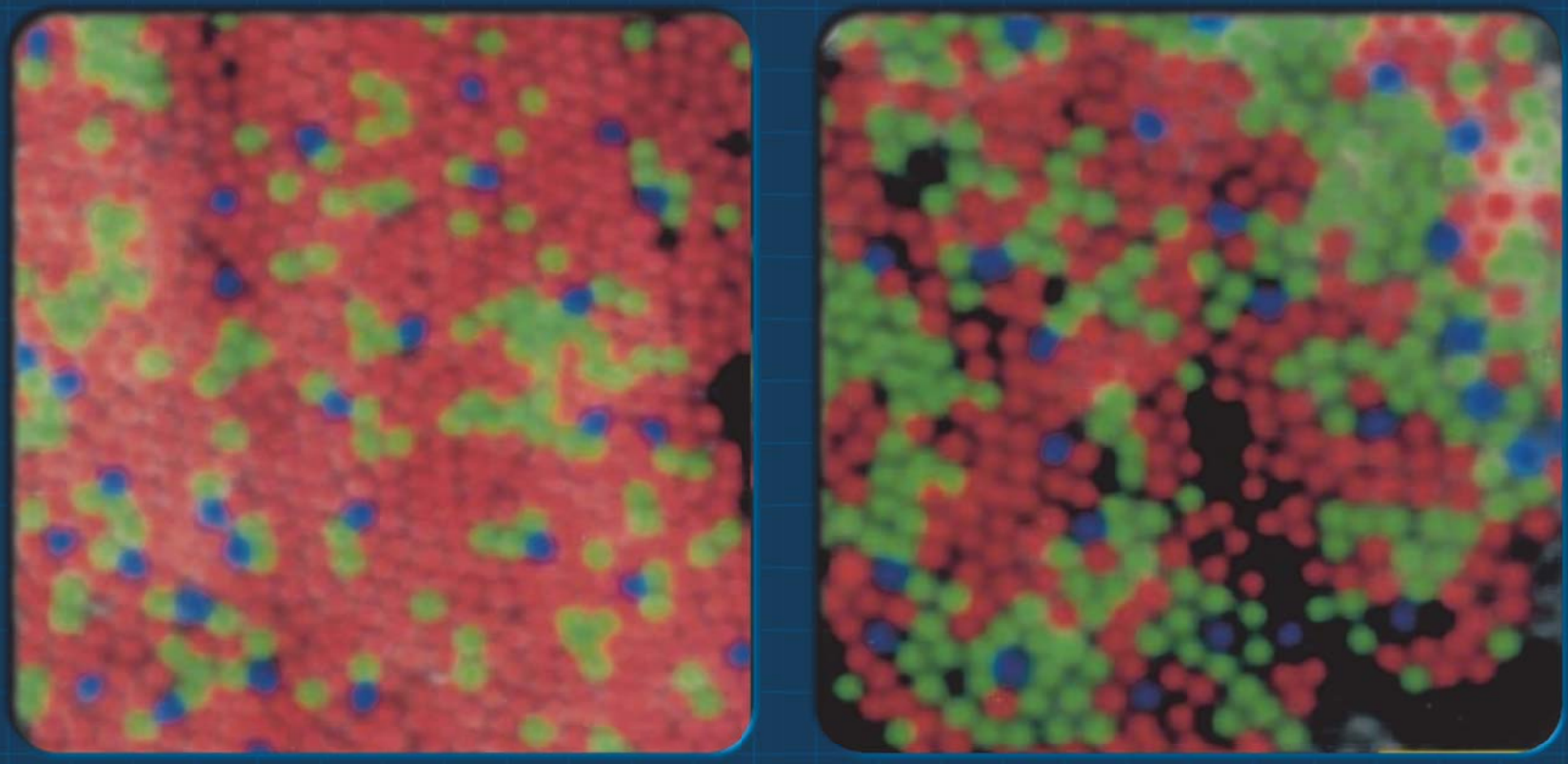
Red filter is increasing the L/M cone contrast ratio



1. The red dichroic filter changes that balance, creating a strong L-cone bias and increasing the L/M ratio.

L/M-cone ratios vary

From Roorda & Williams 1999



L/M = 3.79

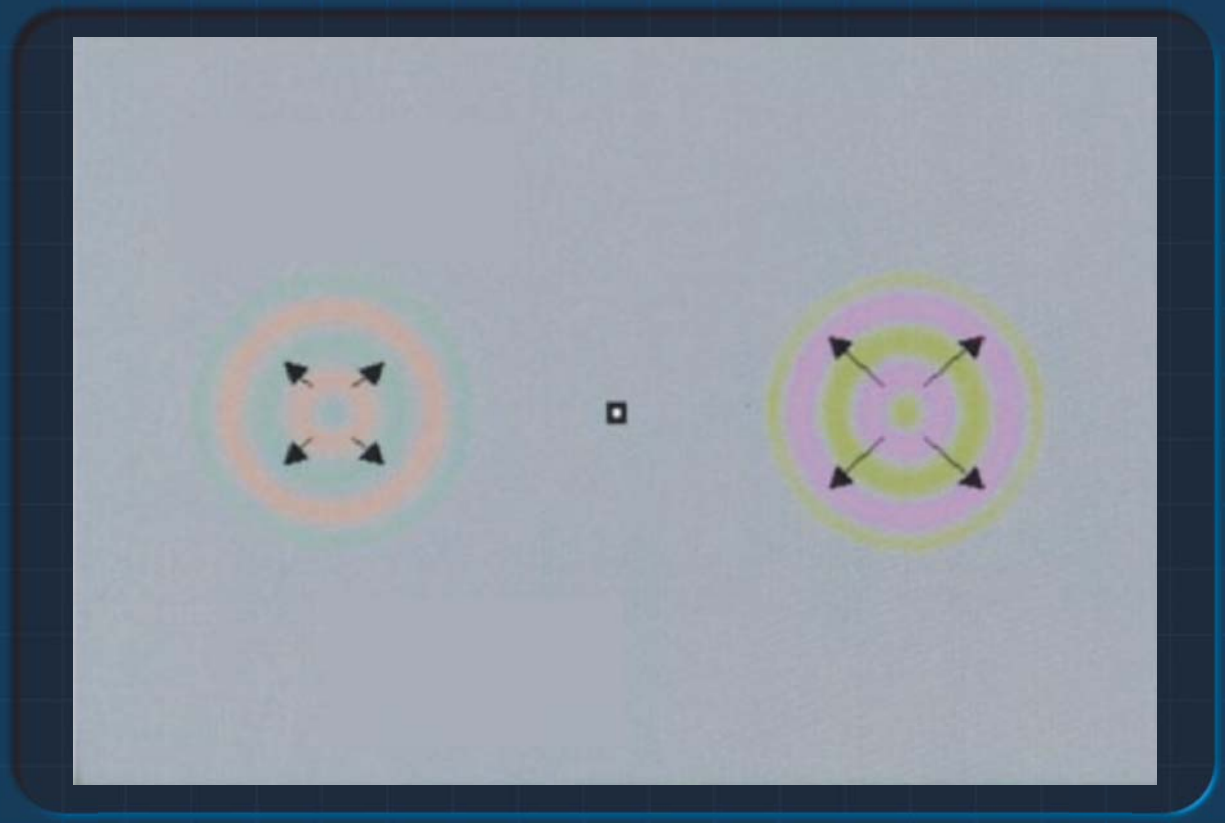
L/M = 1.15

Biological variation is a factor in L/M ratios as well, including effects from: chromatic aberration, cone absorption, relative cone frequency, and macular pigment. This slide shows relative cone frequency variation.

Carroll, Neitz, & Neitz 2002 reported:

1. Average L/M = 1.86
2. Range: 0.4 – 13 (4x difference) or 28% – 93%L

Measuring L/M cone contrast sensitivity



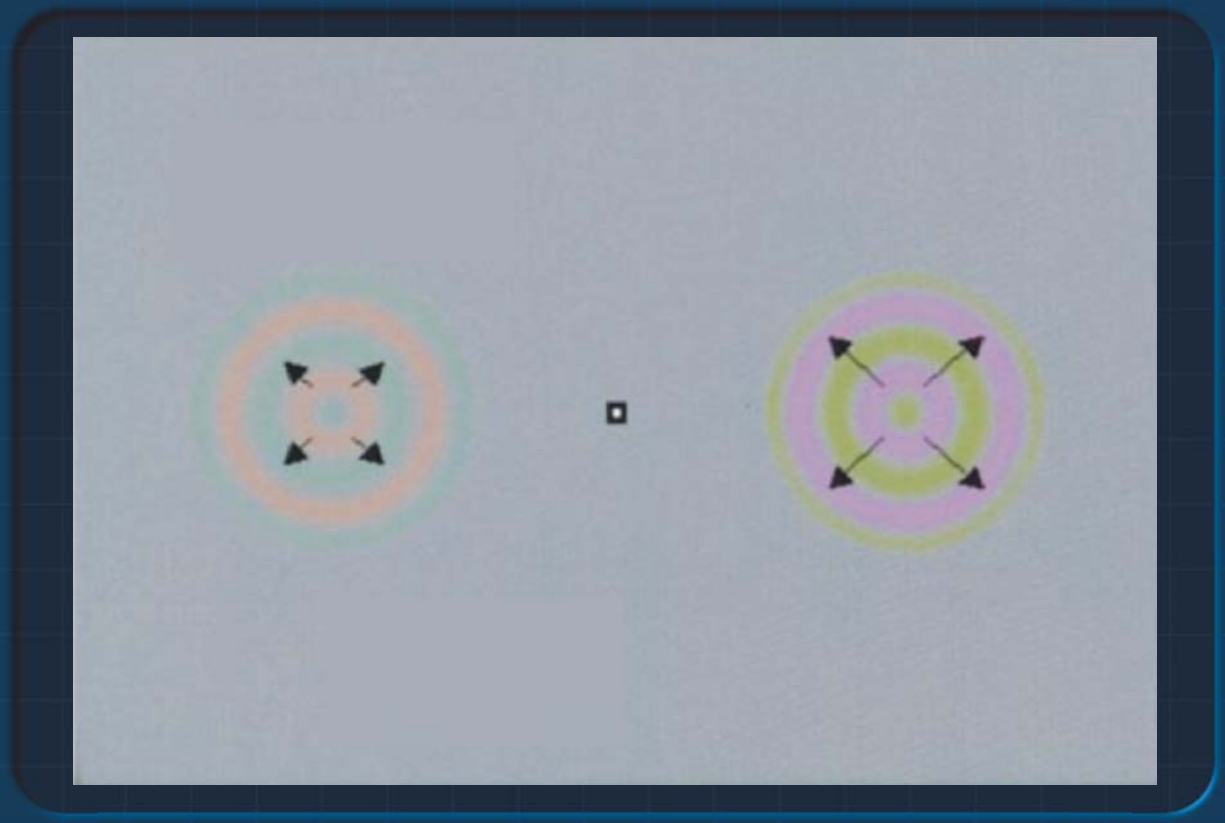
From Chase et al 2007

1. Point of Subjective Equality (PSE) task. Vary the speed of L-cone isolating standard with a fixed cone-contrast to match the target moving at a fixed speed and presented at five different cone-contrast levels.
2. Weaker cone sensitivity = slower moving grating. So, you increase speed of the target until the gratings match and that provides a means to measure the relative cone-signal strength.

3. 41 children, ages 7-15 (mean=10.2) from primary school in Reading and Dyslexia Research Trust Clinic. Screened for neurological problems, normal IQ, acuity, ocular-motor, binocular function, steropsis, color perception.

4. Five excluded for color deficiencies, 17 because of poor task performance.

Measuring L/M cone contrast sensitivity



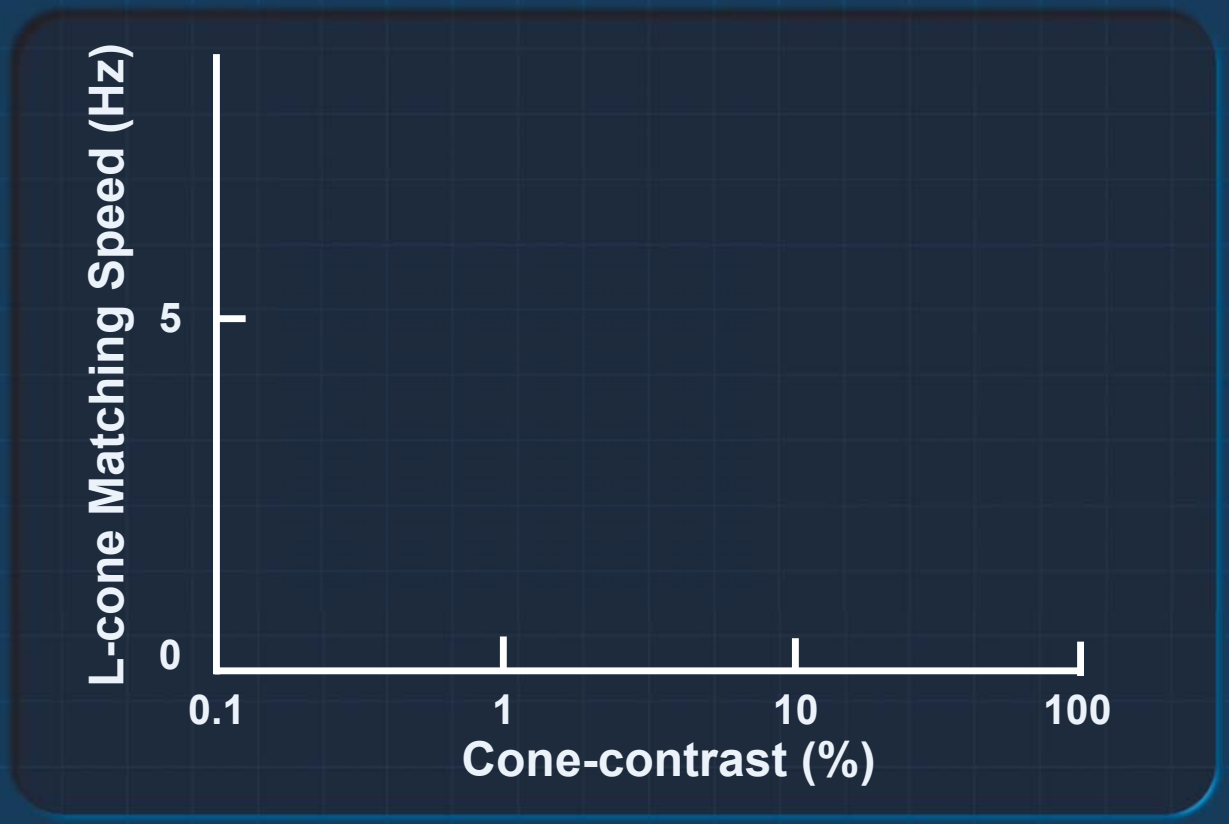
From Chase et al 2007

1. Point of Subjective Equality (PSE) task. Vary the speed of L-cone isolating standard with a fixed cone-contrast to match the target moving at a fixed speed and presented at five different cone-contrast levels.
2. Weaker cone sensitivity = slower moving grating. So, you increase speed of the target until the gratings match and that provides a means to measure the relative cone-signal strength.

3. 41 children, ages 7-15 (mean=10.2) from primary school in Reading and Dyslexia Research Trust Clinic. Screened for neurological problems, normal IQ, acuity, ocular-motor, binocular function, steropsis, color perception.

4. Five excluded for color deficiencies, 17 because of poor task performance.

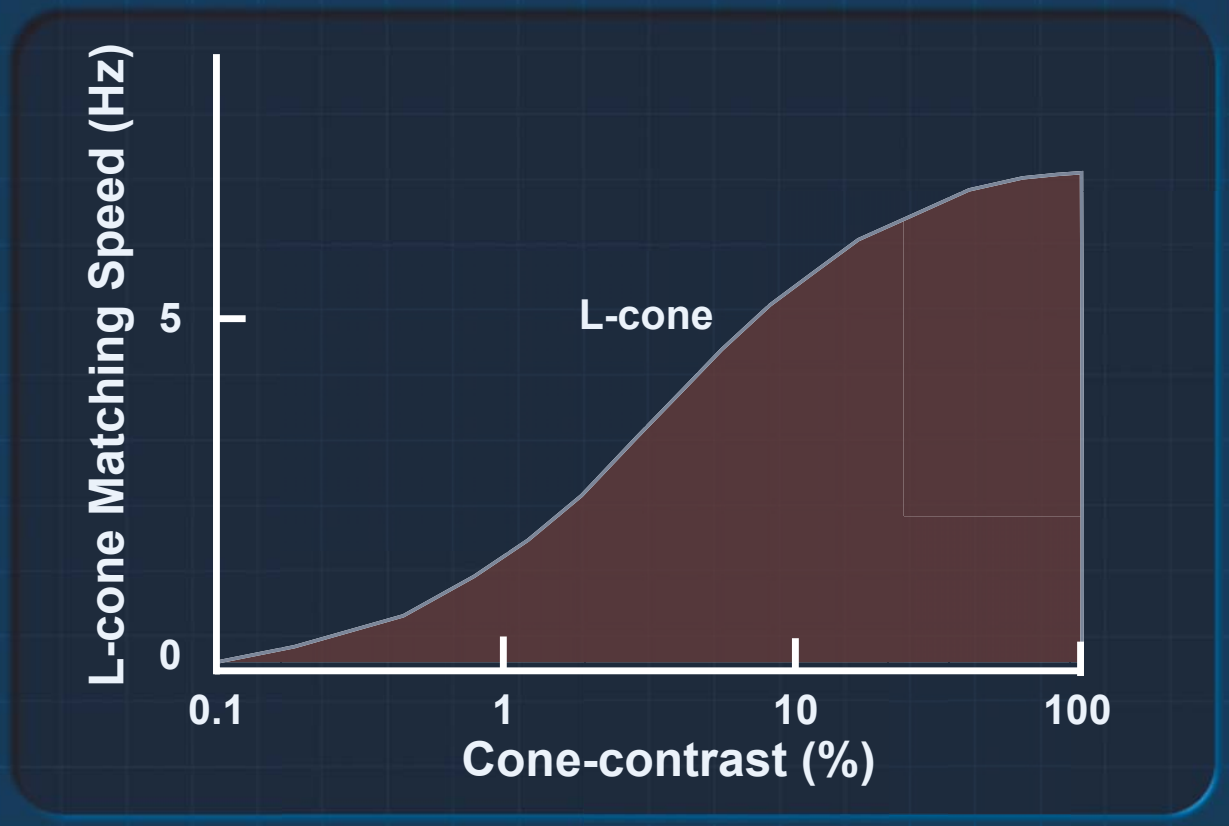
Cone-contrast needed to match L-cone



From Chase et al 2007

1. The apparent speed will vary with the contrast. Weak contrast appears to move slowly. Increasing contrast, speeds it up.
2. Displacement along the x-axis represents relative cone-signal strength in this task.
3. Values were 3.4, 5.0, and 53.0% for L, M, & S-cone contrast functions in the figure on the left. Or L/M = 1.5 and L/S = 15.

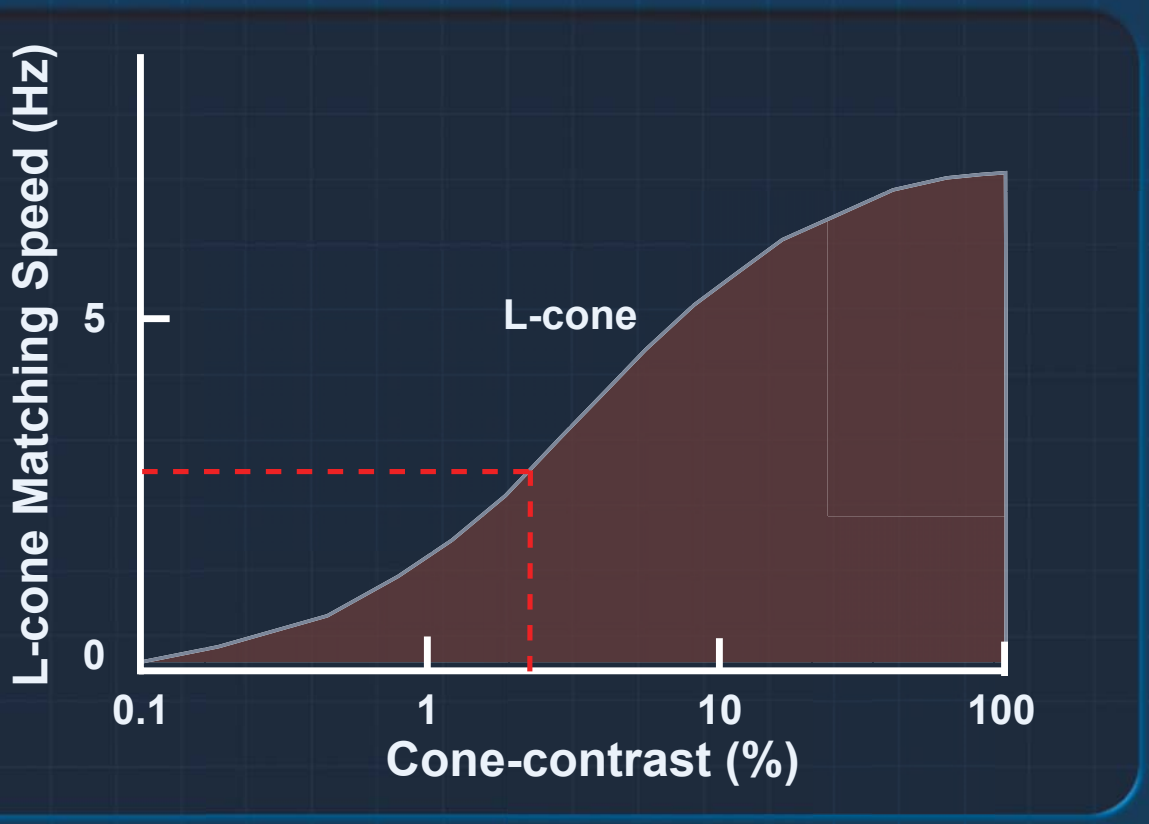
Cone-contrast needed to match L-cone



From Chase et al 2007

1. The apparent speed will vary with the contrast. Weak contrast appears to move slowly. Increasing contrast, speeds it up.
2. Displacement along the x-axis represents relative cone-signal strength in this task.
3. Values were 3.4, 5.0, and 53.0% for L, M, & S-cone contrast functions in the figure on the left. Or L/M = 1.5 and L/S = 15.

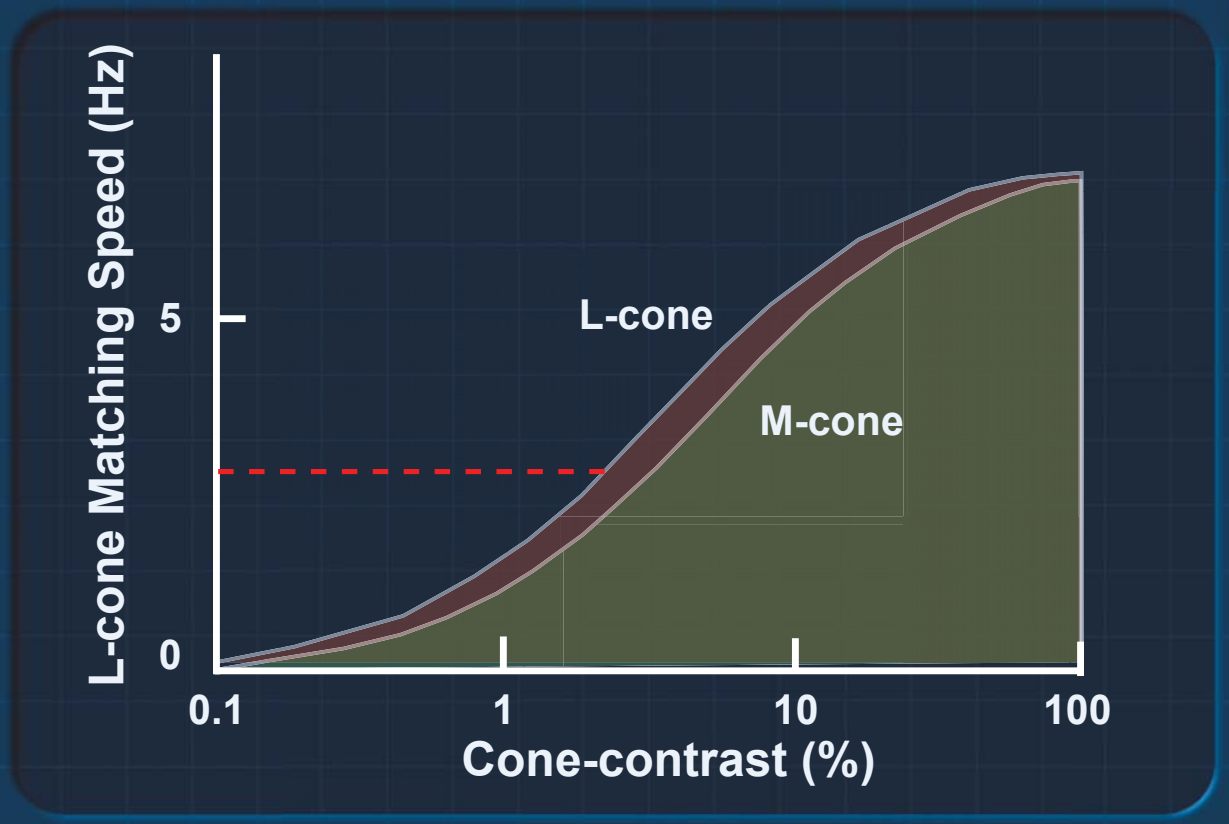
Cone-contrast needed to match L-cone



From Chase et al 2007

1. The apparent speed will vary with the contrast. Weak contrast appears to move slowly. Increasing contrast, speeds it up.
2. Displacement along the x-axis represents relative cone-signal strength in this task.
3. Values were 3.4, 5.0, and 53.0% for L, M, & S-cone contrast functions in the figure on the left. Or L/M = 1.5 and L/S = 15.

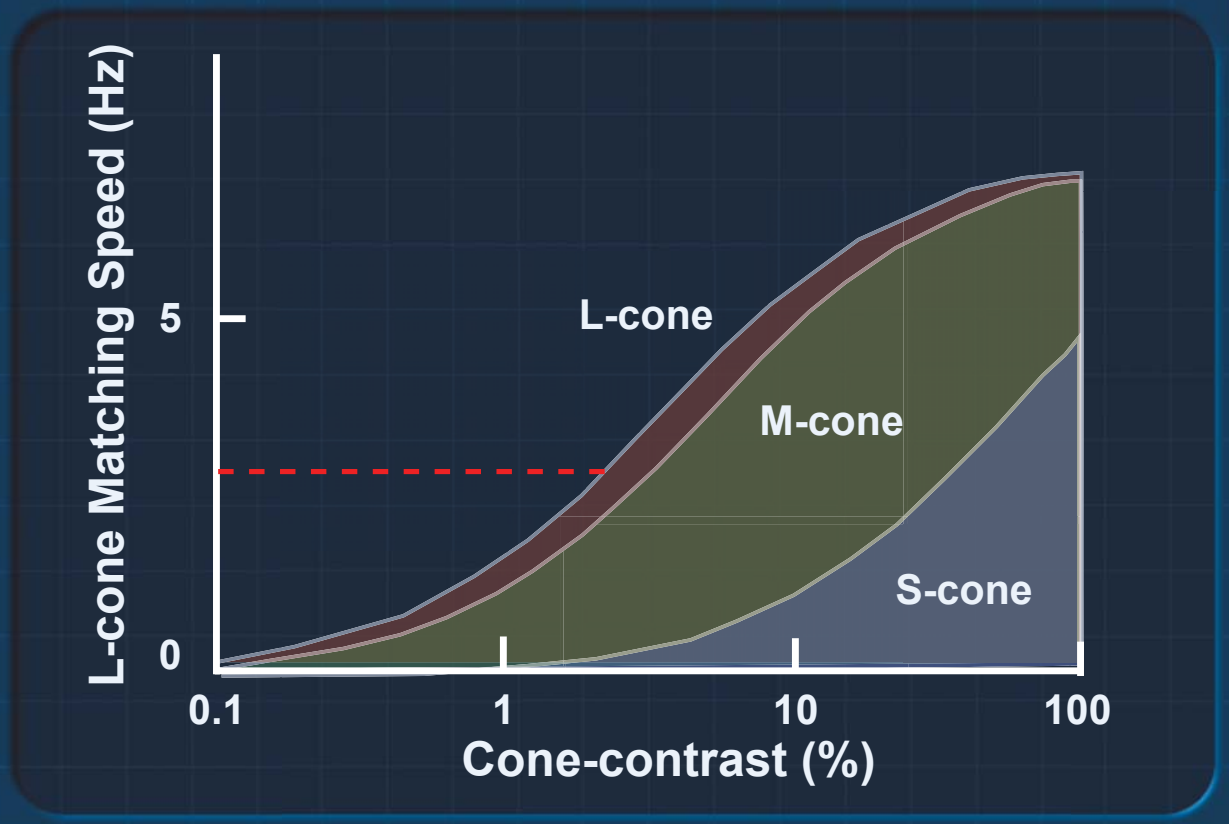
Cone-contrast needed to match L-cone



From Chase et al 2007

1. The apparent speed will vary with the contrast. Weak contrast appears to move slowly. Increasing contrast, speeds it up.
2. Displacement along the x-axis represents relative cone-signal strength in this task.
3. Values were 3.4, 5.0, and 53.0% for L, M, & S-cone contrast functions in the figure on the left. Or L/M = 1.5 and L/S = 15.

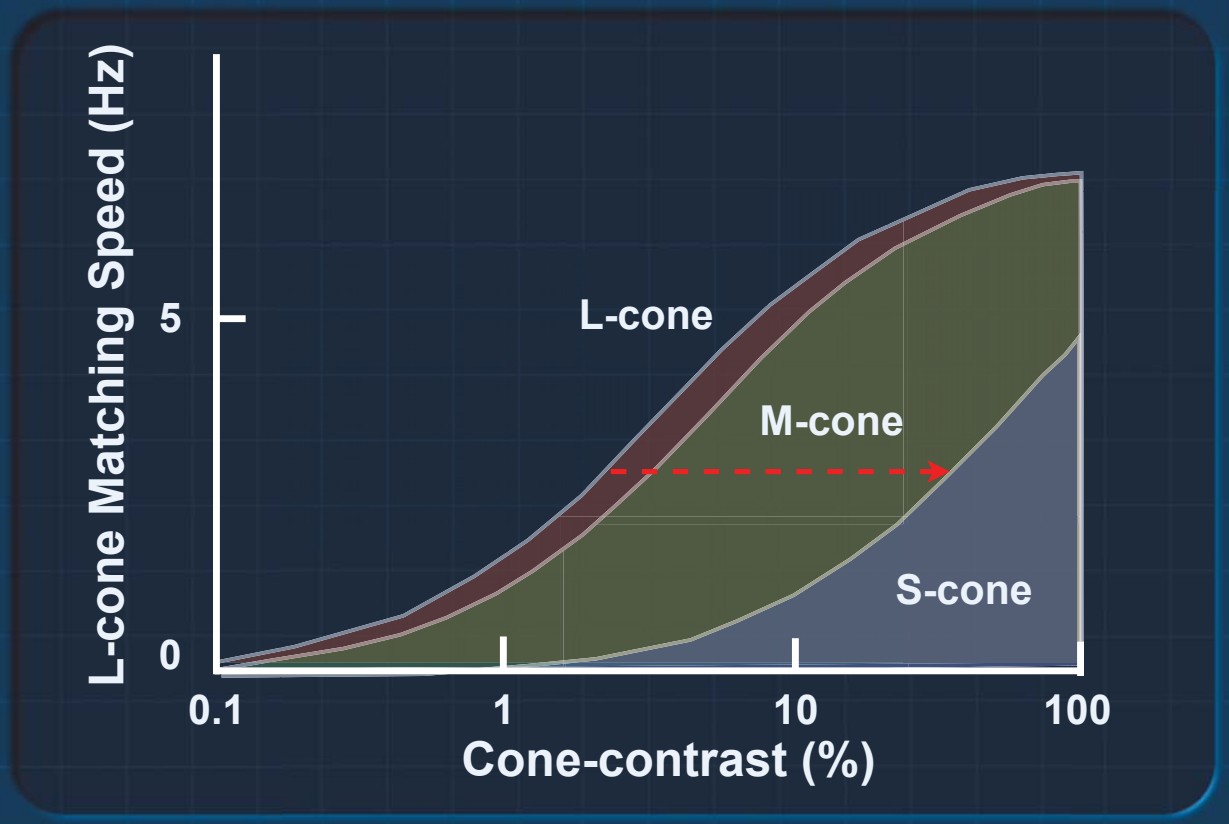
Cone-contrast needed to match L-cone



From Chase et al 2007

1. The apparent speed will vary with the contrast. Weak contrast appears to move slowly. Increasing contrast, speeds it up.
2. Displacement along the x-axis represents relative cone-signal strength in this task.
3. Values were 3.4, 5.0, and 53.0% for L, M, & S-cone contrast functions in the figure on the left. Or L/M = 1.5 and L/S = 15.

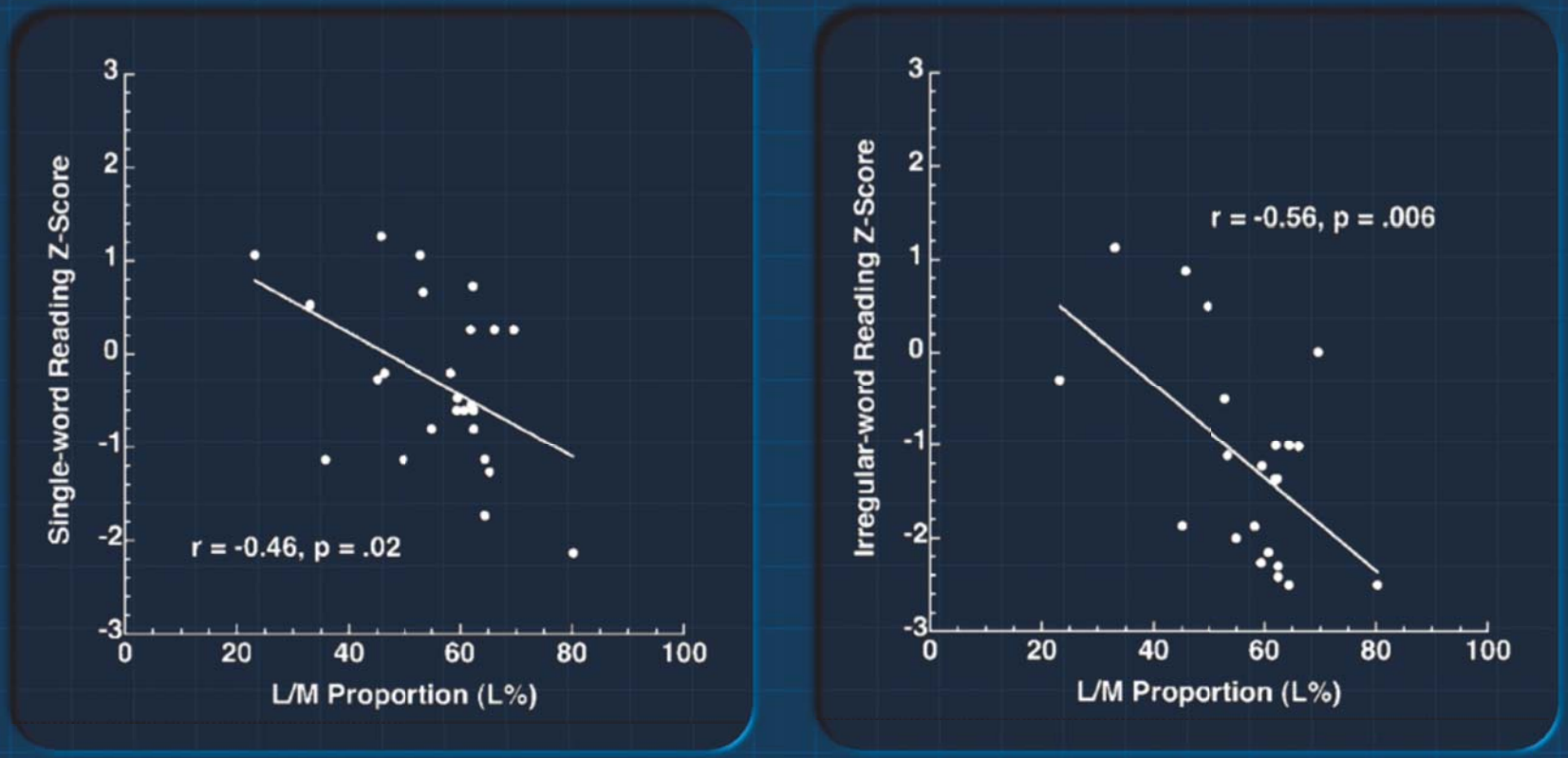
Cone-contrast needed to match L-cone



From Chase et al 2007

1. The apparent speed will vary with the contrast. Weak contrast appears to move slowly. Increasing contrast, speeds it up.
2. Displacement along the x-axis represents relative cone-signal strength in this task.
3. Values were 3.4, 5.0, and 53.0% for L, M, & S-cone contrast functions in the figure on the left. Or L/M = 1.5 and L/S = 15.

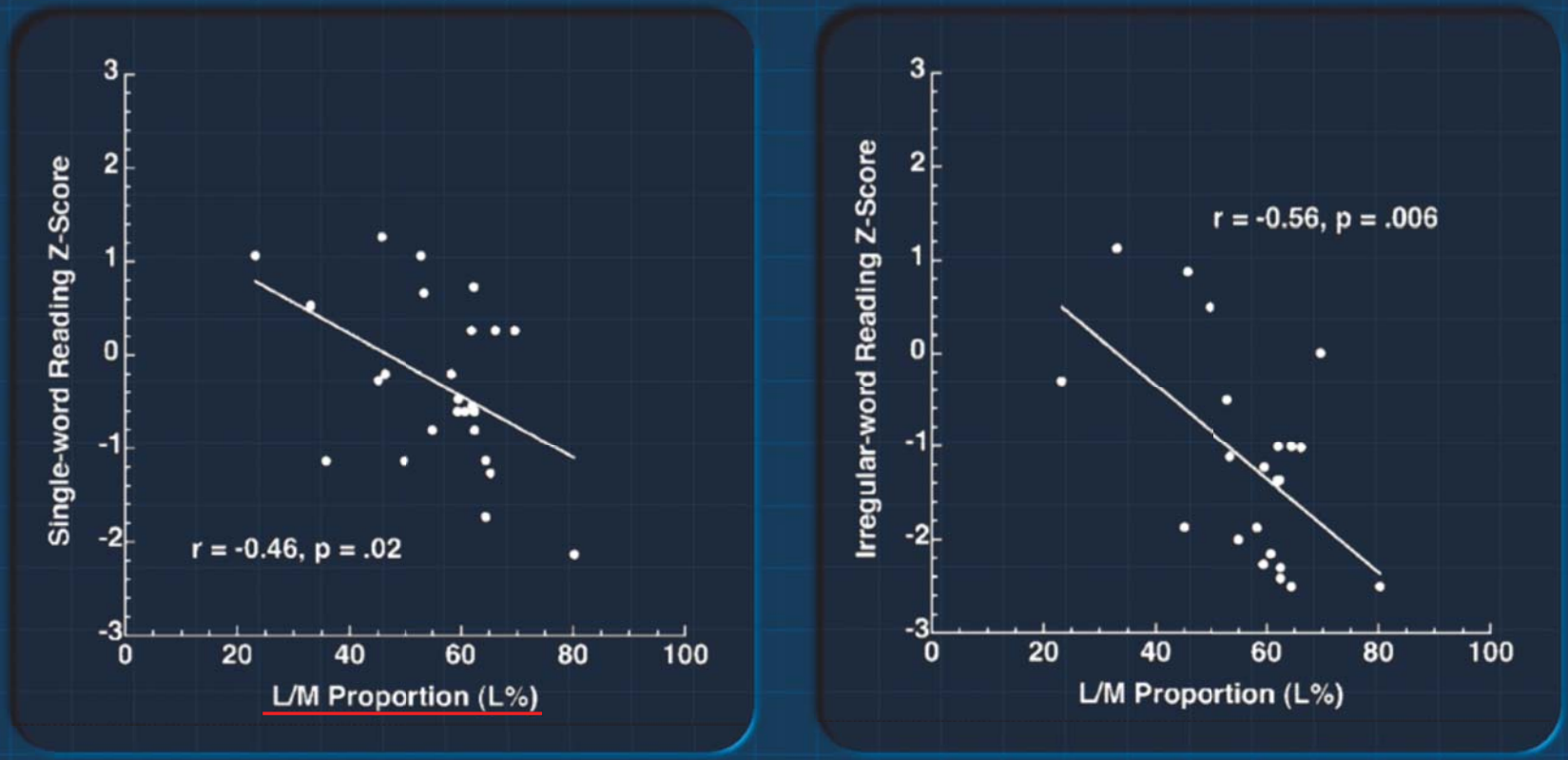
Children with higher L/M sensitivity are poorer readers



From Chase et al 2007

no correlation with non-words.

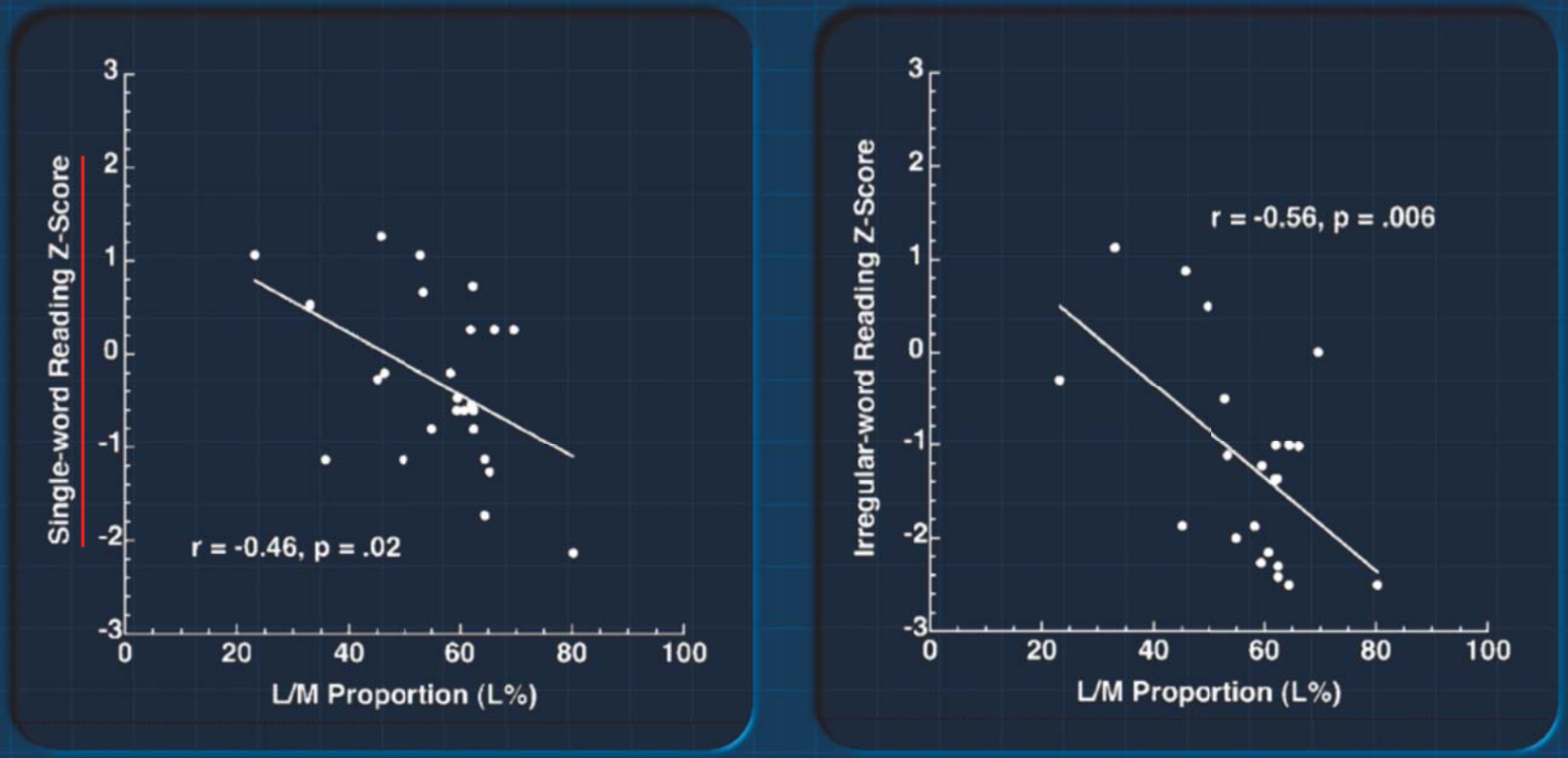
Children with higher L/M sensitivity are poorer readers



From Chase et al 2007

no correlation with non-words.

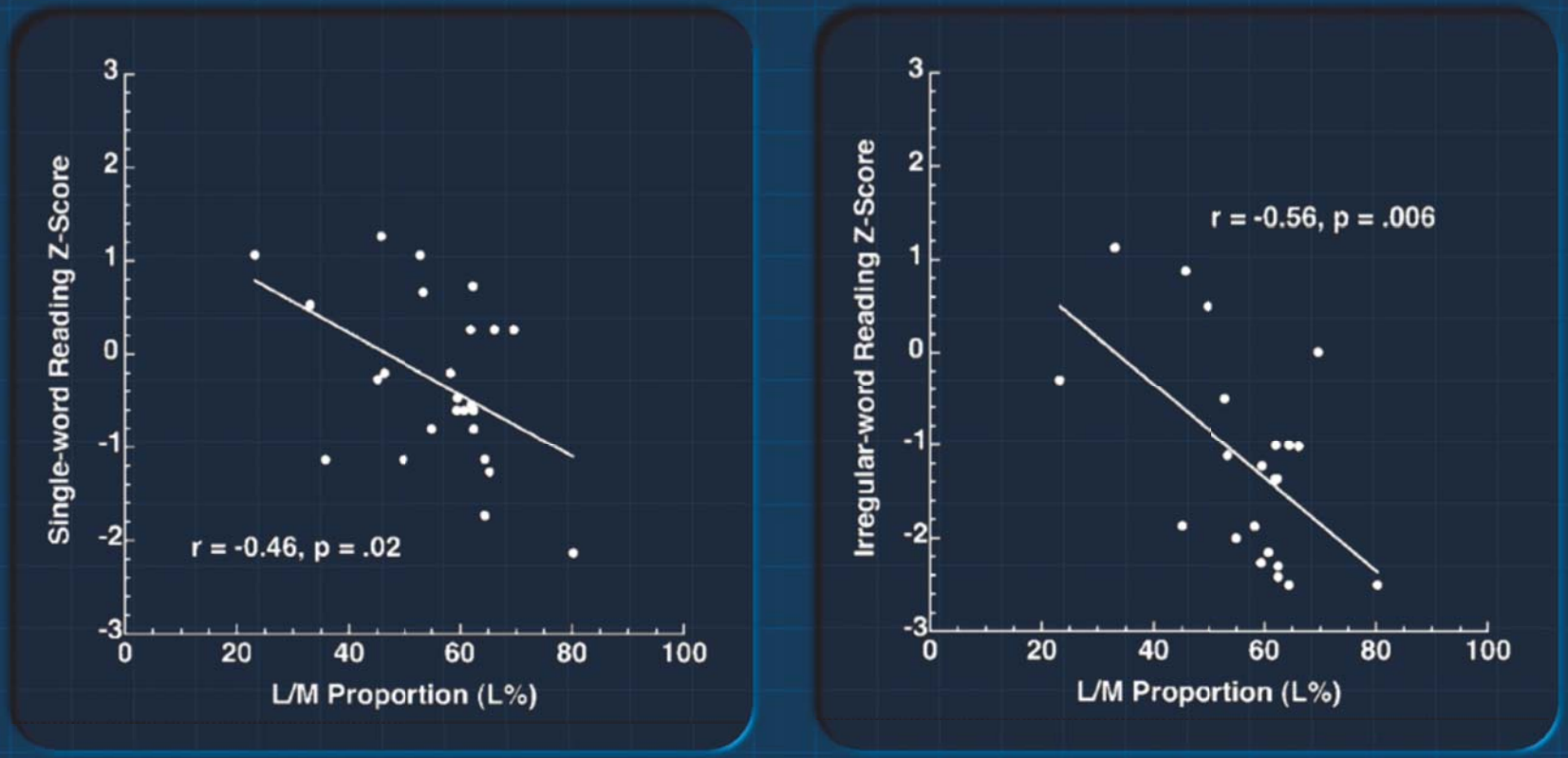
Children with higher L/M sensitivity are poorer readers



From Chase et al 2007

no correlation with non-words.

Children with higher L/M sensitivity are poorer readers



From Chase et al 2007

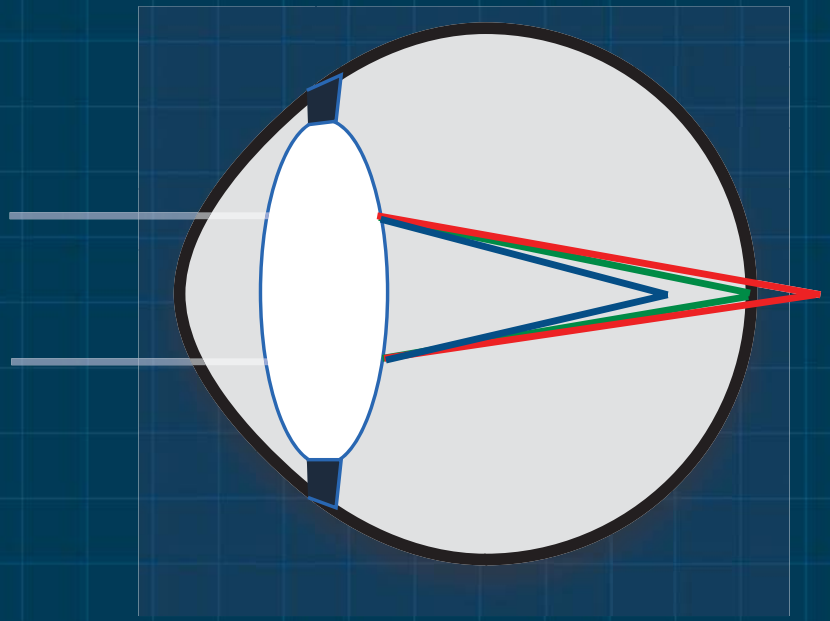
no correlation with non-words.

Color summary

- Lighting or filter conditions change the L/M cone contrast ratio.
- Biological variation in L/M cone sensitivity.
- Either way, increasing the L/M ratio impairs reading performance.
- L/M ratio drives accommodation.

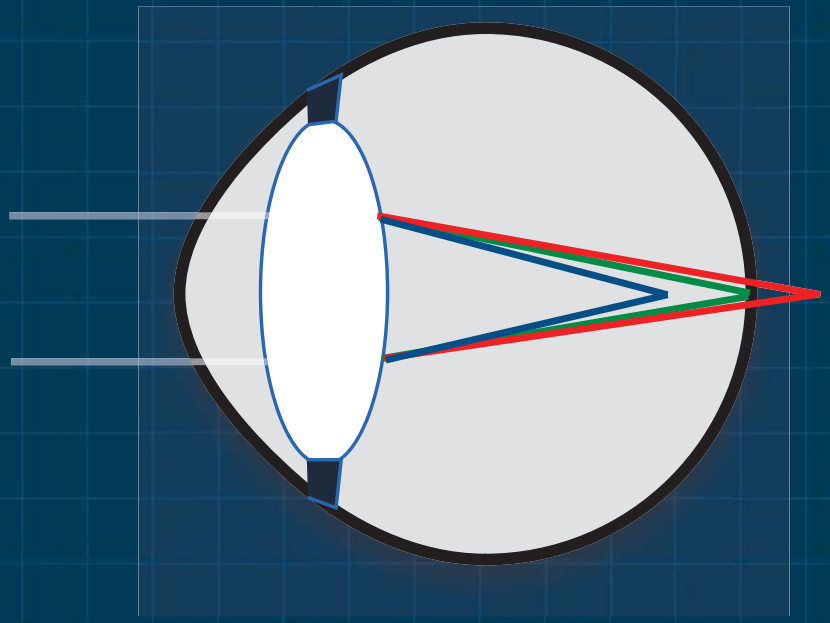
1. I call variation in the light source as L/M cone contrast, and biological variation as L/M-cone or L/M sensitivity.

Part 4: Chromatic Aberration



1. Lens has different refractive index for different wavelengths and disperses the light.
2. Blue leads, but Red lags.

Part 4: Chromatic Aberration

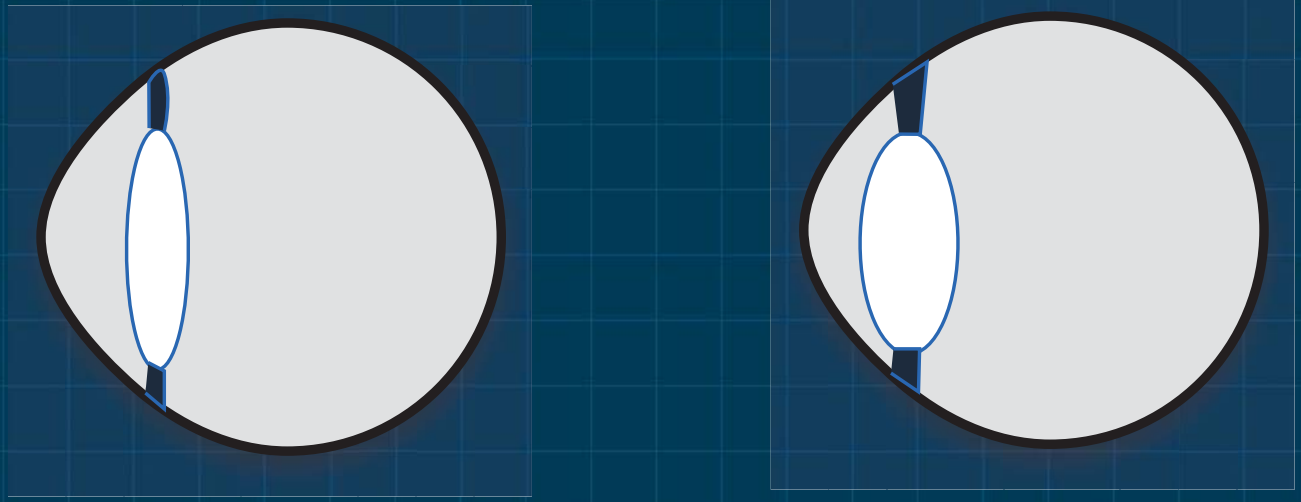


380nm ---------- 760nm

~2.5D relative defocus

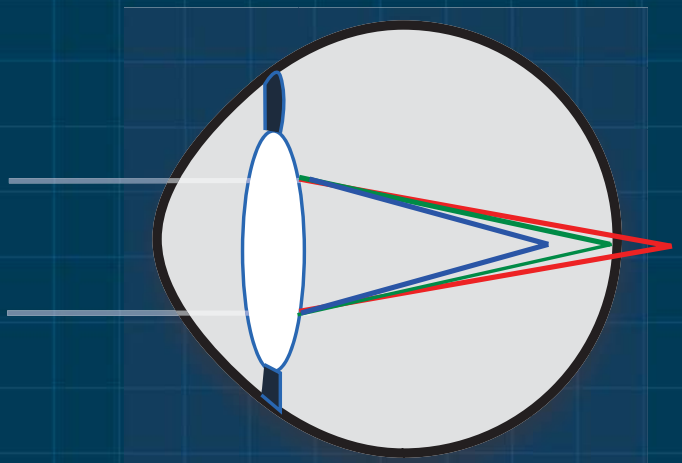
1. Lens has different refractive index for different wavelengths and disperses the light.
2. Blue leads, but Red lags.

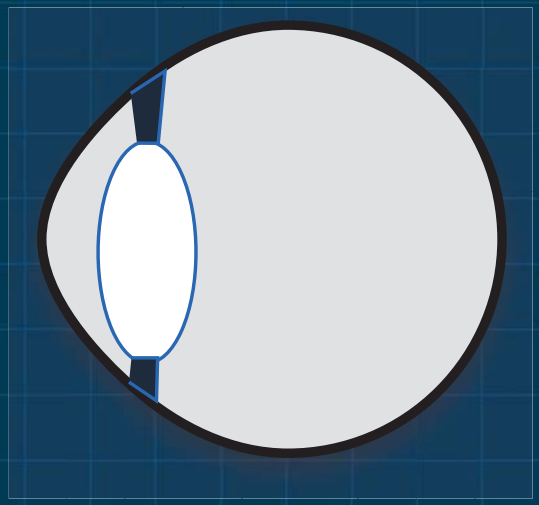
Accommodative demand varies by wavelength of light



1. Without accommodation, Medium wavelengths imaged on retina (left).
2. Long wavelengths out of focus (left); more accommodation required.
3. (Right) long wavelengths now in focus after accommodation.
4. Larger proportion of long wavelengths requires more accommodative effort.

Accommodative demand varies by wavelength of light

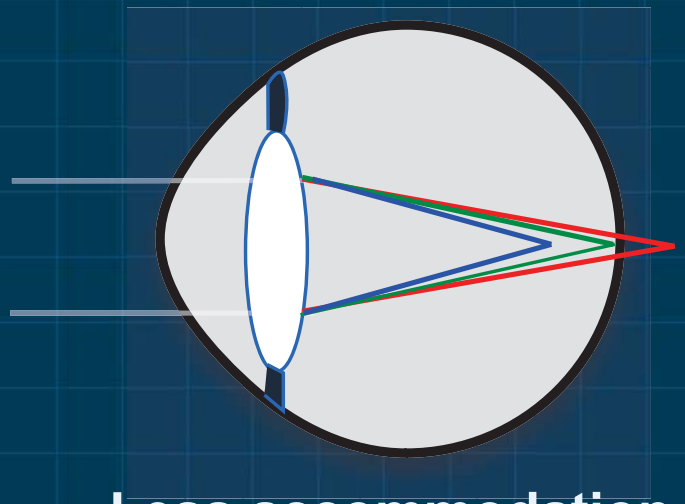




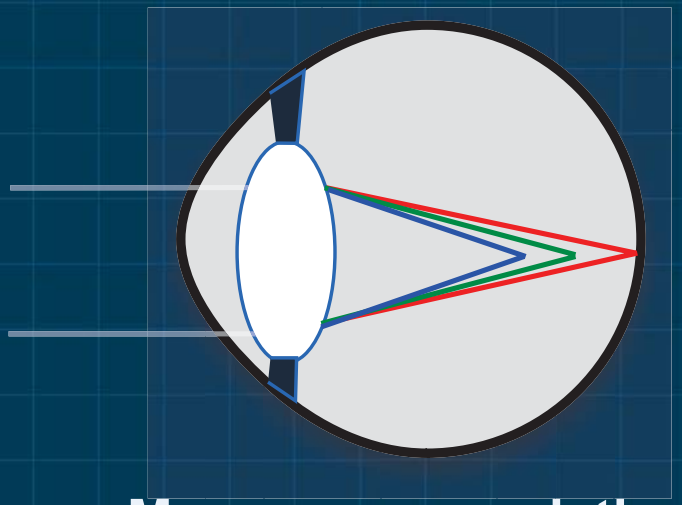
Less accommodation needed for M-wavelengths

1. Without accommodation, Medium wavelengths imaged on retina (left).
2. Long wavelengths out of focus (left); more accommodation required.
3. (Right) long wavelengths now in focus after accommodation.
4. Larger proportion of long wavelengths requires more accommodative effort.

Accommodative demand varies by wavelength of light

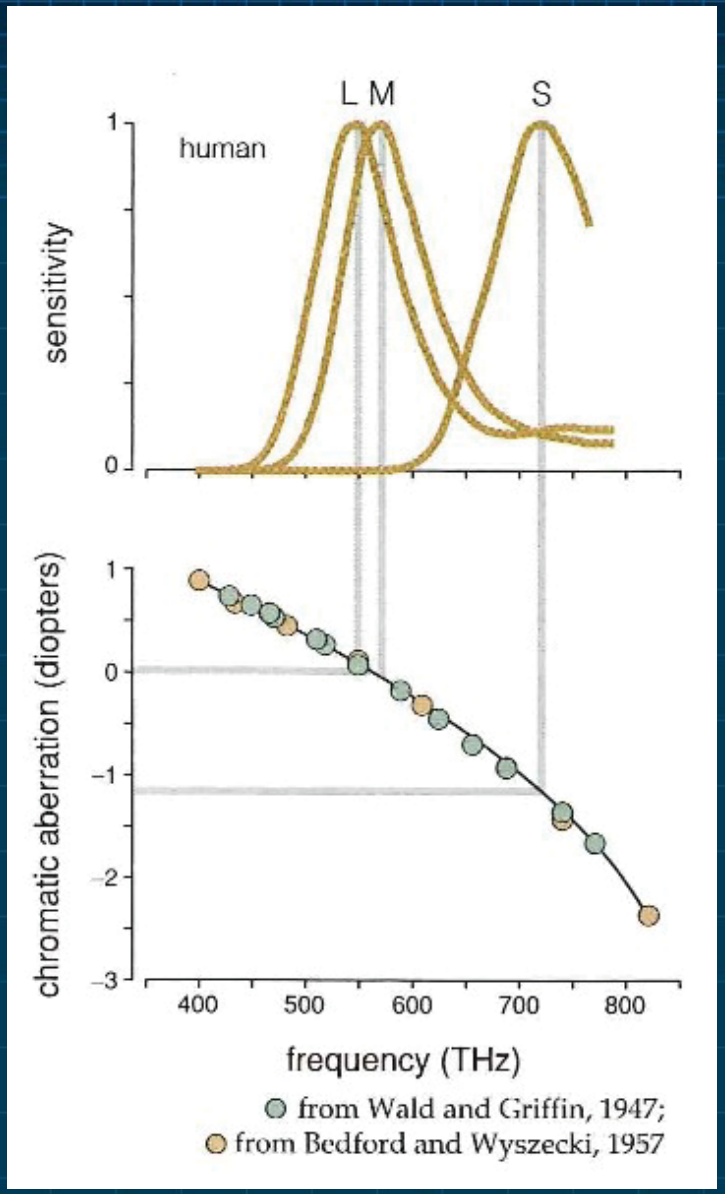


Less accommodation needed for M-wavelengths



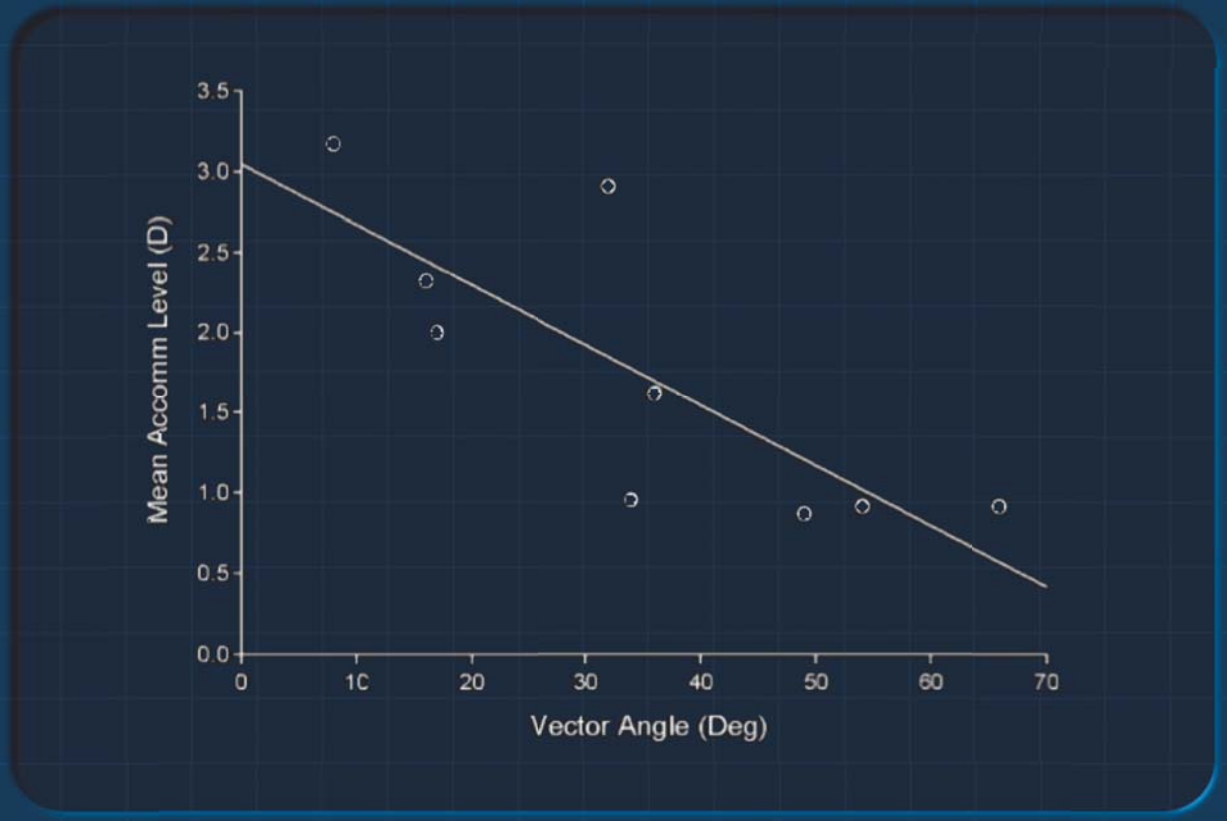
More accommodation needed for L-wavelengths

1. Without accommodation, Medium wavelengths imaged on retina (left).
2. Long wavelengths out of focus (left); more accommodation required.
3. (Right) long wavelengths now in focus after accommodation.
4. Larger proportion of long wavelengths requires more accommodative effort.



S-cones are out of focus

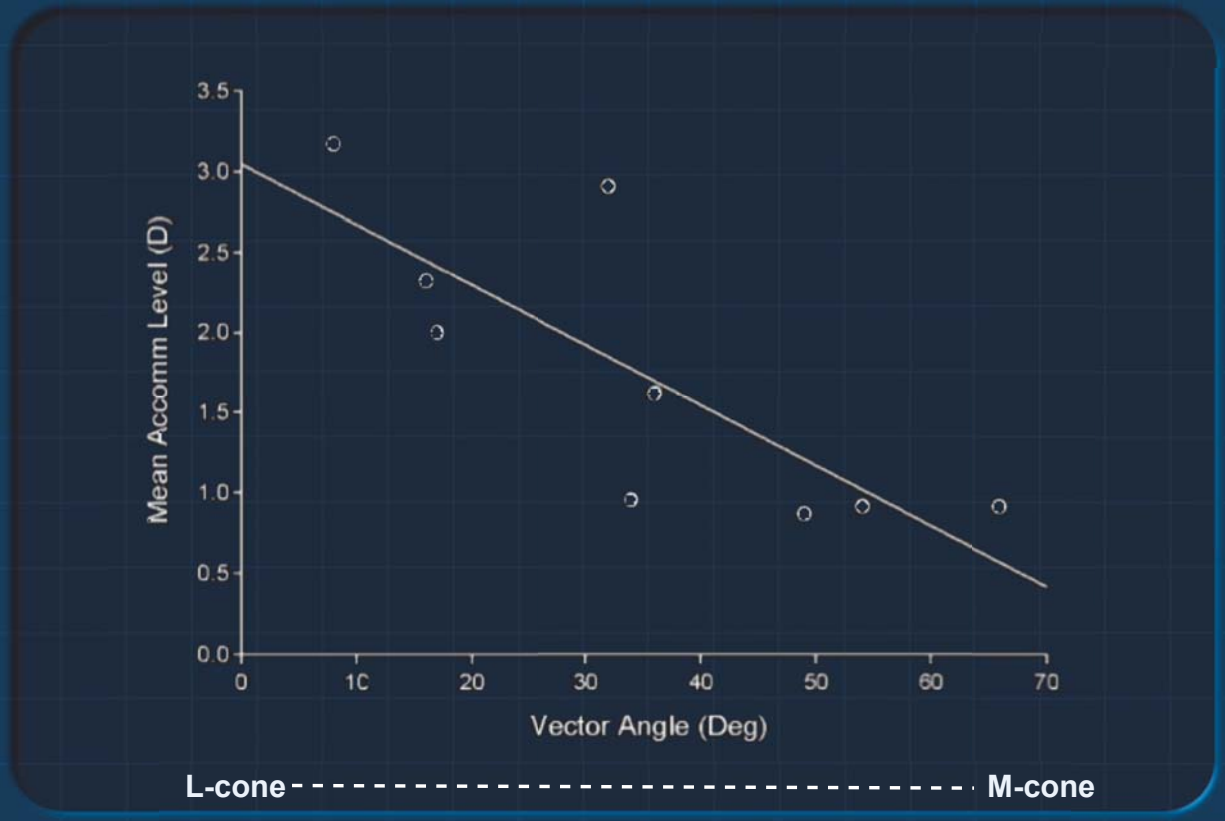
L/M ratio of light affects accommodative response



From Rucker & Kruger 2006

1. Stimuli were 2.2 c/d sine-wave gratings with different ratios of L- and M-cone contrast.
2. Increasing relative L/M-cone contrast raised accommodative demand by 2 D.

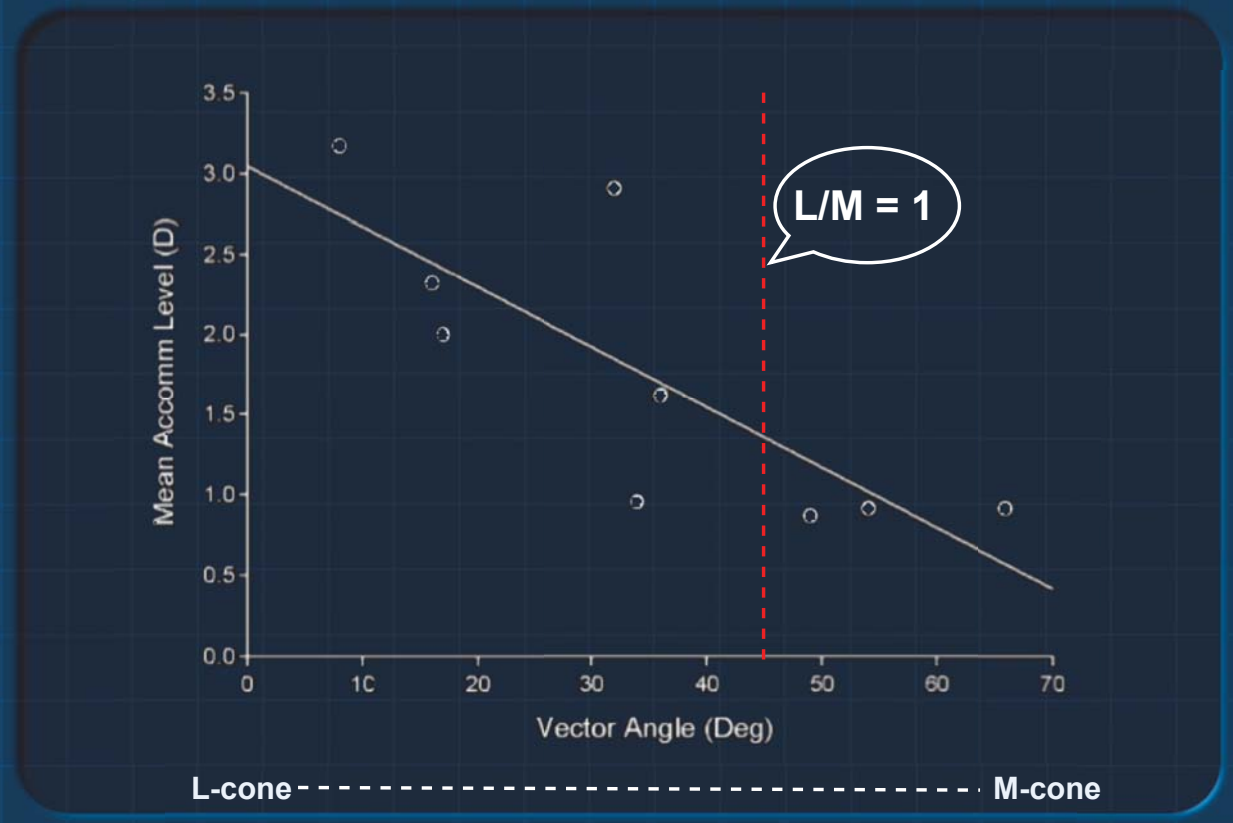
L/M ratio of light affects accommodative response



From Rucker & Kruger 2006

1. Stimuli were 2.2 c/d sine-wave gratings with different ratios of L- and M-cone contrast.
2. Increasing relative L/M-cone contrast raised accommodative demand by 2 D.

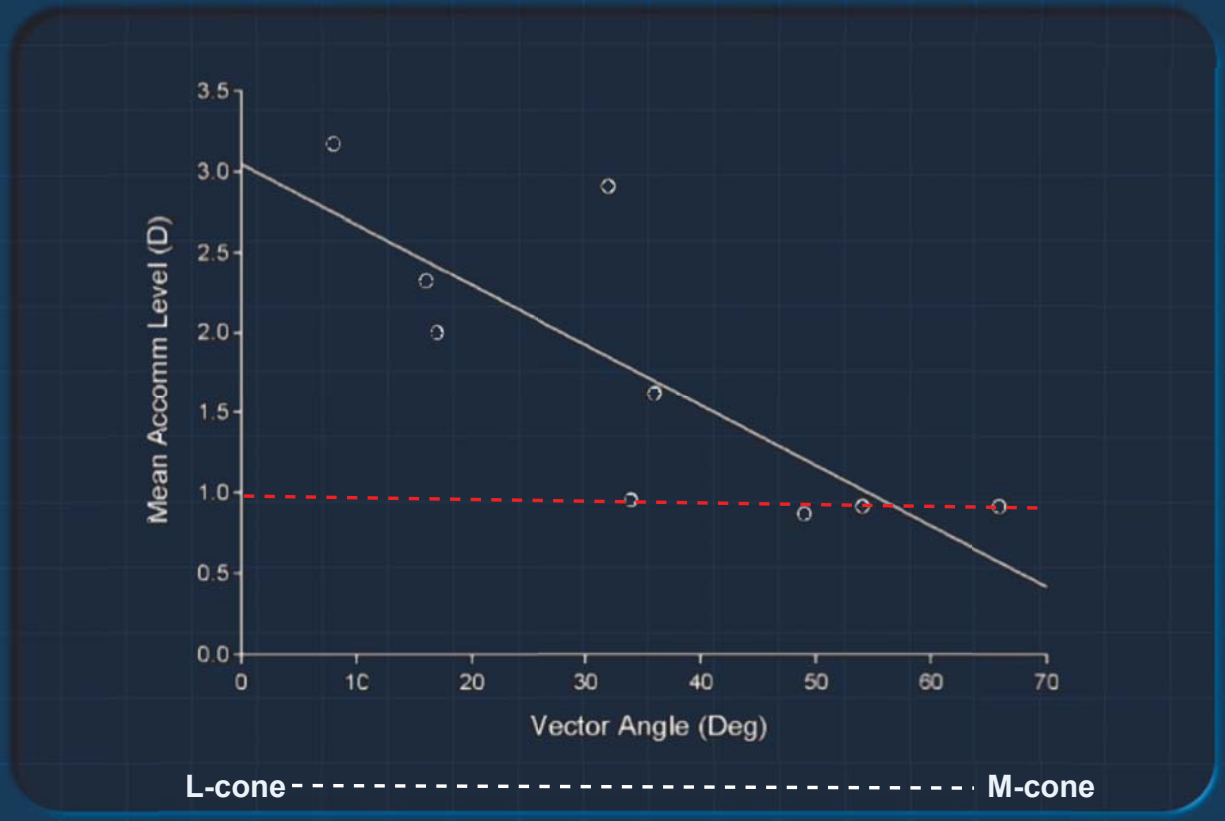
L/M ratio of light affects accommodative response



From Rucker & Kruger 2006

1. Stimuli were 2.2 c/d sine-wave gratings with different ratios of L- and M-cone contrast.
2. Increasing relative L/M-cone contrast raised accommodative demand by 2 D.

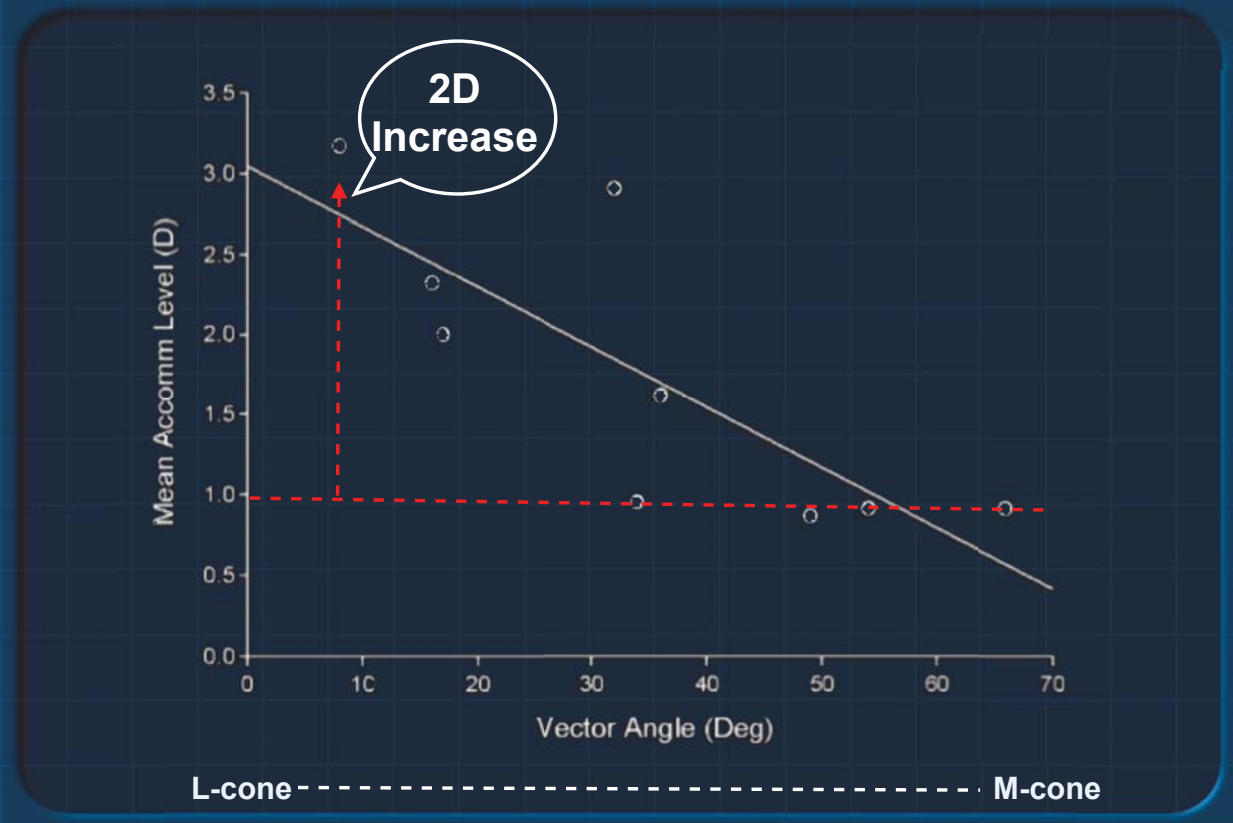
L/M ratio of light affects accommodative response



From Rucker & Kruger 2006

1. Stimuli were 2.2 c/d sine-wave gratings with different ratios of L- and M-cone contrast.
2. Increasing relative L/M-cone contrast raised accommodative demand by 2 D.

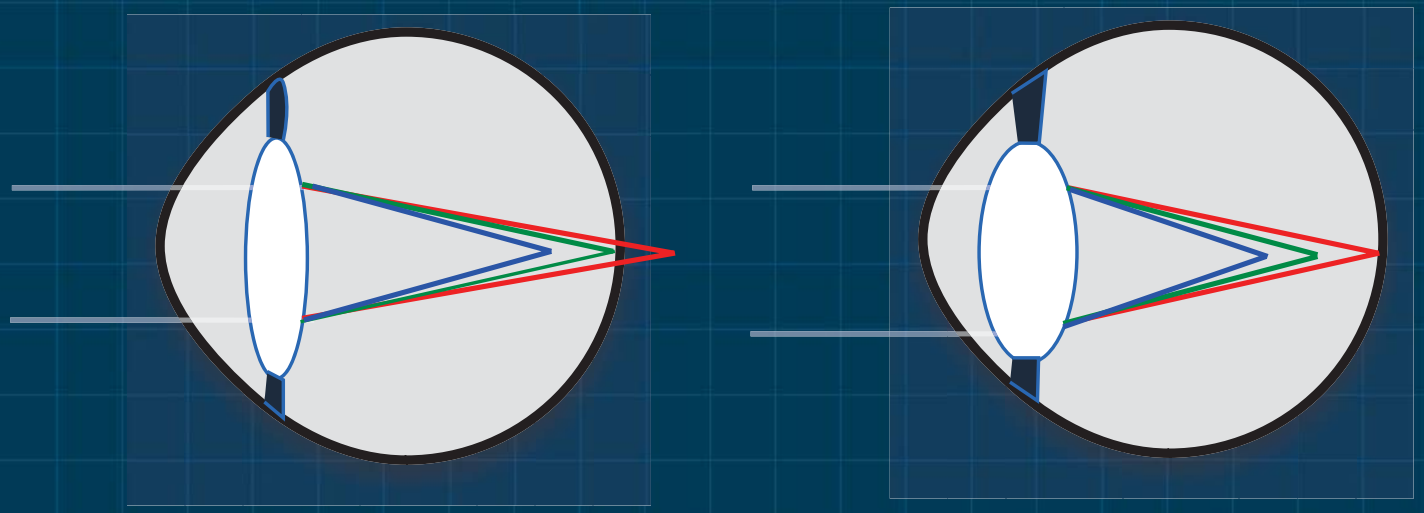
L/M ratio of light affects accommodative response



From Rucker & Kruger 2006

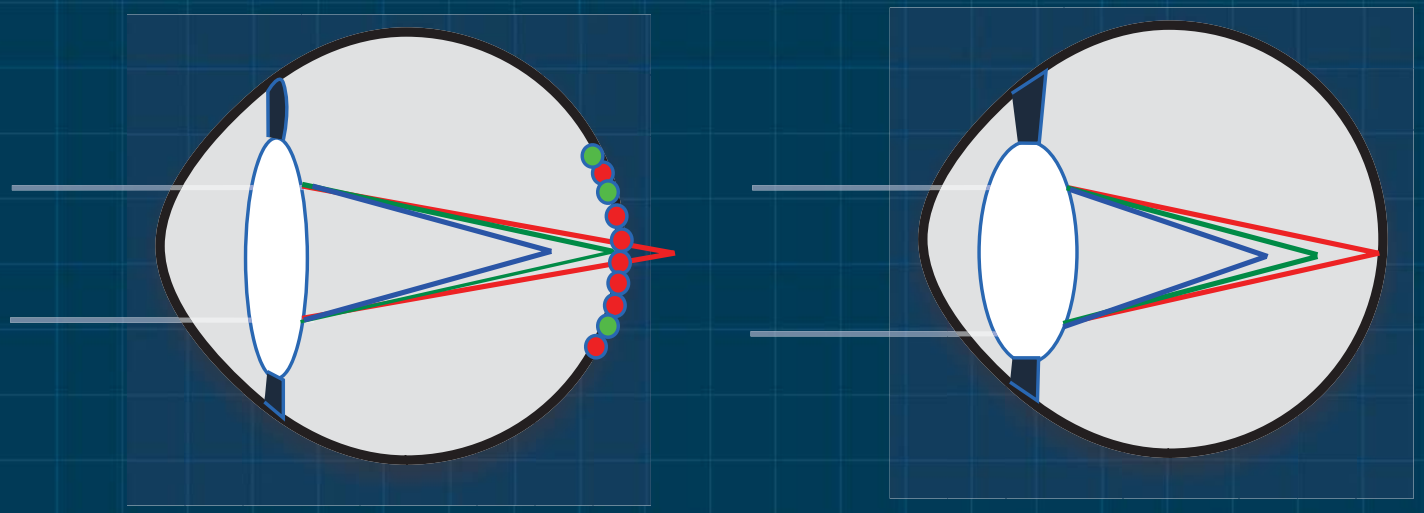
1. Stimuli were 2.2 c/d sine-wave gratings with different ratios of L- and M-cone contrast.
2. Increasing relative L/M-cone contrast raised accommodative demand by 2 D.

A larger L/M-cone ratio may increase accommodation



1. Medium wavelengths focused on retina but few M-cones to activate (on the left).
2. Long wavelengths out of focus (on the left) sending a blur signal through the L-cones in the retina.
3. (Right) long wavelengths now in focus and producing a focused signal on retina.
4. I don't know of any empirical evidence to support this claim; study needs to be done.

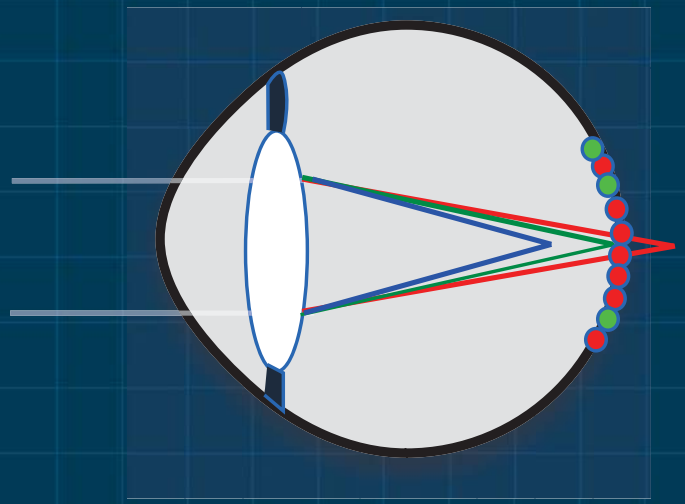
A larger L/M-cone ratio may increase accommodation



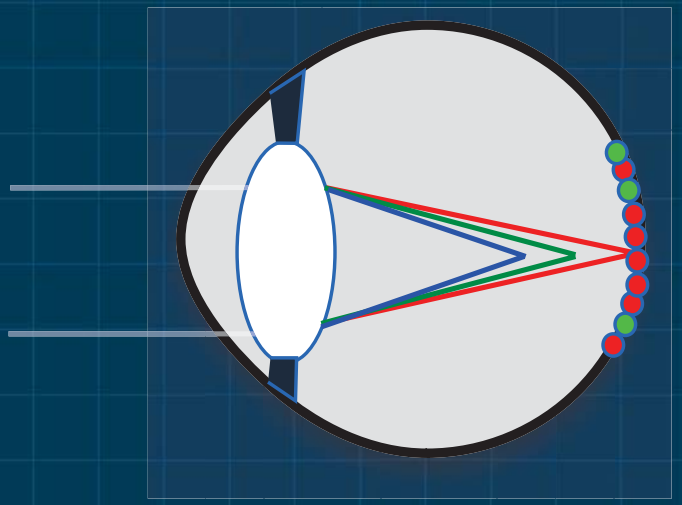
L-wavelength blurred
M-wavelength signal weak

1. Medium wavelengths focused on retina but few M-cones to activate (on the left).
2. Long wavelengths out of focus (on the left) sending a blur signal through the L-cones in the retina.
3. (Right) long wavelengths now in focus and producing a focused signal on retina.
4. I don't know of any empirical evidence to support this claim; study needs to be done.

A larger L/M-cone ratio may increase accommodation



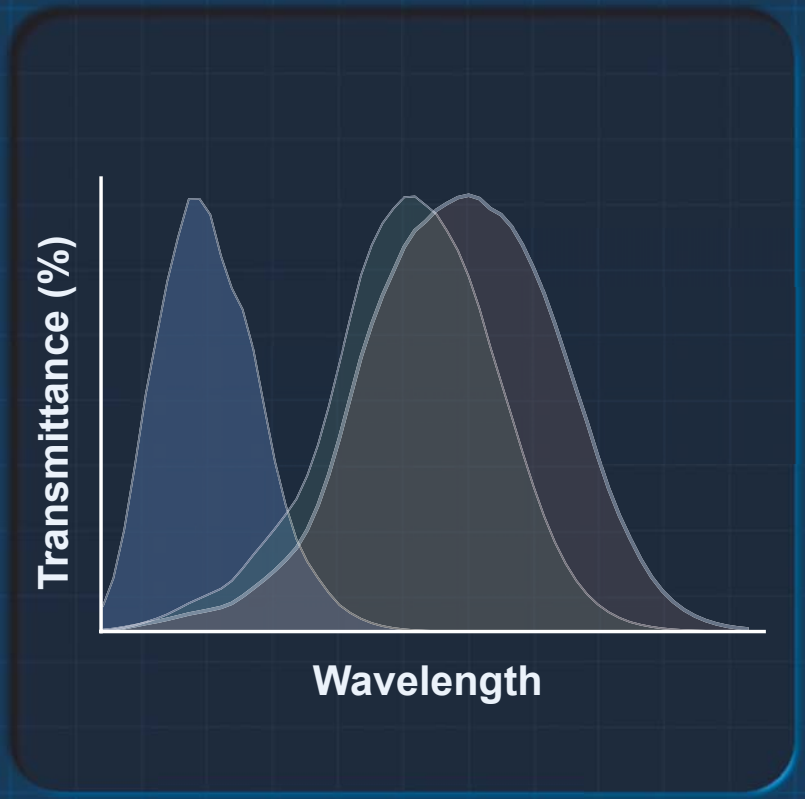
L-wavelength blurred
M-wavelength signal weak

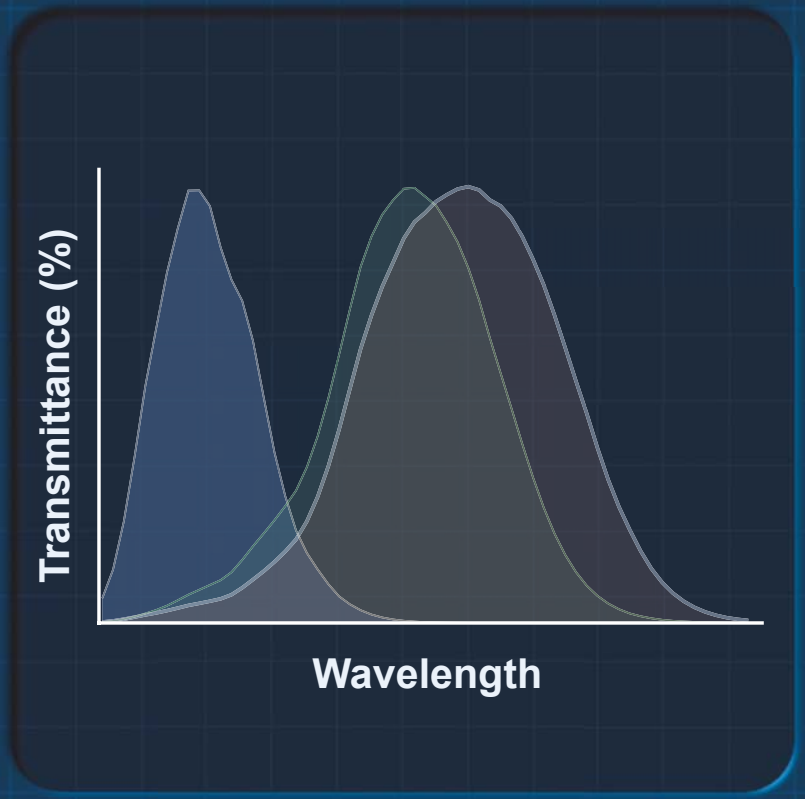


L-wavelength focused with accommodation

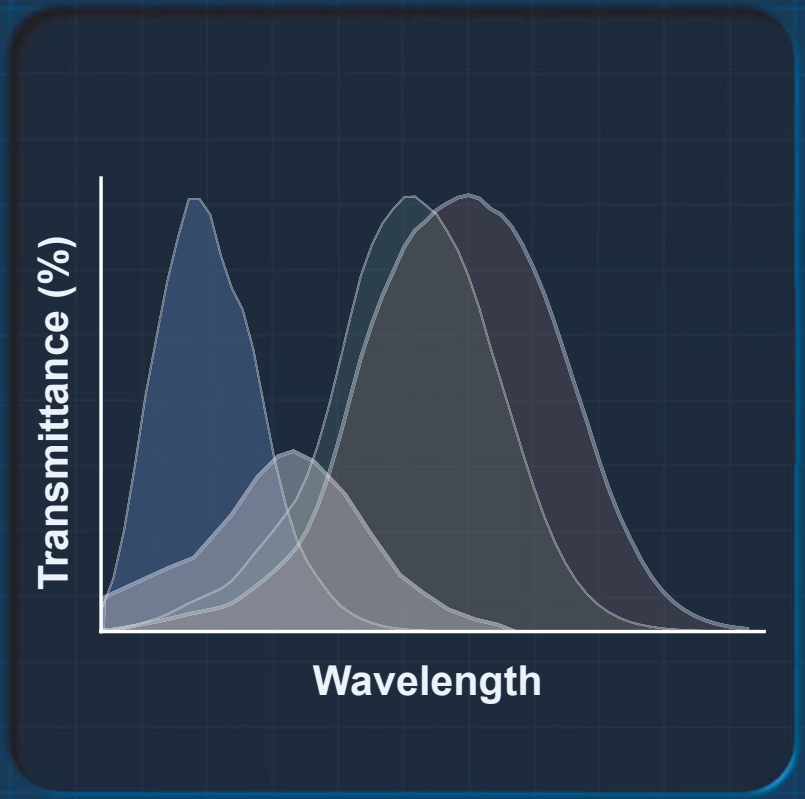
1. Medium wavelengths focused on retina but few M-cones to activate (on the left).
2. Long wavelengths out of focus (on the left) sending a blur signal through the L-cones in the retina.
3. (Right) long wavelengths now in focus and producing a focused signal on retina.
4. I don't know of any empirical evidence to support this claim; study needs to be done.

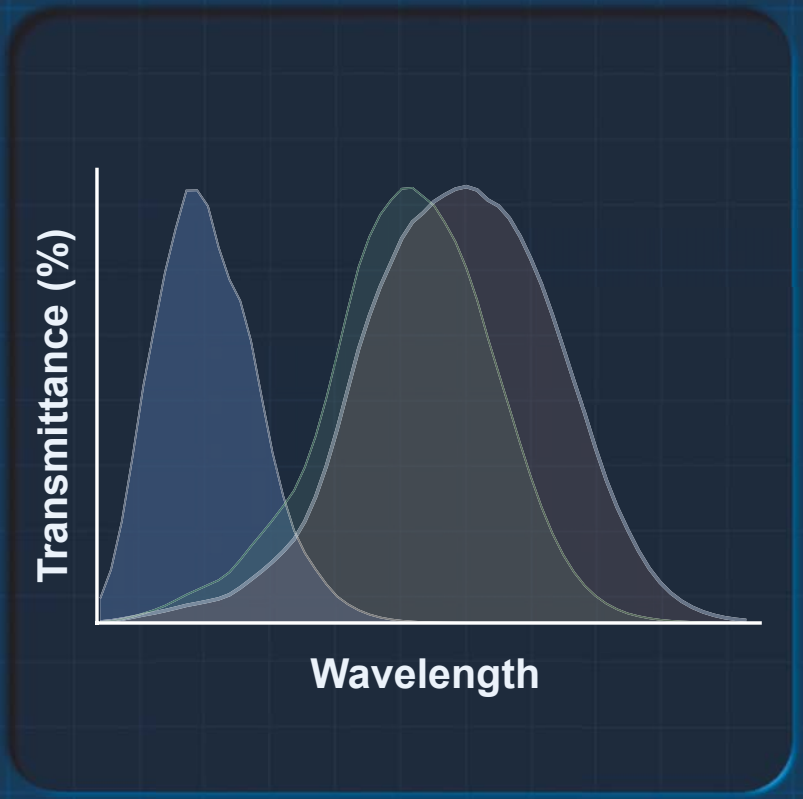
Which colors change L/M contrast ratios?



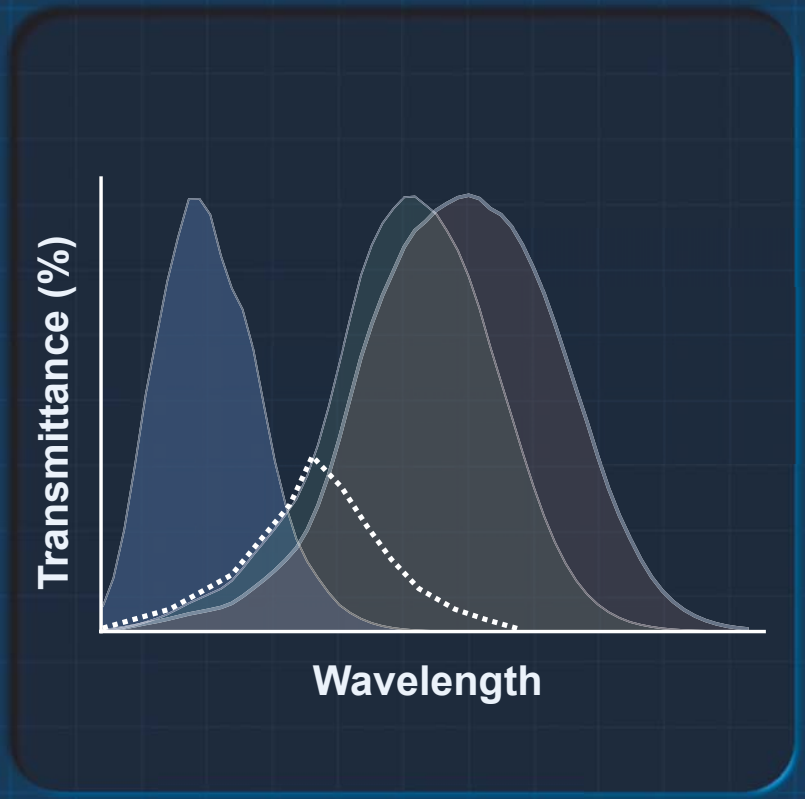


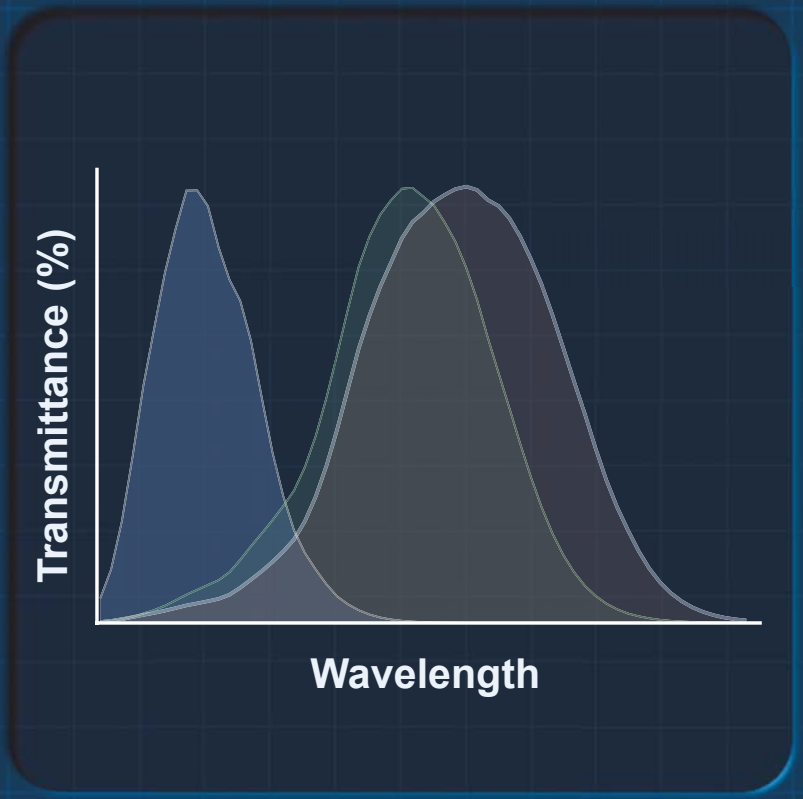
Which colors change L/M contrast ratios?



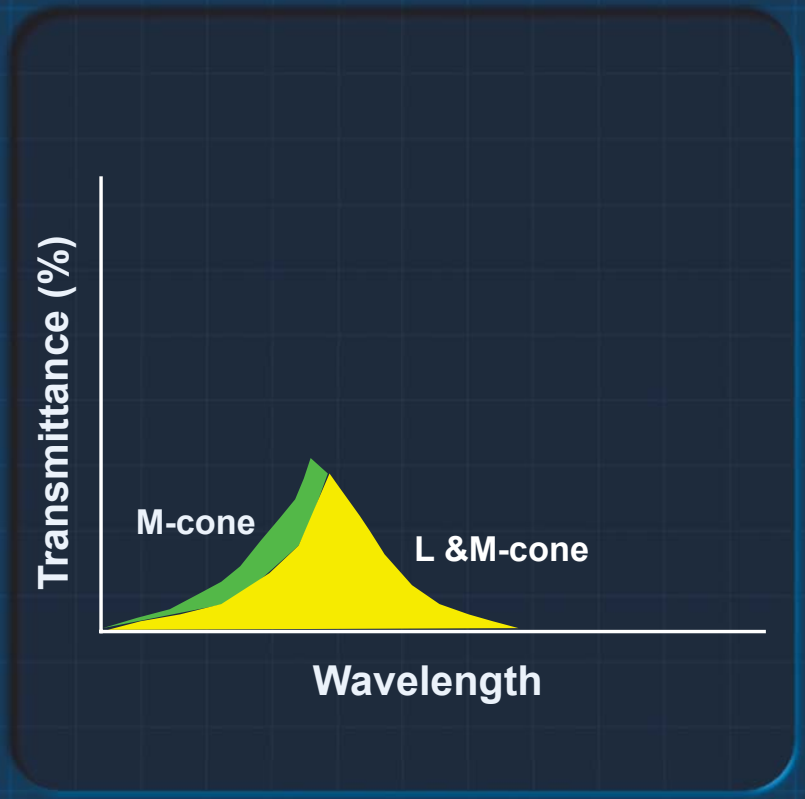


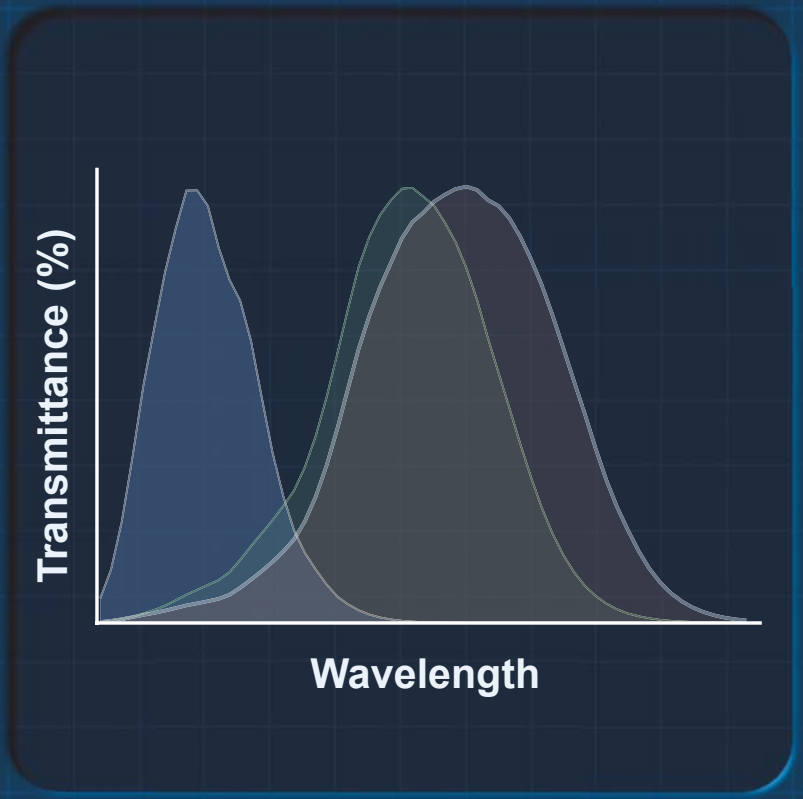
Which colors change L/M contrast ratios?





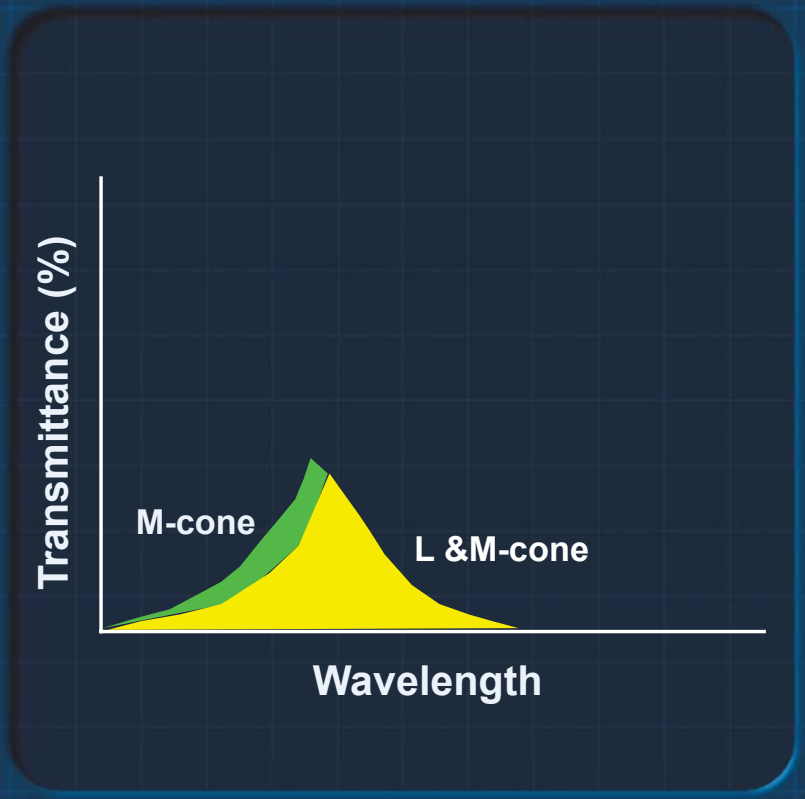
Which colors change L/M contrast ratios?

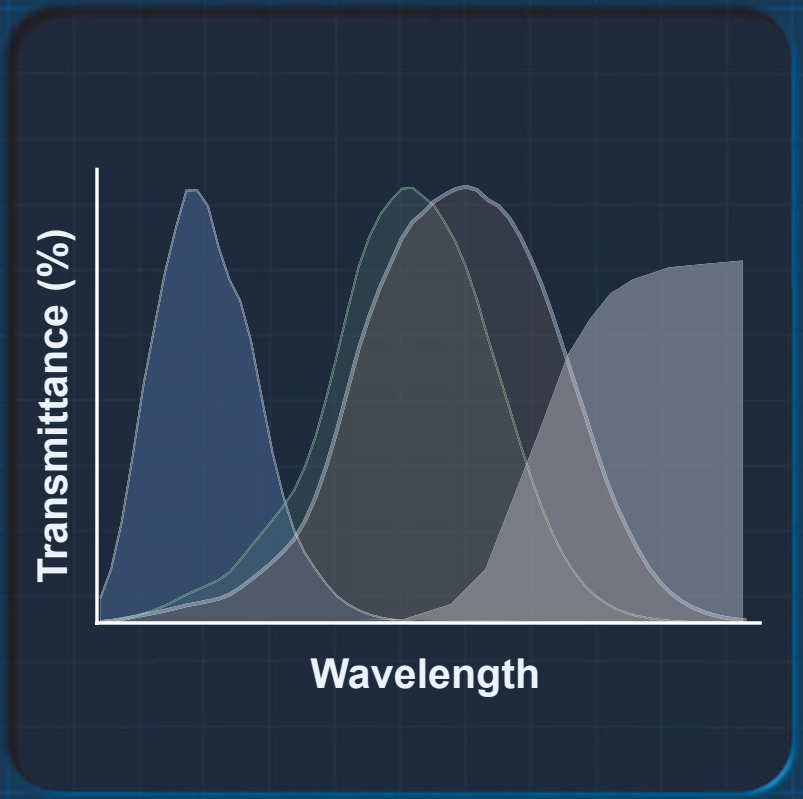




Low-pass filter decreases L/M ratio

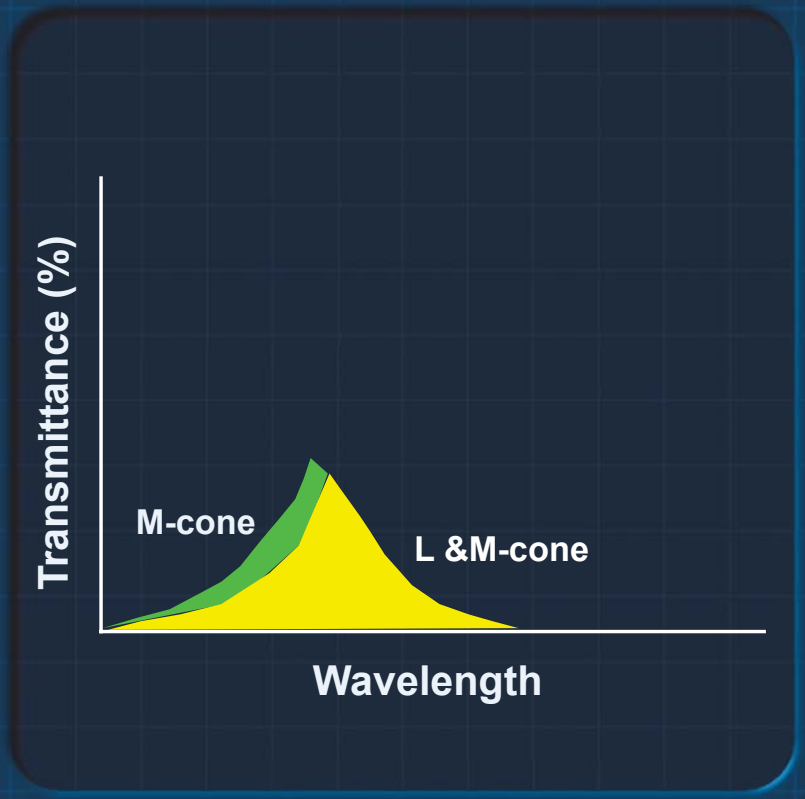
Which colors change L/M contrast ratios?

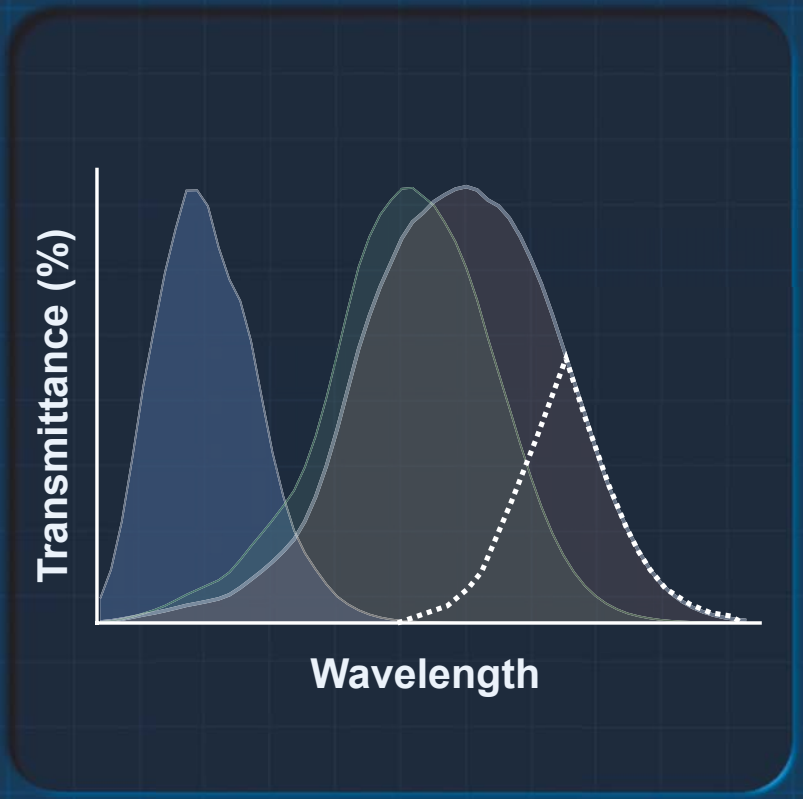




Low-pass filter decreases L/M ratio

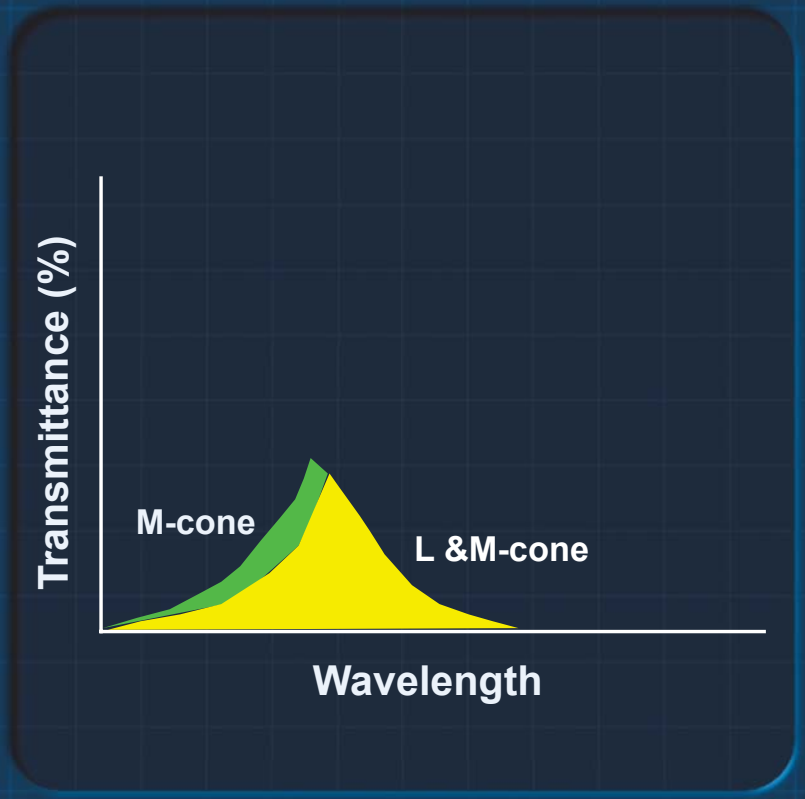
Which colors change L/M contrast ratios?



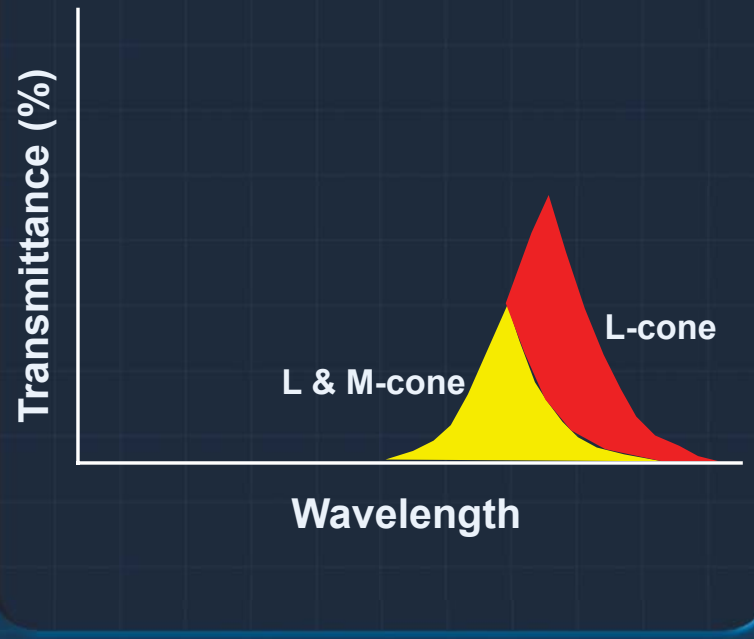


Low-pass filter decreases L/M ratio

Which colors change L/M contrast ratios?

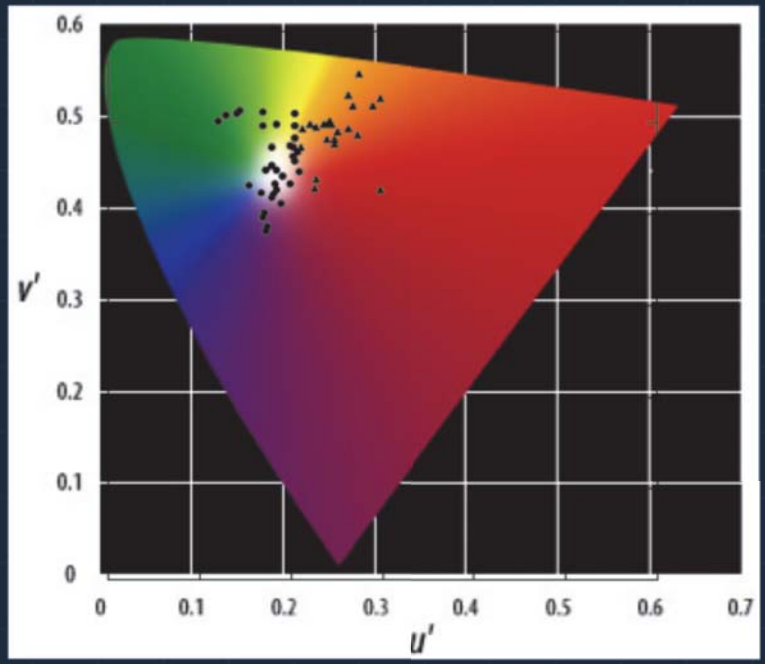


Low-pass filter
decreases L/M ratio



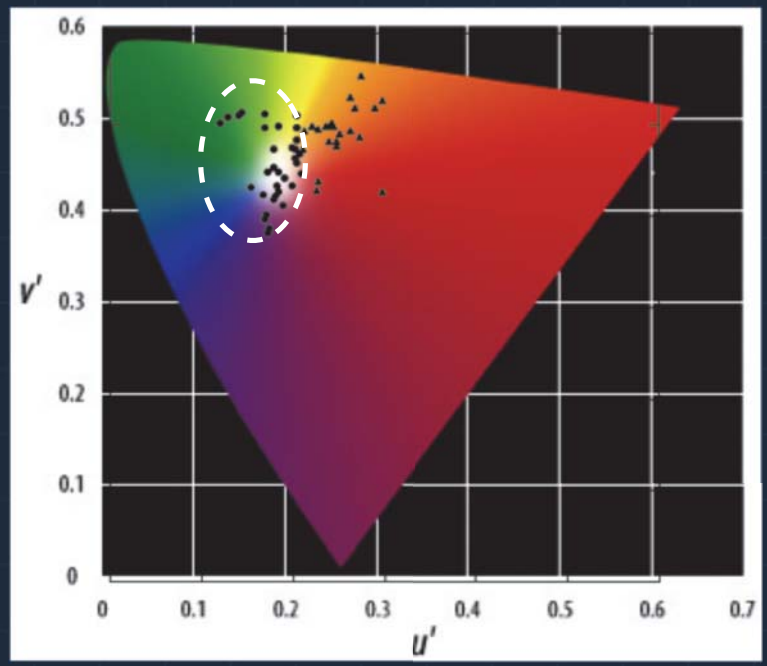
High-pass filter
increases L/M ratio

L/M cone contrast ratios in CIE LUV space



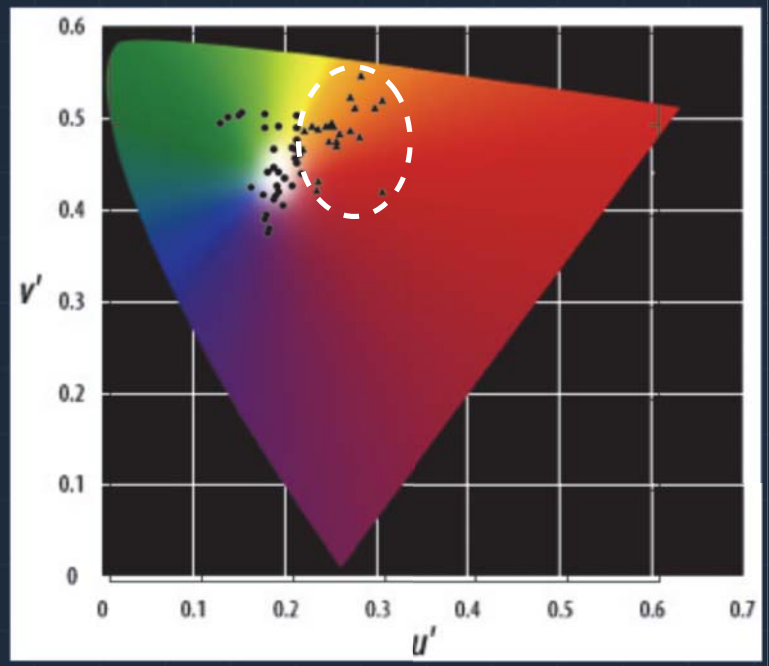
1. Data from college students on their colour preferences using the Colorimeter.
2. The circle on the left identifies colour choices that reduce the L/M wavelength ratio.
3. The circle on the right are colours that increase the ratio.

L/M cone contrast ratios in CIE LUV space



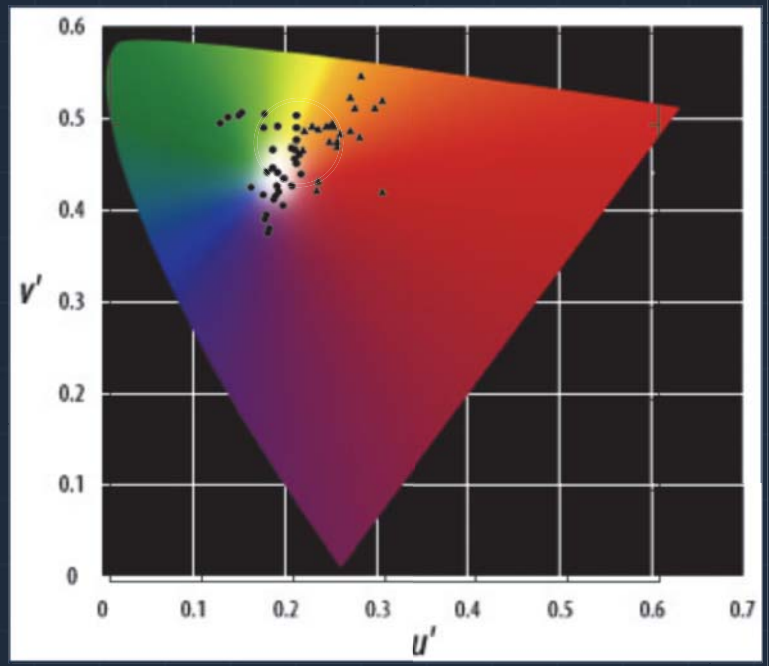
1. Data from college students on their colour preferences using the Colorimeter.
2. The circle on the left identifies colour choices that reduce the L/M wavelength ratio.
3. The circle on the right are colours that increase the ratio.

L/M cone contrast ratios in CIE LUV space



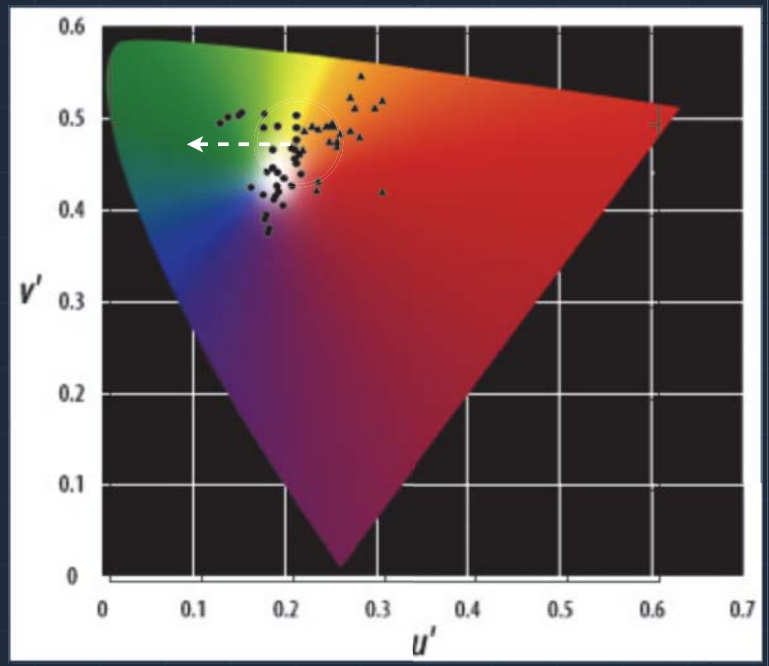
1. Data from college students on their colour preferences using the Colorimeter.
2. The circle on the left identifies colour choices that reduce the L/M wavelength ratio.
3. The circle on the right are colours that increase the ratio.

L/M cone contrast ratios in CIE LUV space



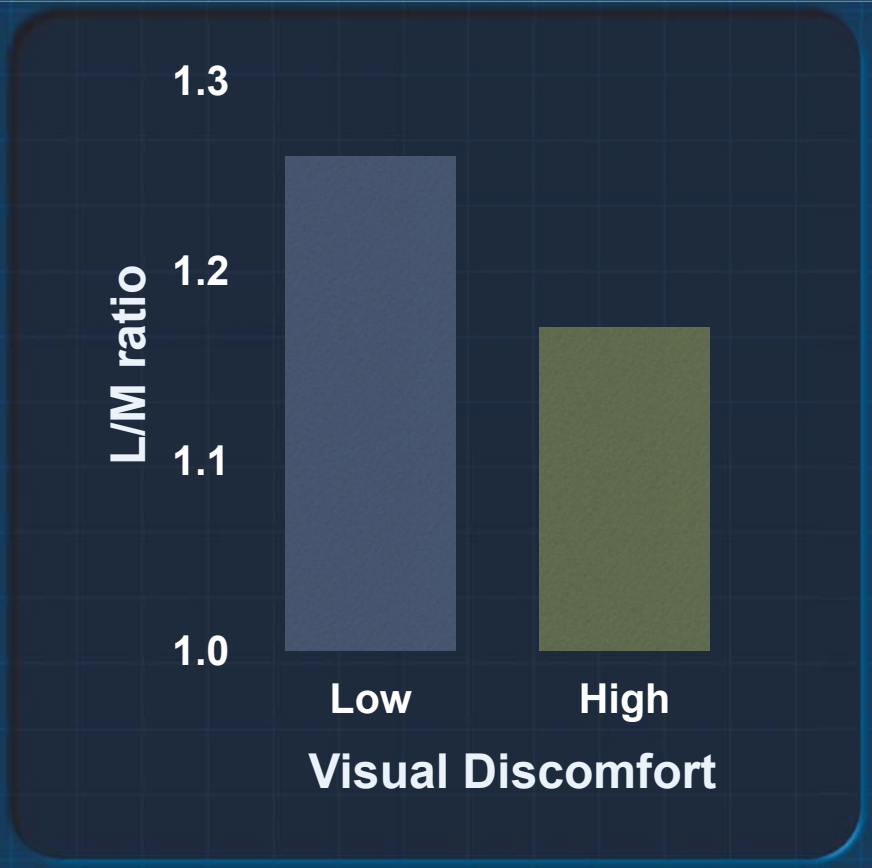
1. Data from college students on their colour preferences using the Colorimeter.
2. The circle on the left identifies colour choices that reduce the L/M wavelength ratio.
3. The circle on the right are colours that increase the ratio.

L/M cone contrast ratios in CIE LUV space



1. Data from college students on their colour preferences using the Colorimeter.
2. The circle on the left identifies colour choices that reduce the L/M wavelength ratio.
3. The circle on the right are colours that increase the ratio.

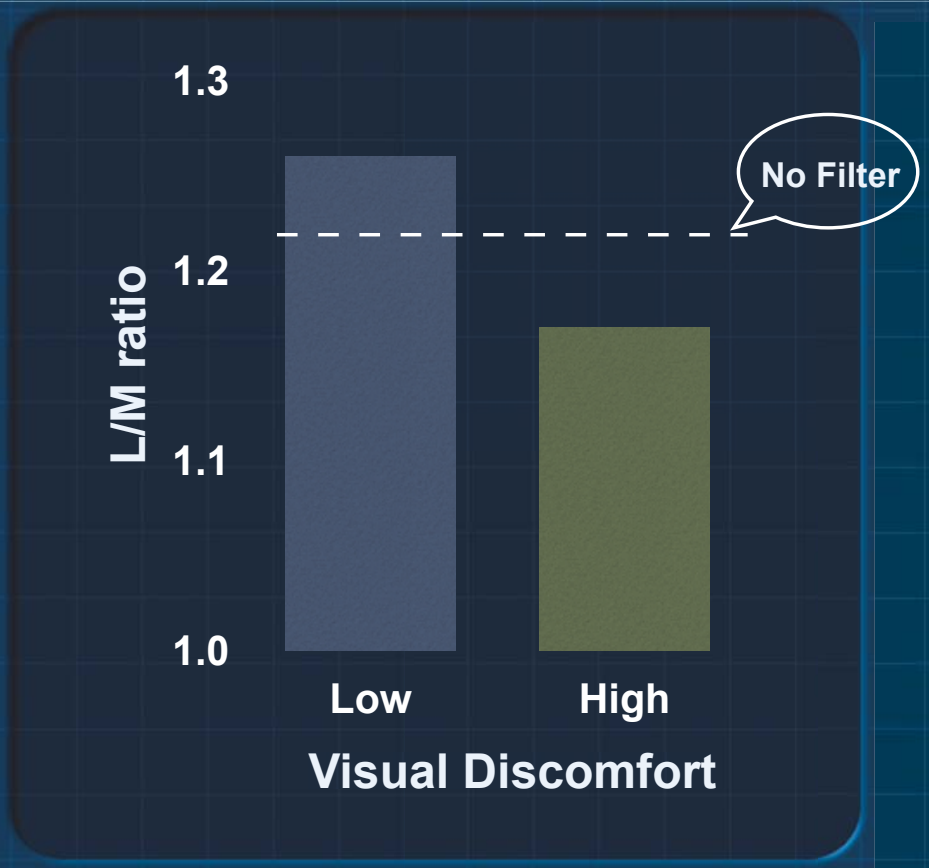
Symptomatic students select colors that reduce L/M ratio



t(59) = 2.07, p = .02

1. High symptomatic group significantly different from 1.22; Low Conlon group no difference.

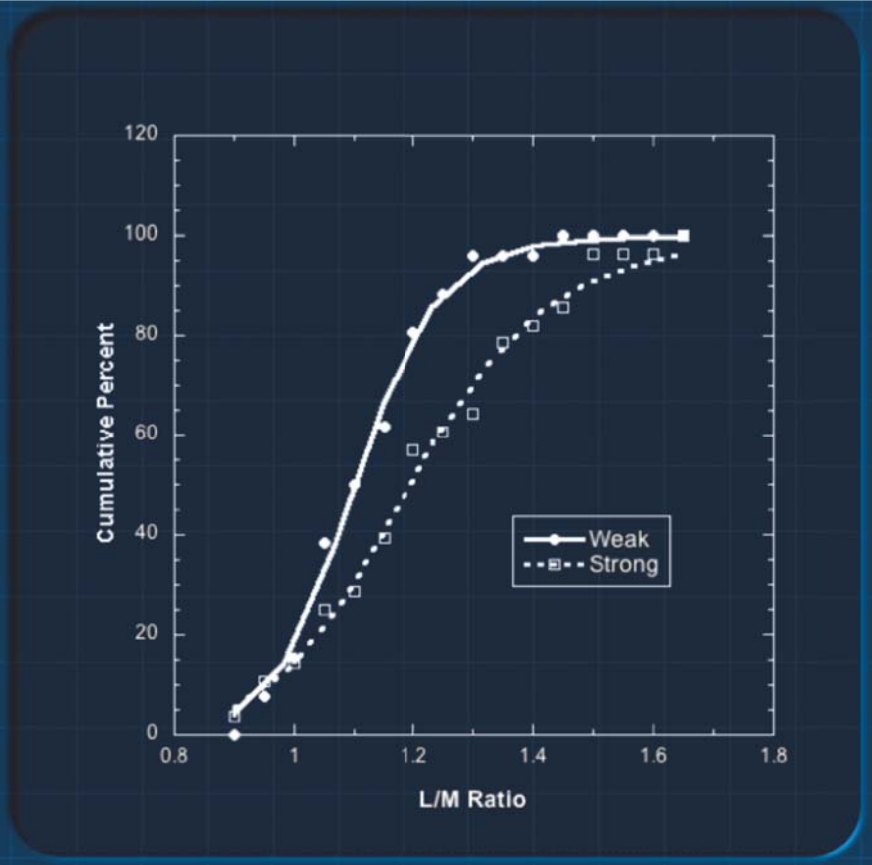
Symptomatic students select colors that reduce L/M ratio



t(59) = 2.07, p = .02

1. High symptomatic group significantly different from 1.22; Low Conlon group no difference.

Weak accommodation select colors that reduce L/M ratio

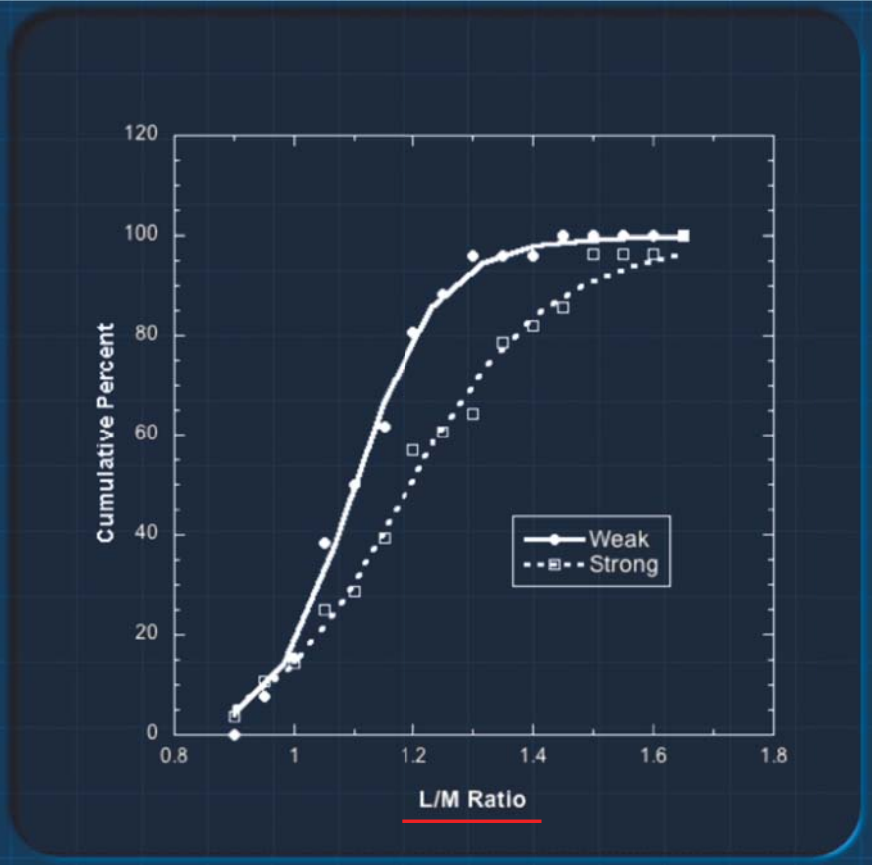


t(52) = 2.30, p = 0.01

1. Accommodation function based on amplitude measures.
2. Median split on Acc Amp to group subjects.

3. L/M ratio
High Acc Amp Group = 1.26
Low Acc Amp Group = 1.16

Weak accommodation select colors that reduce L/M ratio

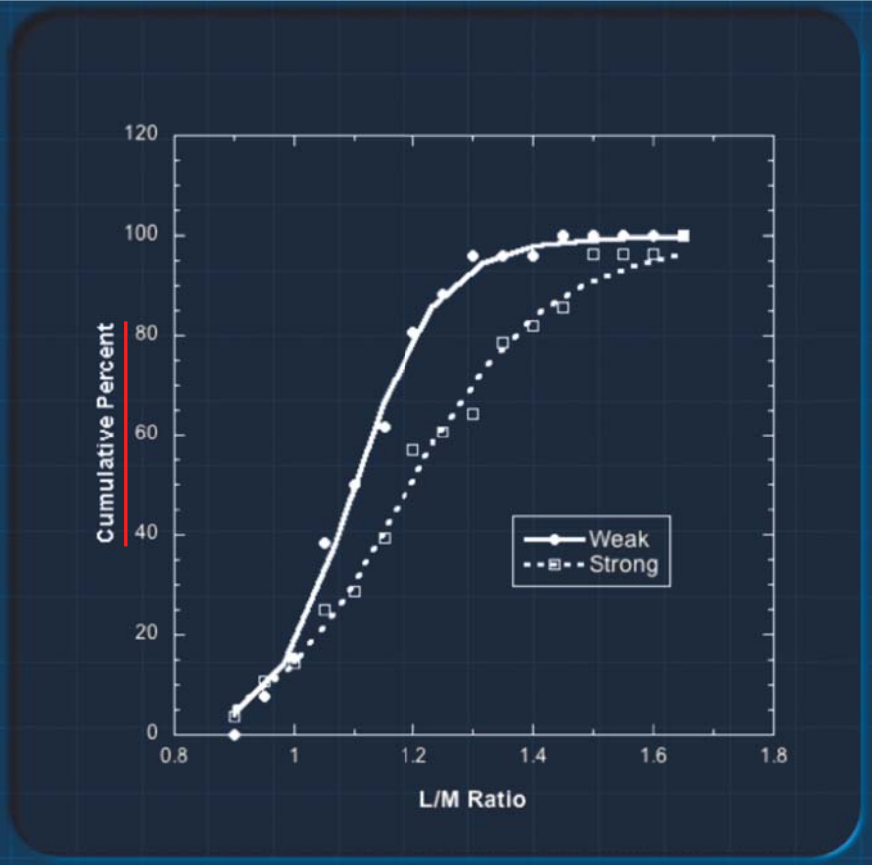


t(52) = 2.30, p = 0.01

1. Accommodation function based on amplitude measures.
2. Median split on Acc Amp to group subjects.

3. L/M ratio
High Acc Amp Group = 1.26
Low Acc Amp Group = 1.16

Weak accommodation select colors that reduce L/M ratio

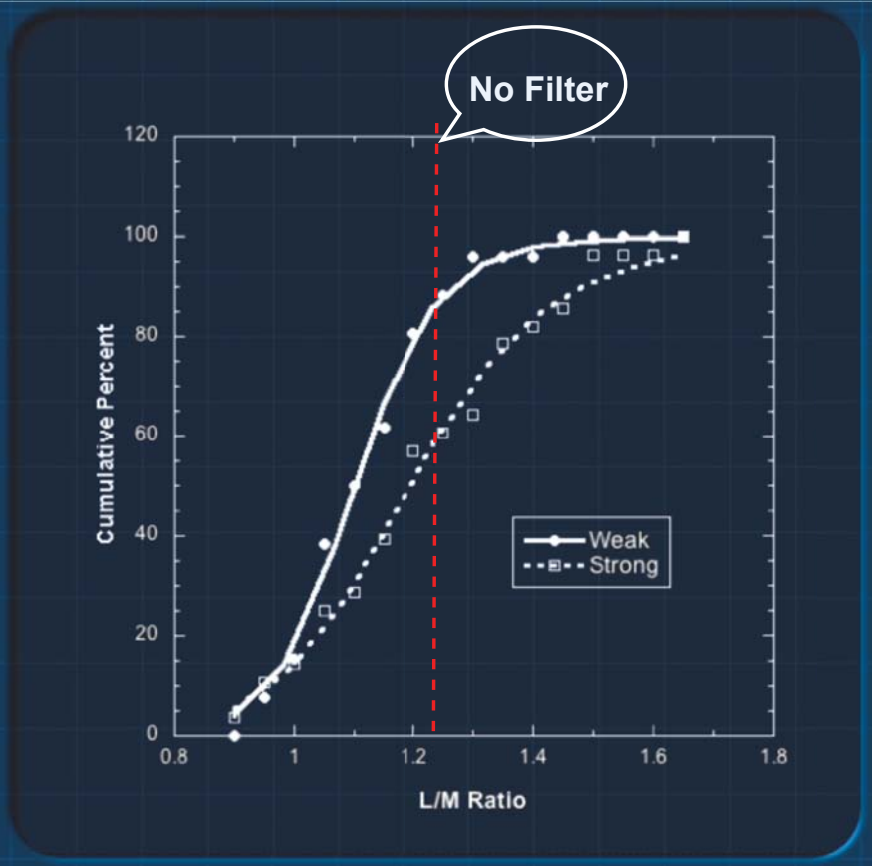


t(52) = 2.30, p = 0.01

1. Accommodation function based on amplitude measures.
2. Median split on Acc Amp to group subjects.

3. L/M ratio
High Acc Amp Group = 1.26
Low Acc Amp Group = 1.16

Weak accommodation select colors that reduce L/M ratio

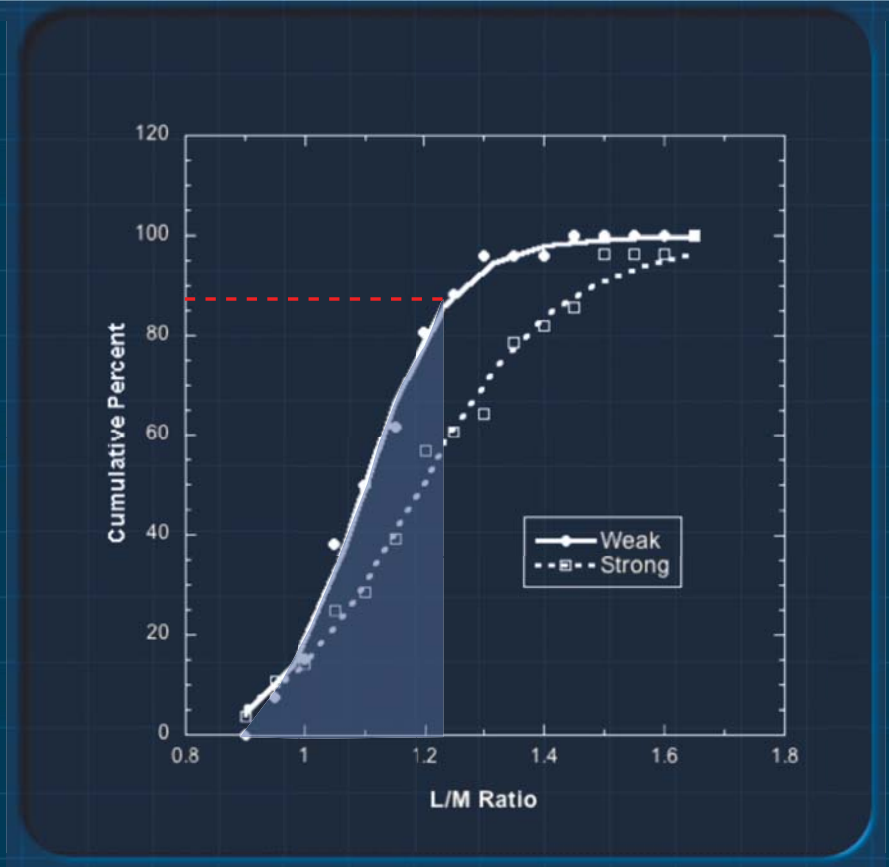


t(52) = 2.30, p = 0.01

1. Accommodation function based on amplitude measures.
2. Median split on Acc Amp to group subjects.

3. L/M ratio
High Acc Amp Group = 1.26
Low Acc Amp Group = 1.16

Weak accommodation select colors that reduce L/M ratio

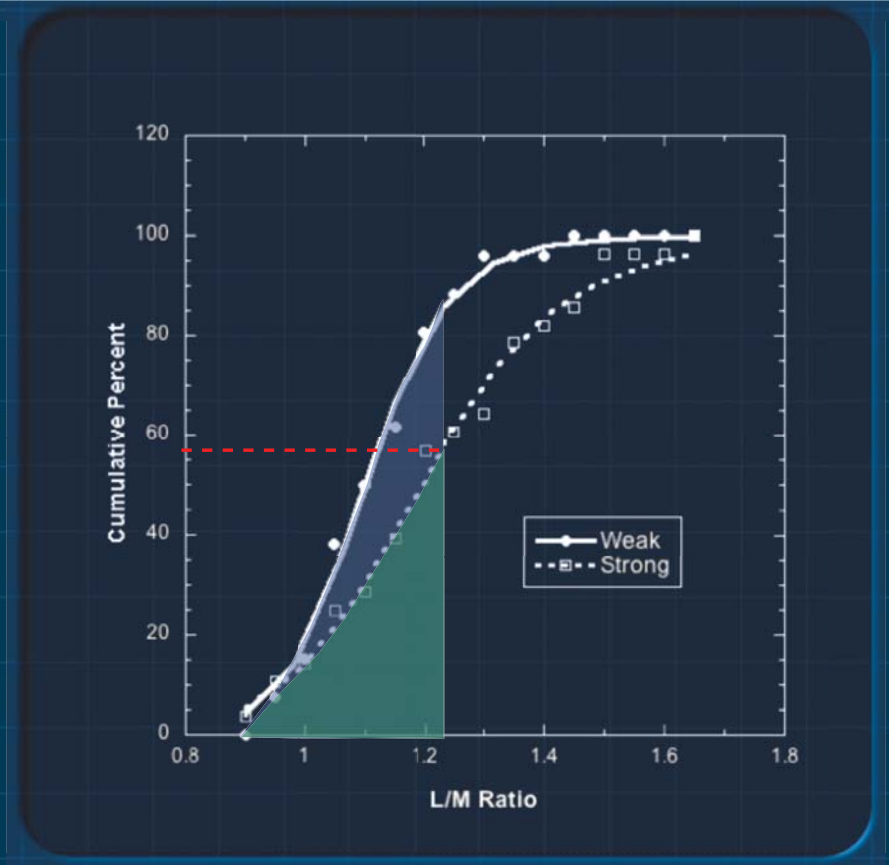


t(52) = 2.30, p = 0.01

1. Accommodation function based on amplitude measures.
2. Median split on Acc Amp to group subjects.

3. L/M ratio
High Acc Amp Group = 1.26
Low Acc Amp Group = 1.16

Weak accommodation select colors that reduce L/M ratio



t(52) = 2.30, p = 0.01

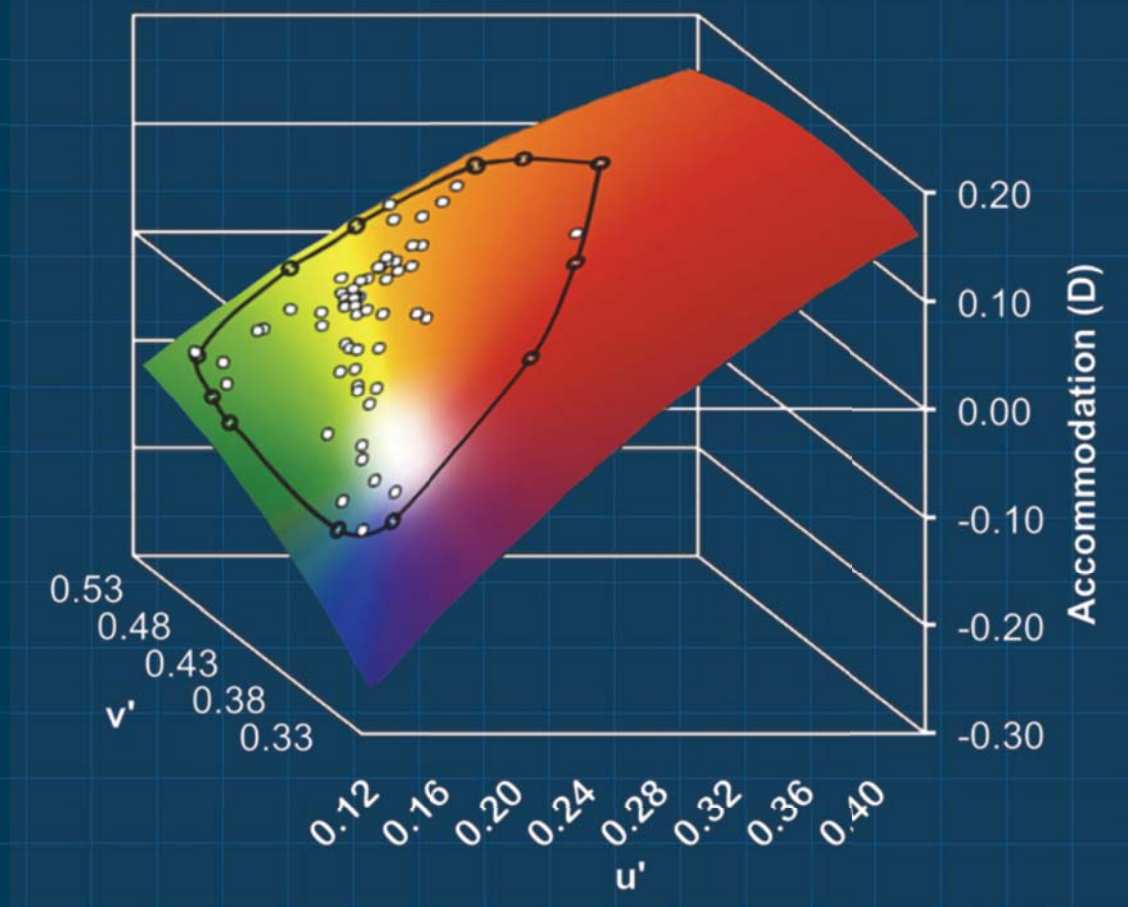
1. Accommodation function based on amplitude measures.
2. Median split on Acc Amp to group subjects.

3. L/M ratio
High Acc Amp Group = 1.26
Low Acc Amp Group = 1.16

Chromatic Aberration Summary

- High symptoms: weak accommodation & slow reading.
- Higher L/M ratios: impair reading & increase accommodative demand.
- Colors with lower L/M ratios: preferred by high symptoms or weak accommodation.
- Chromatic aberration: accommodation, symptoms, and color.

Part 5: Eyestrain, Color, & Accommodation



1. Three directions.
2. Changes are small (.5D range) but variability in LCA gain on accommodative responses are not known.
3. Larger gamut needed.

Three factors are related

Eyestrain

Accommodation

Color

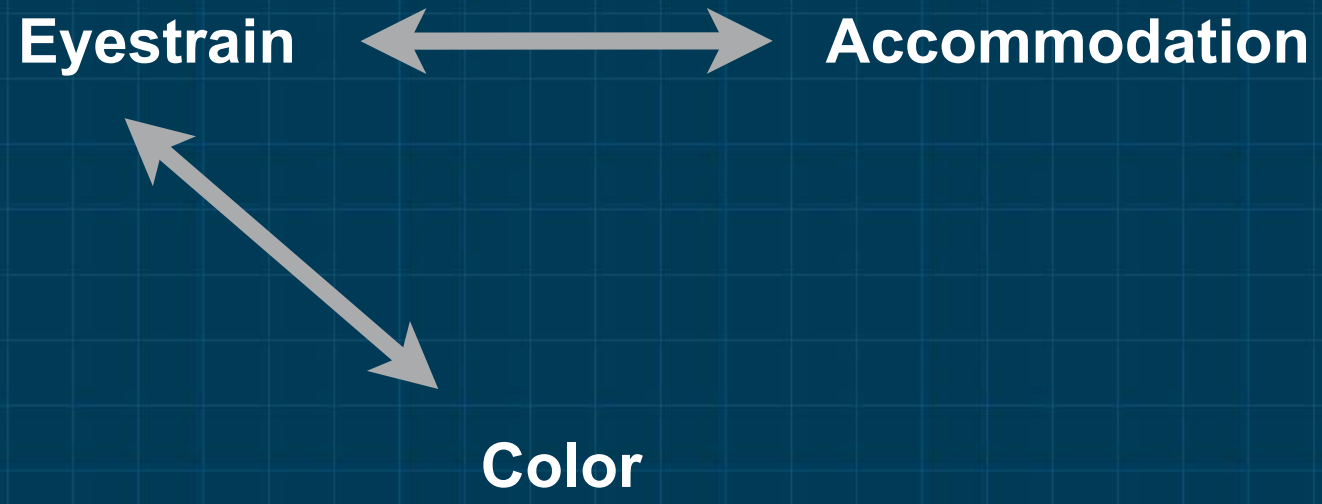
Eye strain: reading performance, uncomfortable symptoms, text distortion

Three factors are related

Color

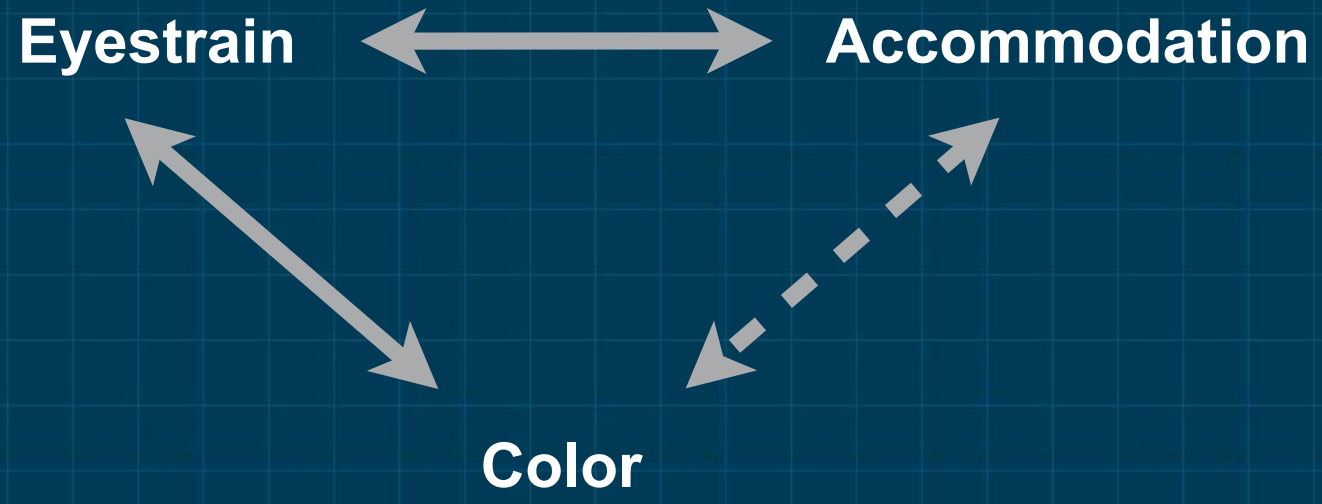
Eye strain: reading performance, uncomfortable symptoms, text distortion

Three factors are related



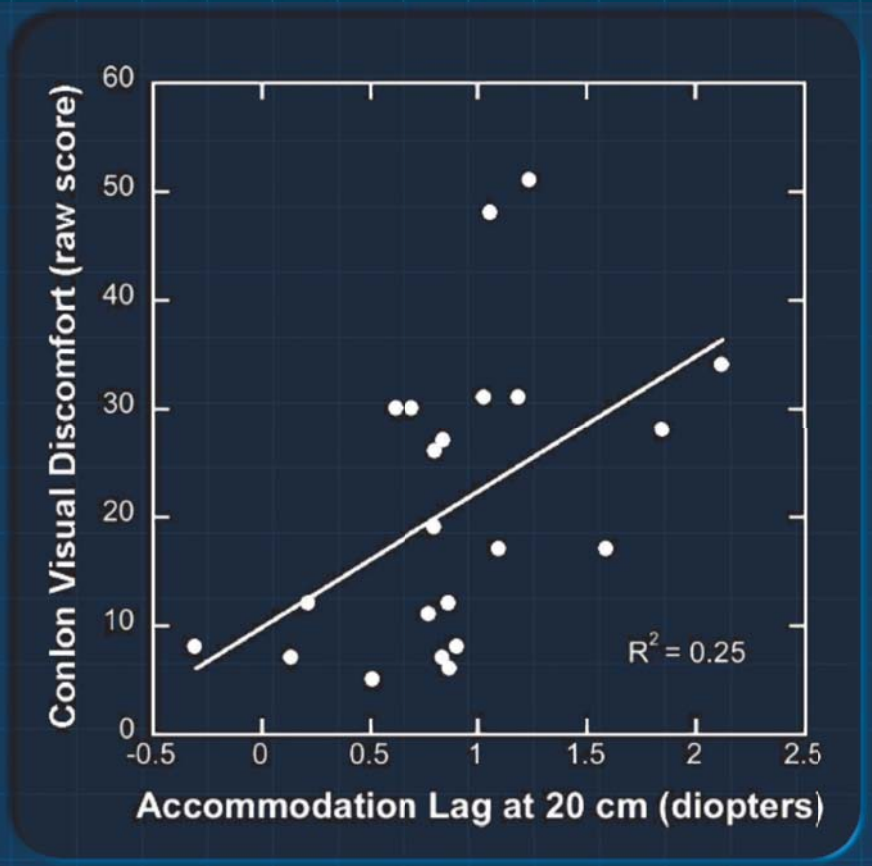
Eye strain: reading performance, uncomfortable symptoms, text distortion

Three factors are related



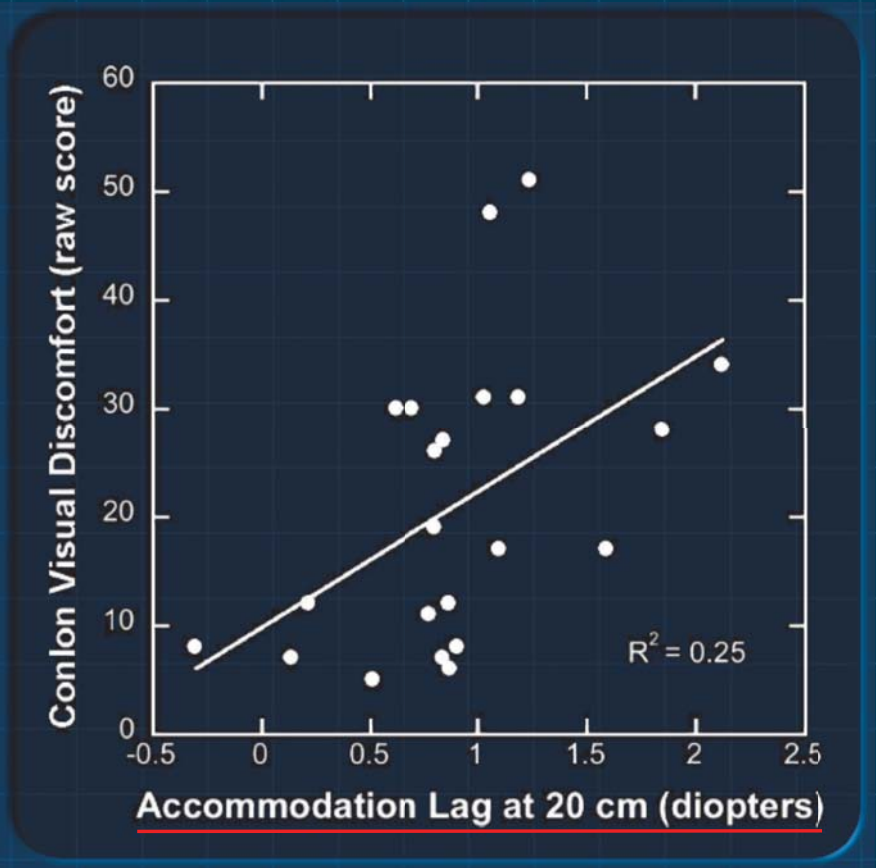
Eye strain: reading performance, uncomfortable symptoms, text distortion

Eyestrain ⟷ Accommodation



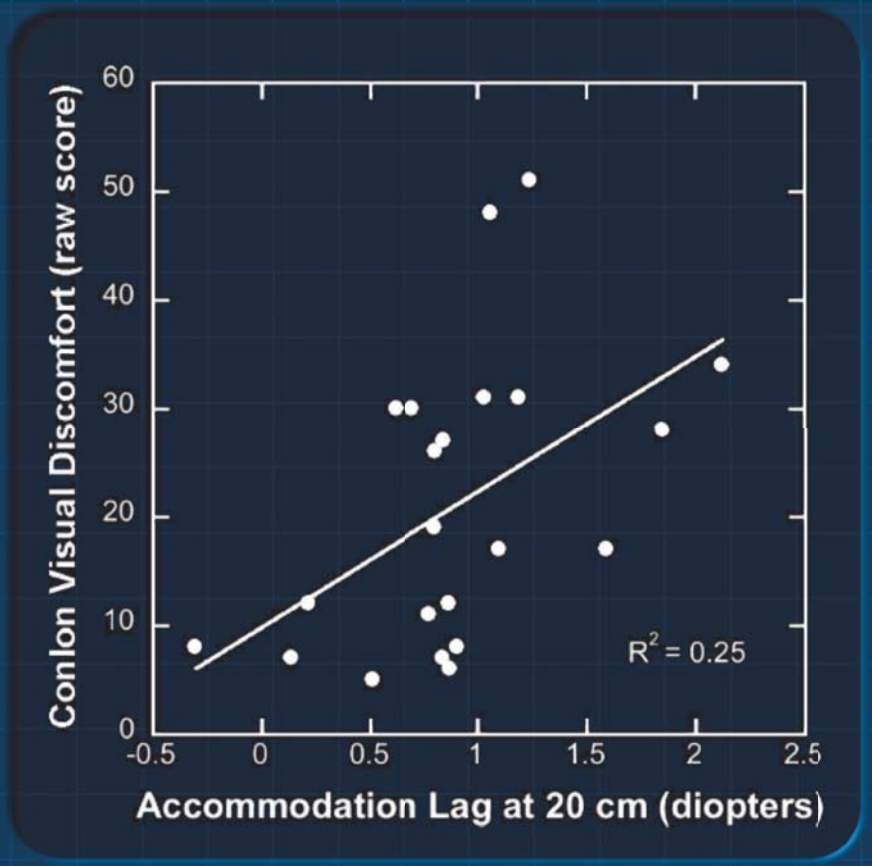
Chase et al 2009

Eyestrain ⟷ Accommodation



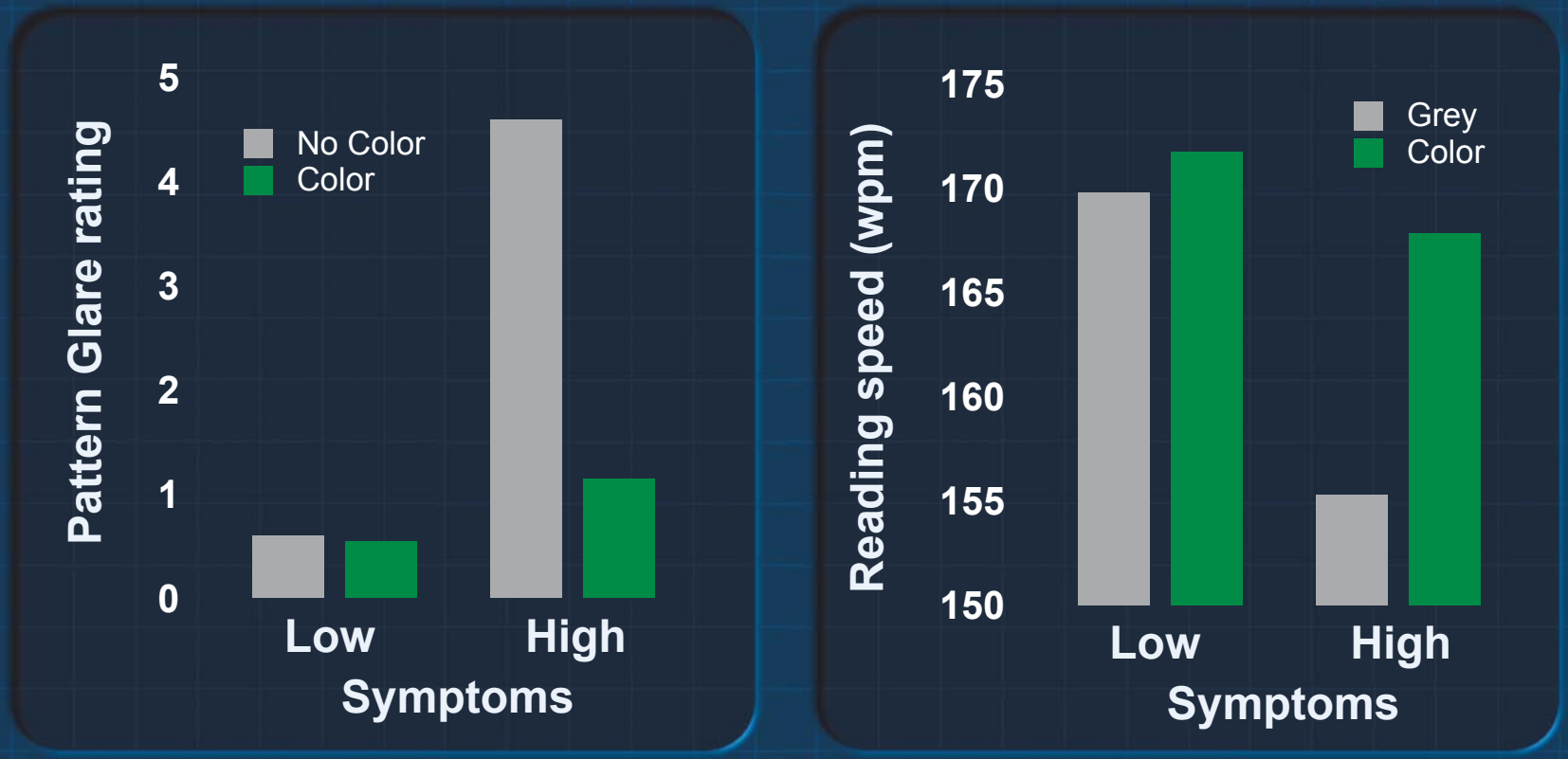
Chase et al 2009

Eyestrain ⟷ Accommodation



Chase et al 2009

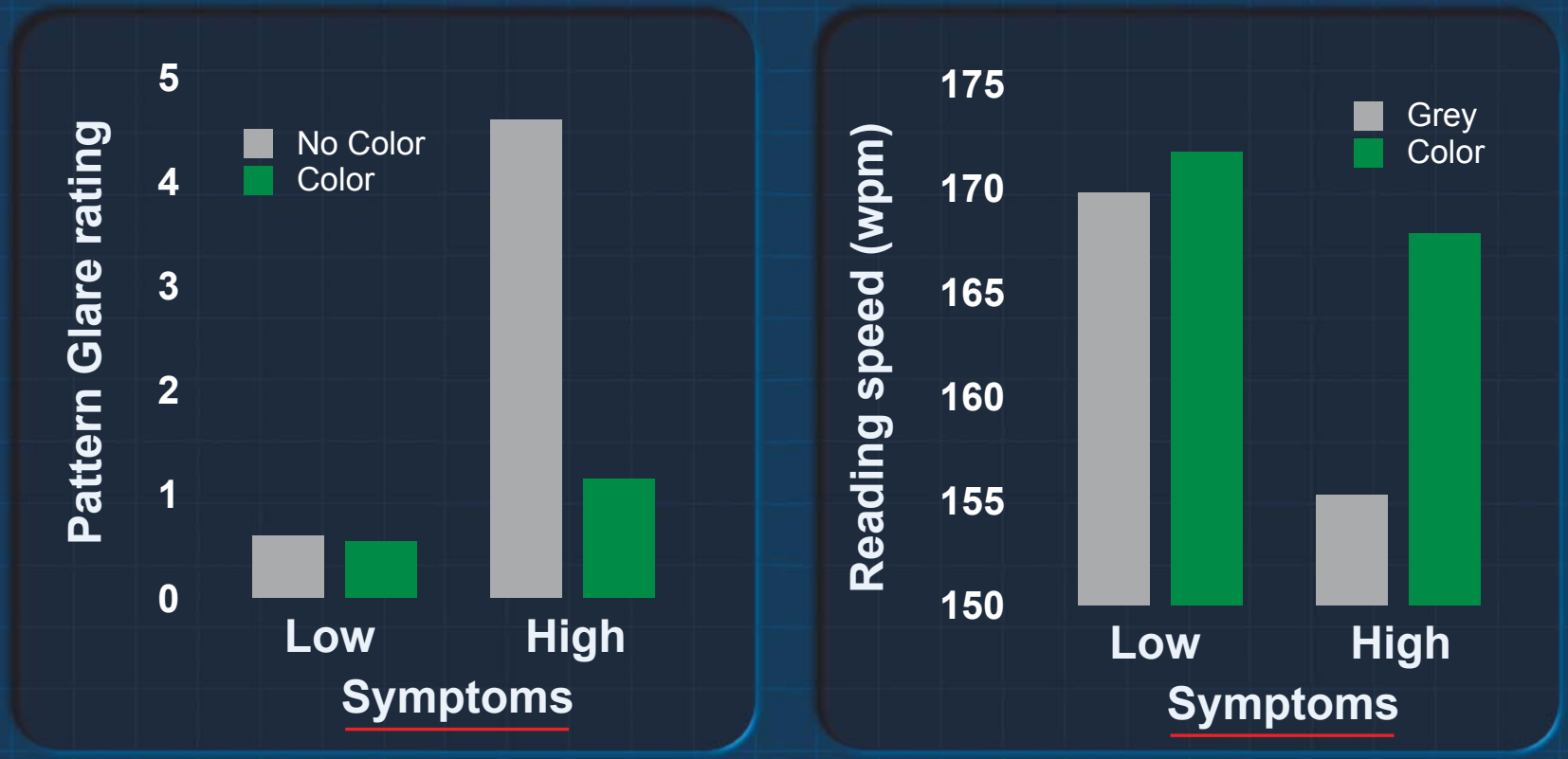
Eyestrain ⟷ Color



Allen et al, unpublished

All students selected IOO color transparency of choice.

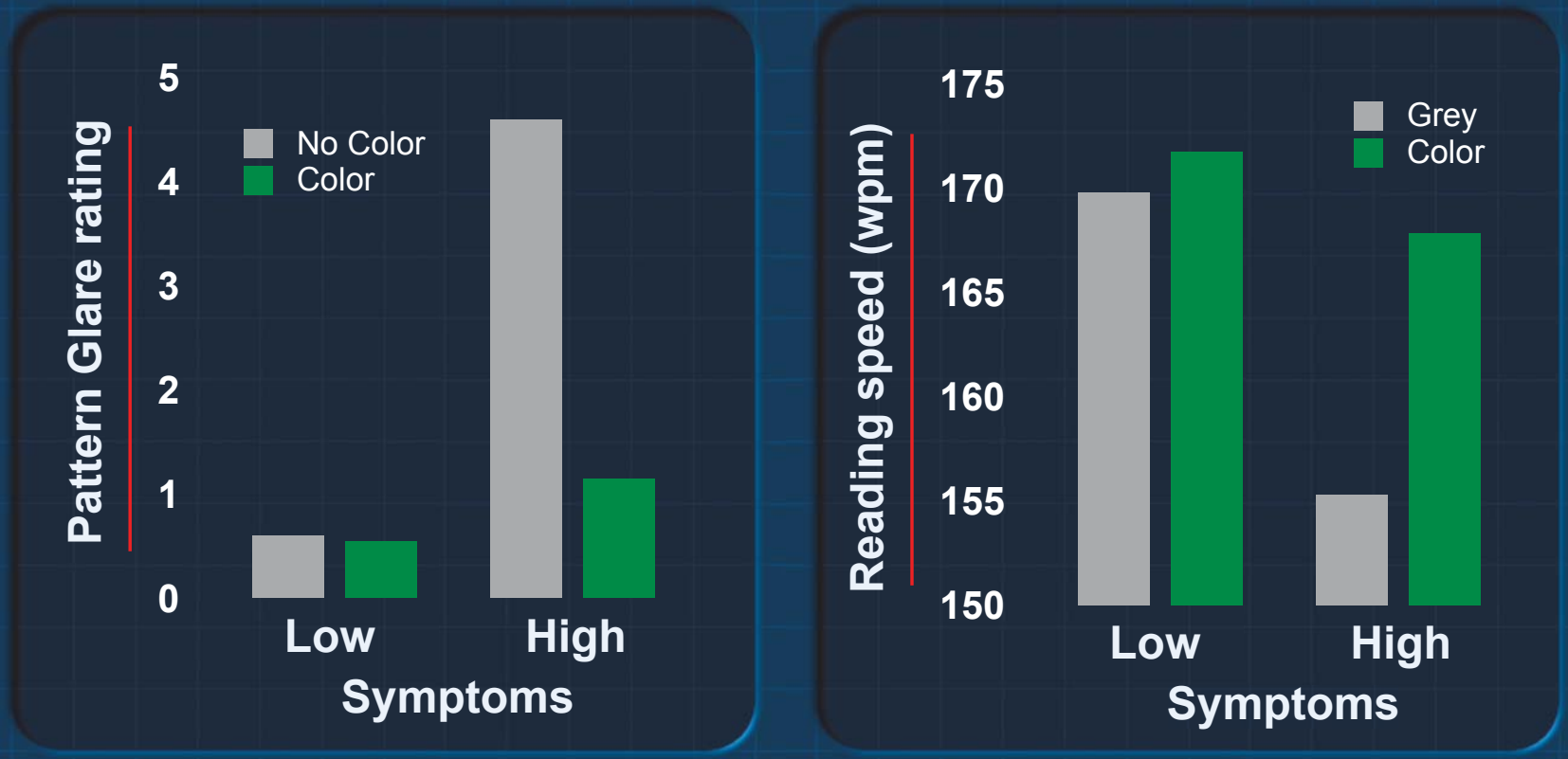
Eyestrain ⟷ Color



Allen et al, unpublished

All students selected IOO color transparency of choice.

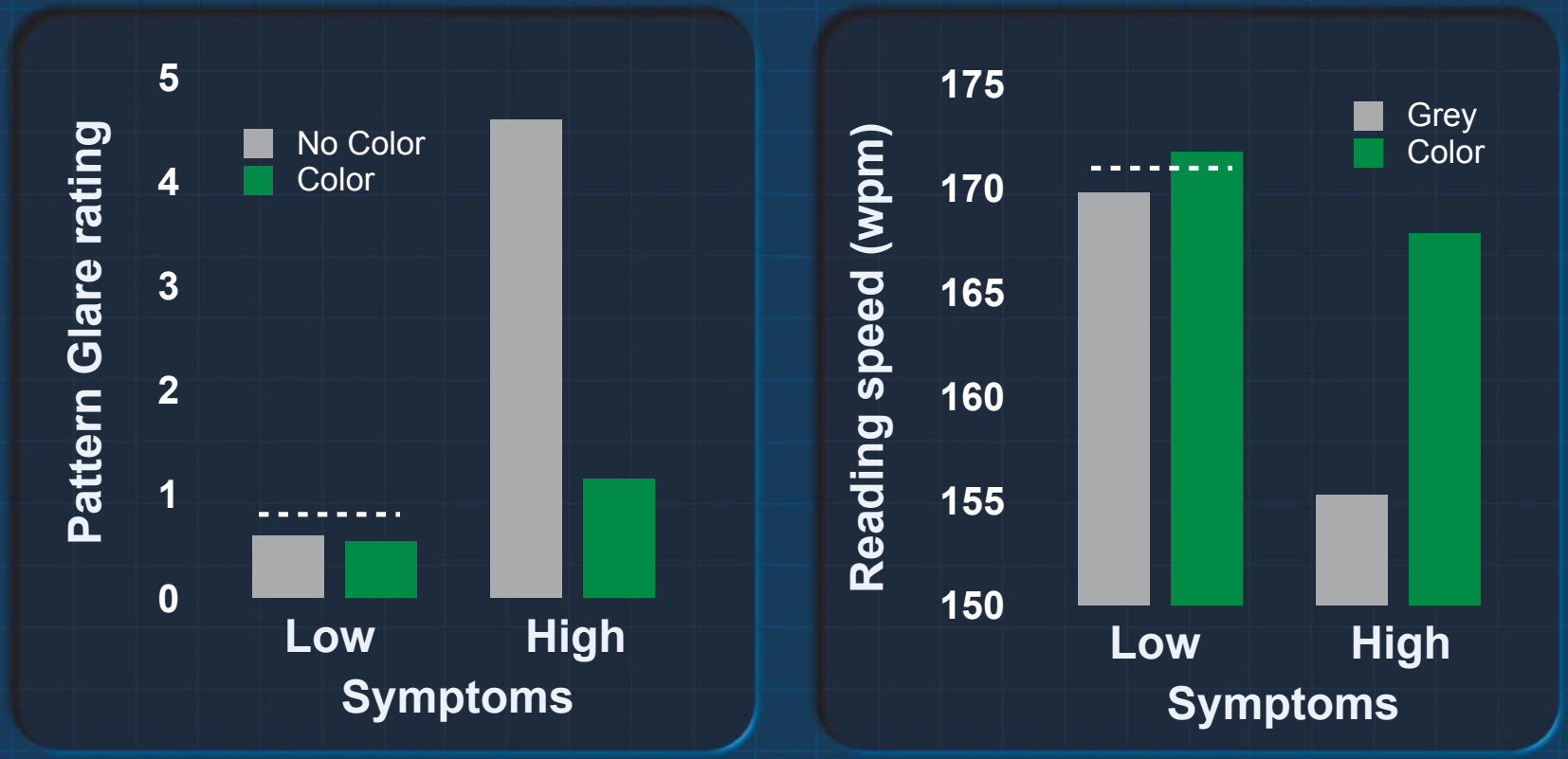
Eyestrain ⟷ Color



Allen et al, unpublished

All students selected IOO color transparency of choice.

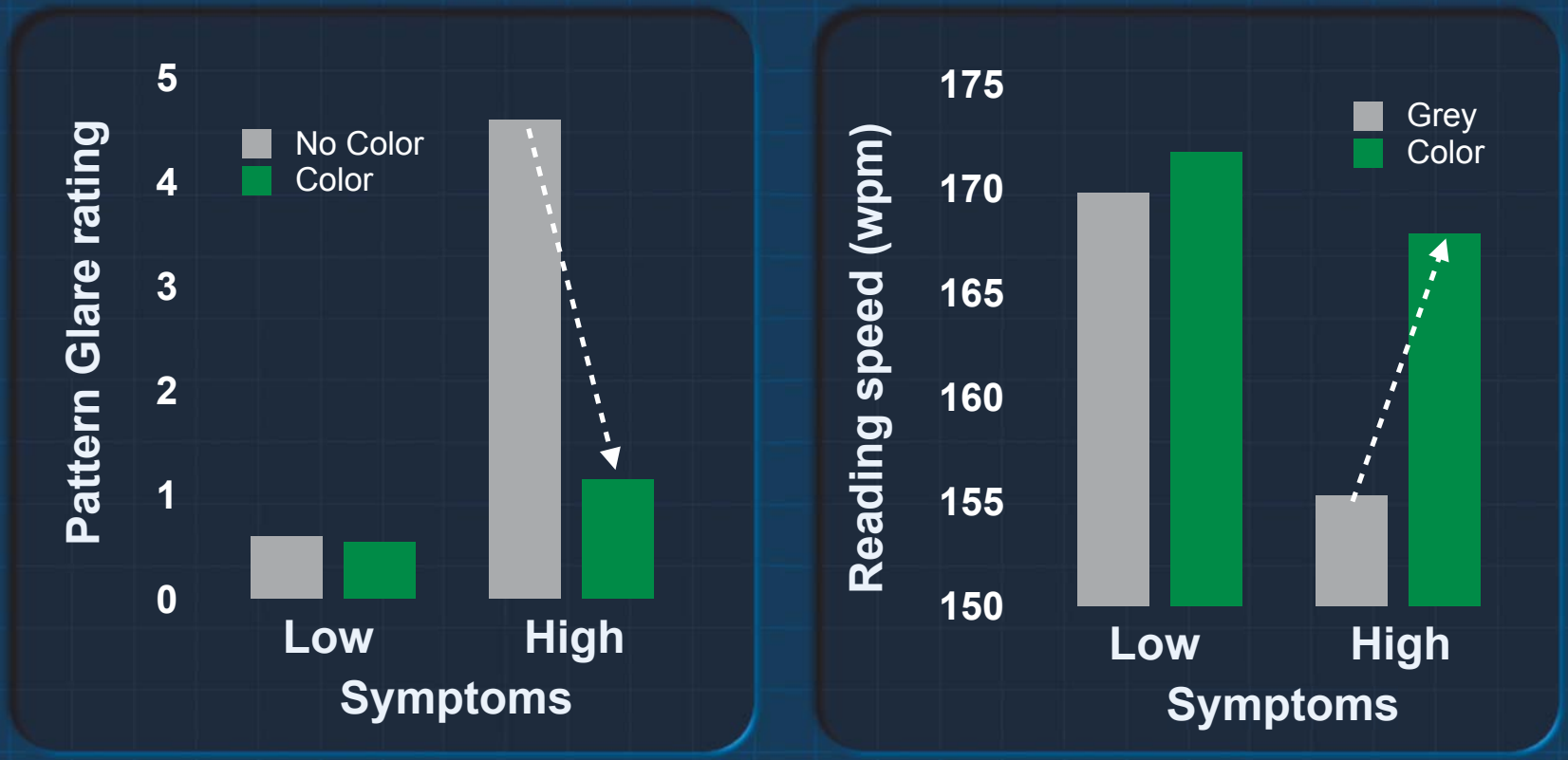
Eyestrain ⟷ Color



Allen et al, unpublished

All students selected IOO color transparency of choice.

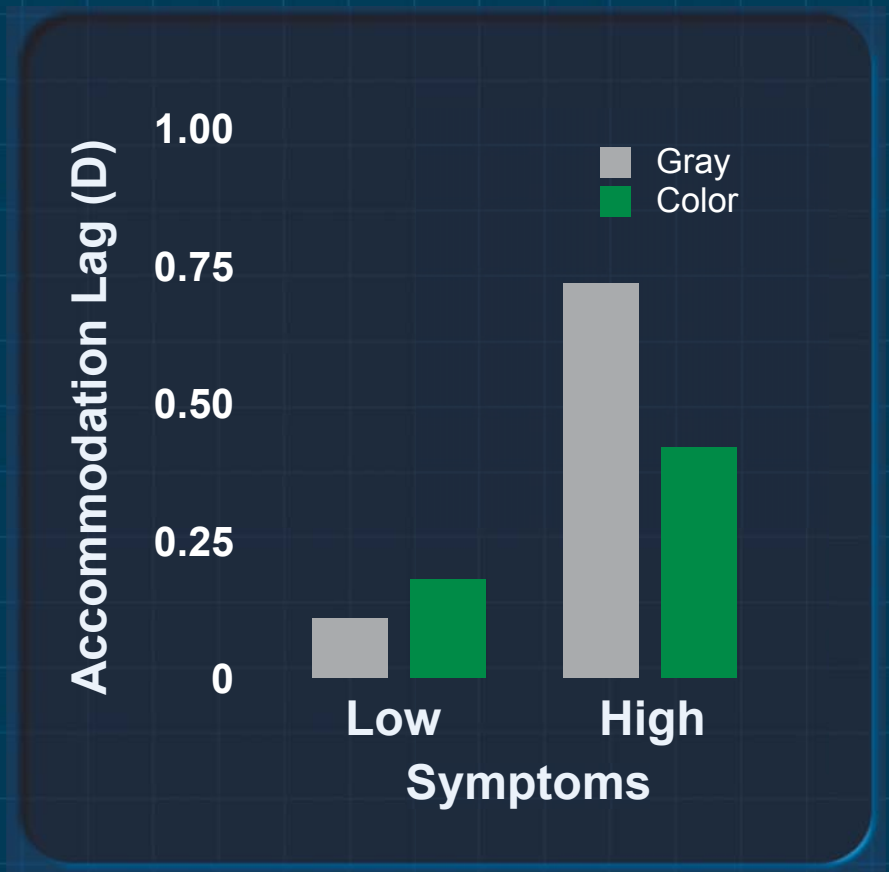
Eyestrain ⟷ Color



Allen et al, unpublished

All students selected IOO color transparency of choice.

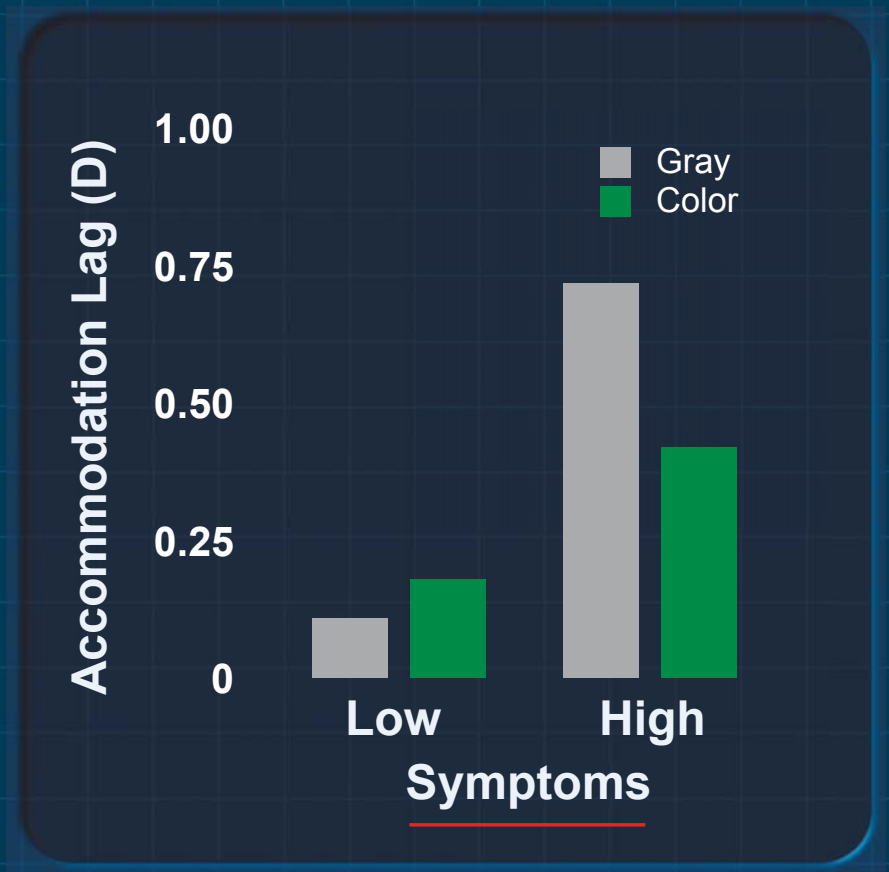
Color ⟷ Accommodation



Allen et al, 2010.

All subjects selected IOO color transparency of choice. 2D viewing distance.

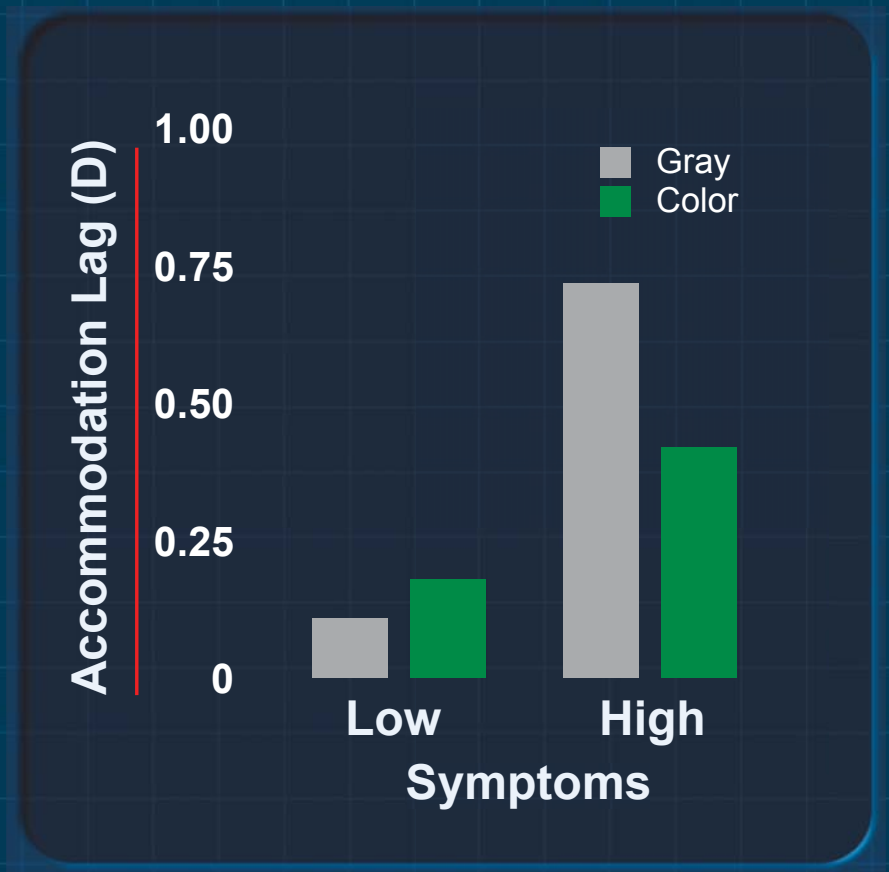
Color ⟷ Accommodation



Allen et al, 2010.

All subjects selected IOO color transparency of choice. 2D viewing distance.

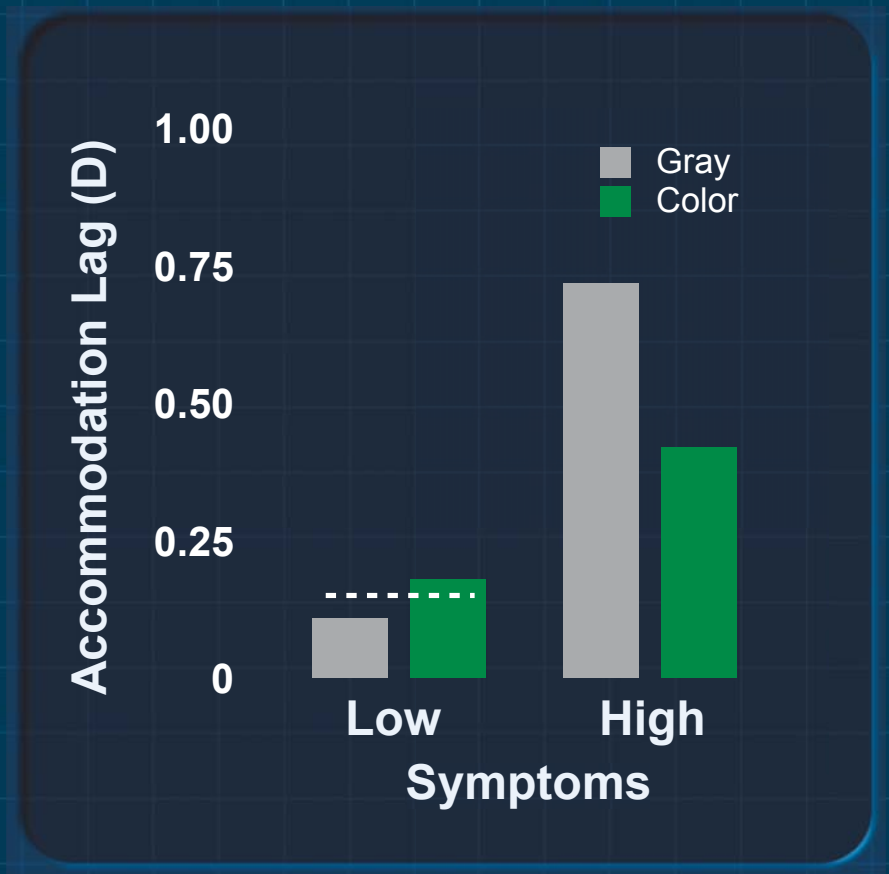
Color ⟷ Accommodation



Allen et al, 2010.

All subjects selected IOO color transparency of choice. 2D viewing distance.

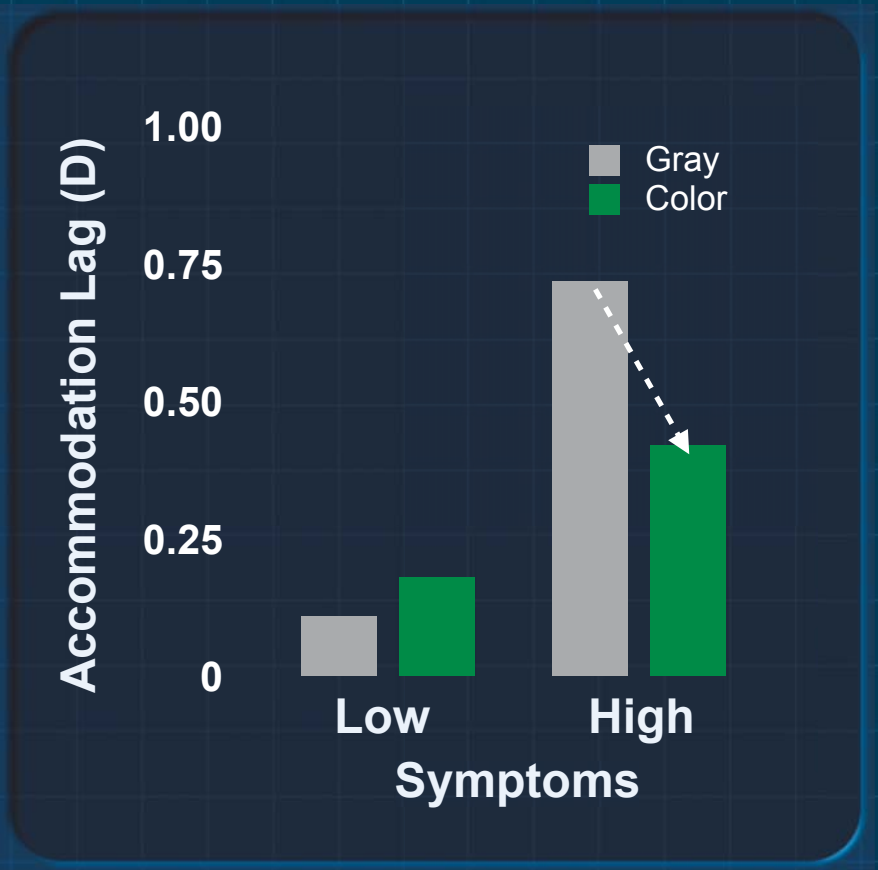
Color ⟷ Accommodation



Allen et al, 2010.

All subjects selected IOO color transparency of choice. 2D viewing distance.

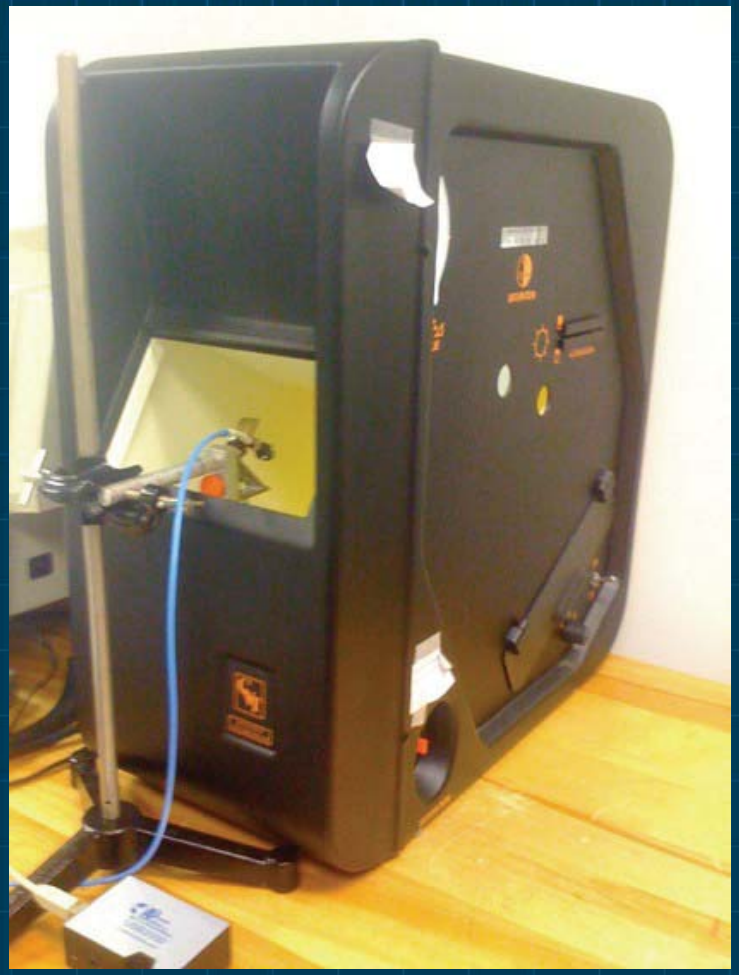
Color ⟷ Accommodation



Allen et al, 2010.

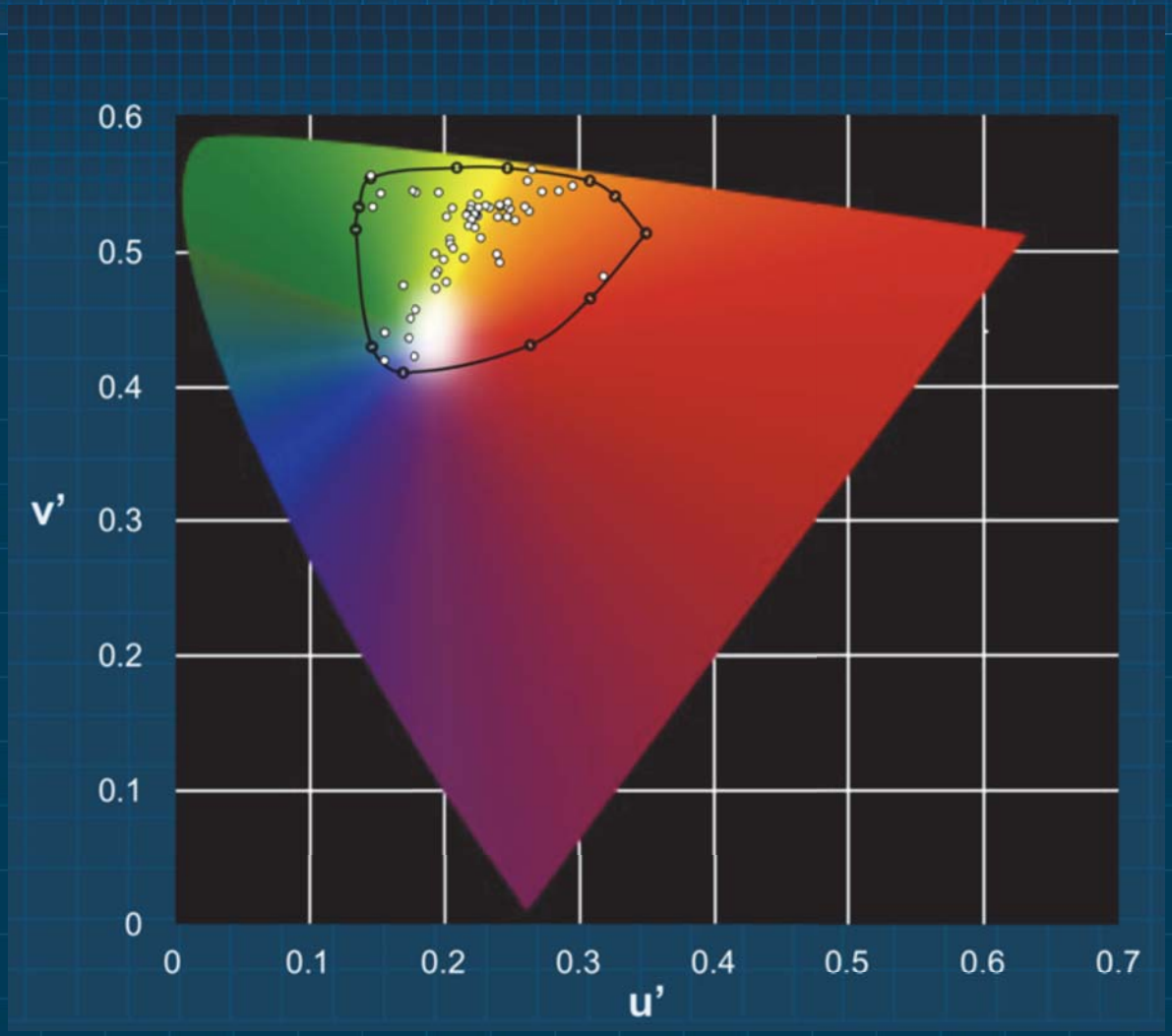
All subjects selected IOO color transparency of choice. 2D viewing distance.

Intuitive Colorimeter



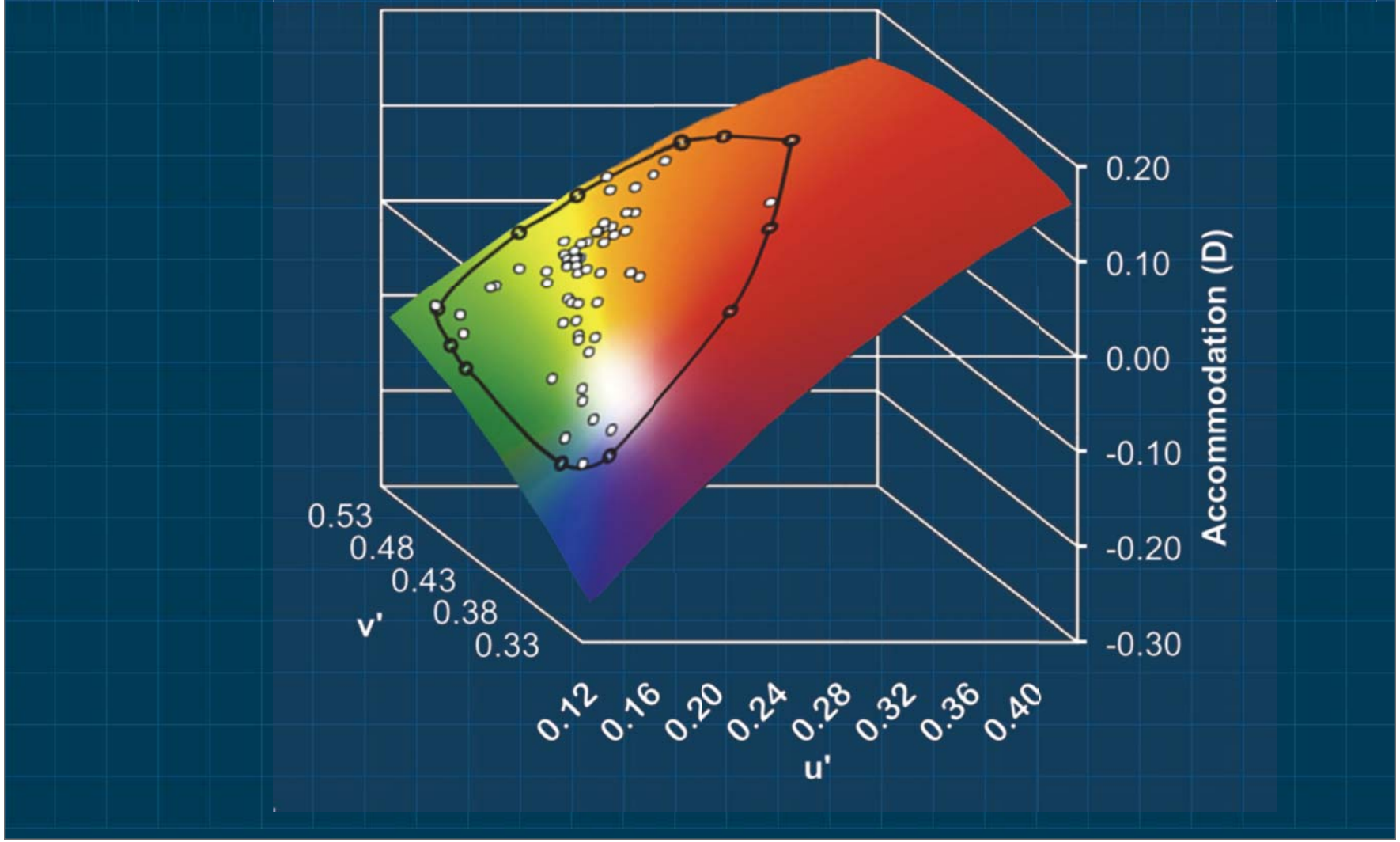
viewing distance of 40 cm to text.

Colorimeter CIE Gamut



Determine by absolute irradiance experiment to measure spectra for subject's color choices.

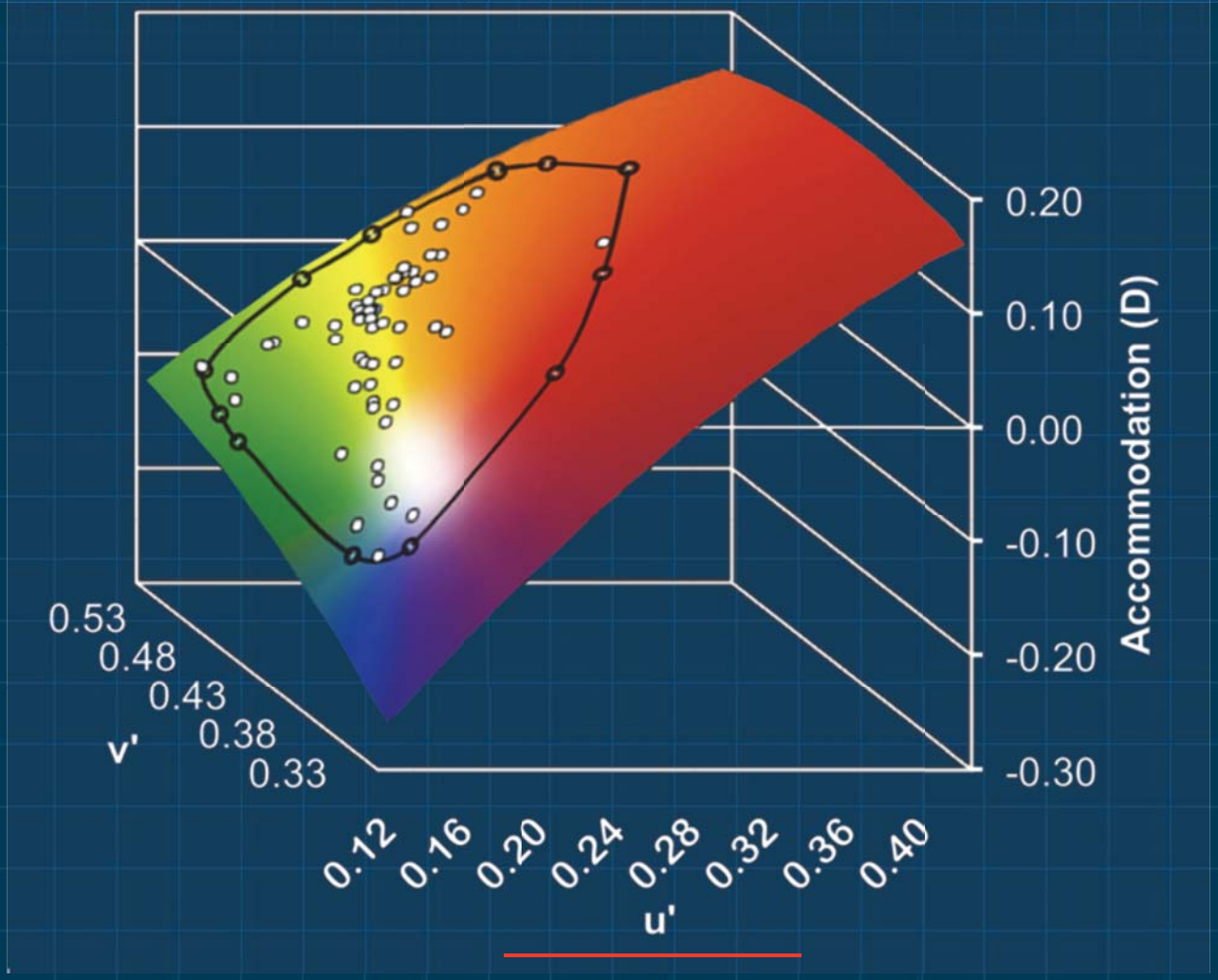
Change of accommodation demand in color space



LCA modeled using Thibos Chromatic Eye.

Colors mapped in CIE Luv with accommodation demand relative to neutral standard lighting in Colorimeter.

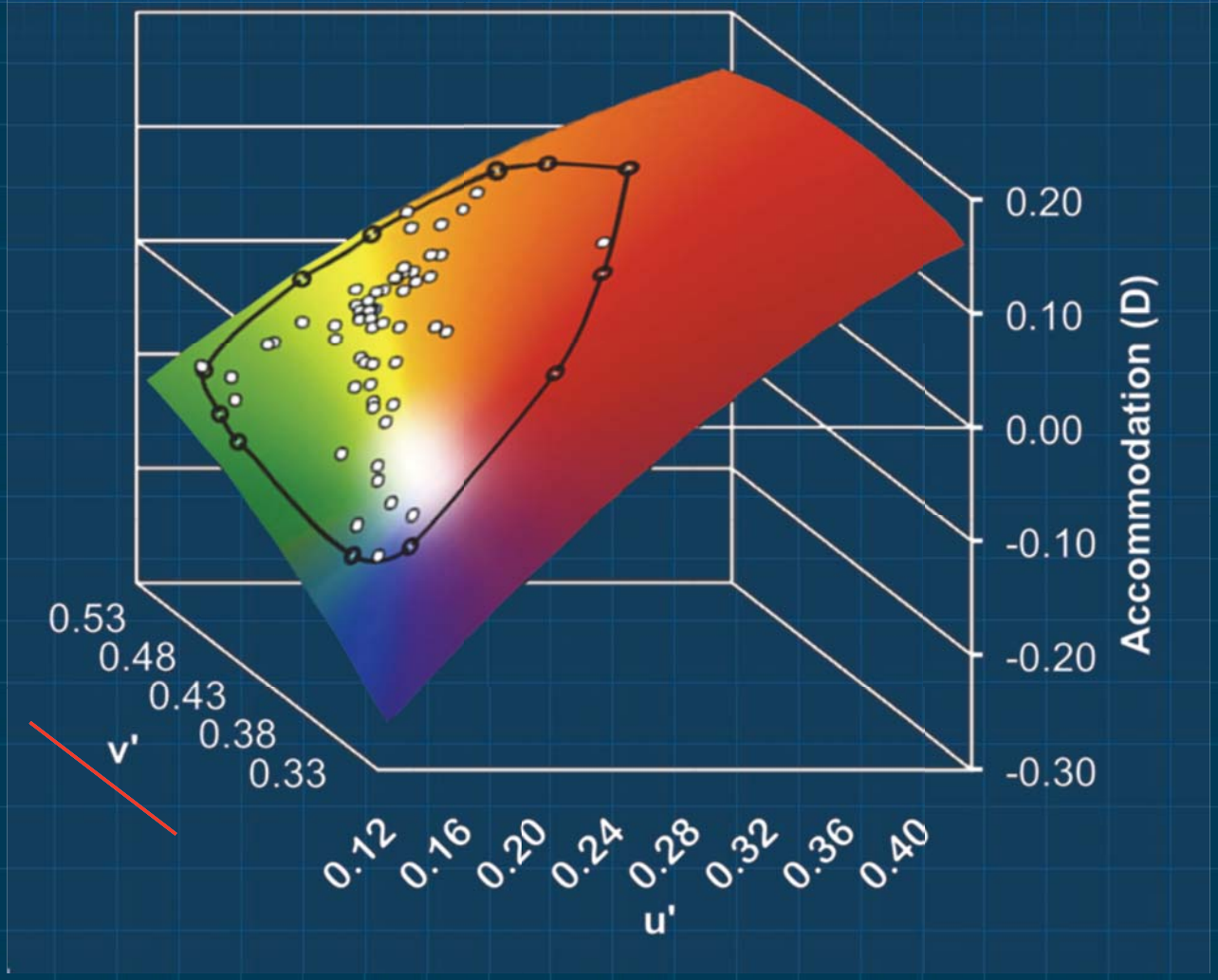
Change of accommodation demand in color space



LCA modeled using Thibos Chromatic Eye.

Colors mapped in CIE Luv with accommodation demand relative to neutral standard lighting in Colorimeter.

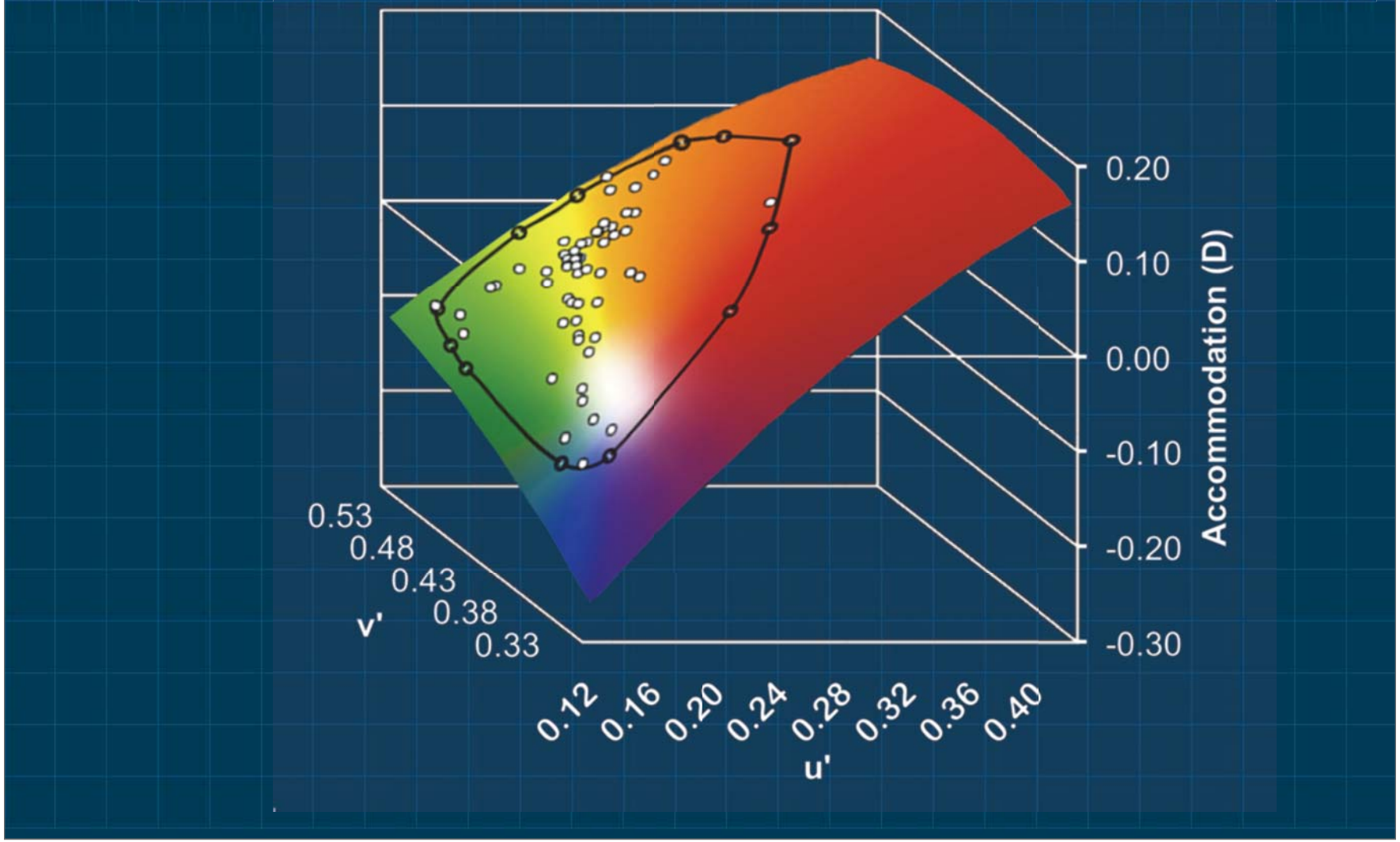
Change of accommodation demand in color space



LCA modeled using Thibos Chromatic Eye.

Colors mapped in CIE Luv with accommodation demand relative to neutral standard lighting in Colorimeter.

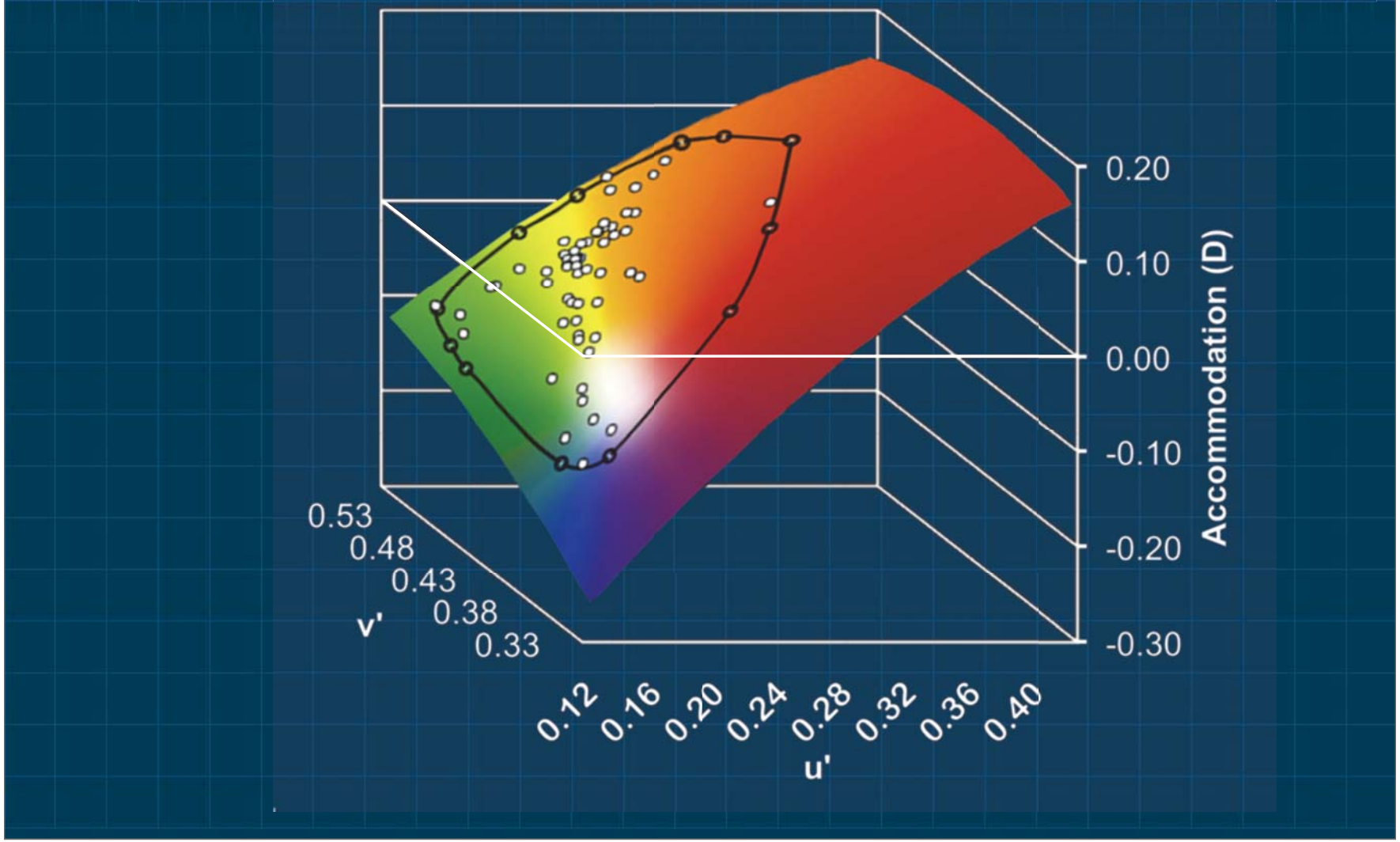
Change of accommodation demand in color space



LCA modeled using Thibos Chromatic Eye.

Colors mapped in CIE Luv with accommodation demand relative to neutral standard lighting in Colorimeter.

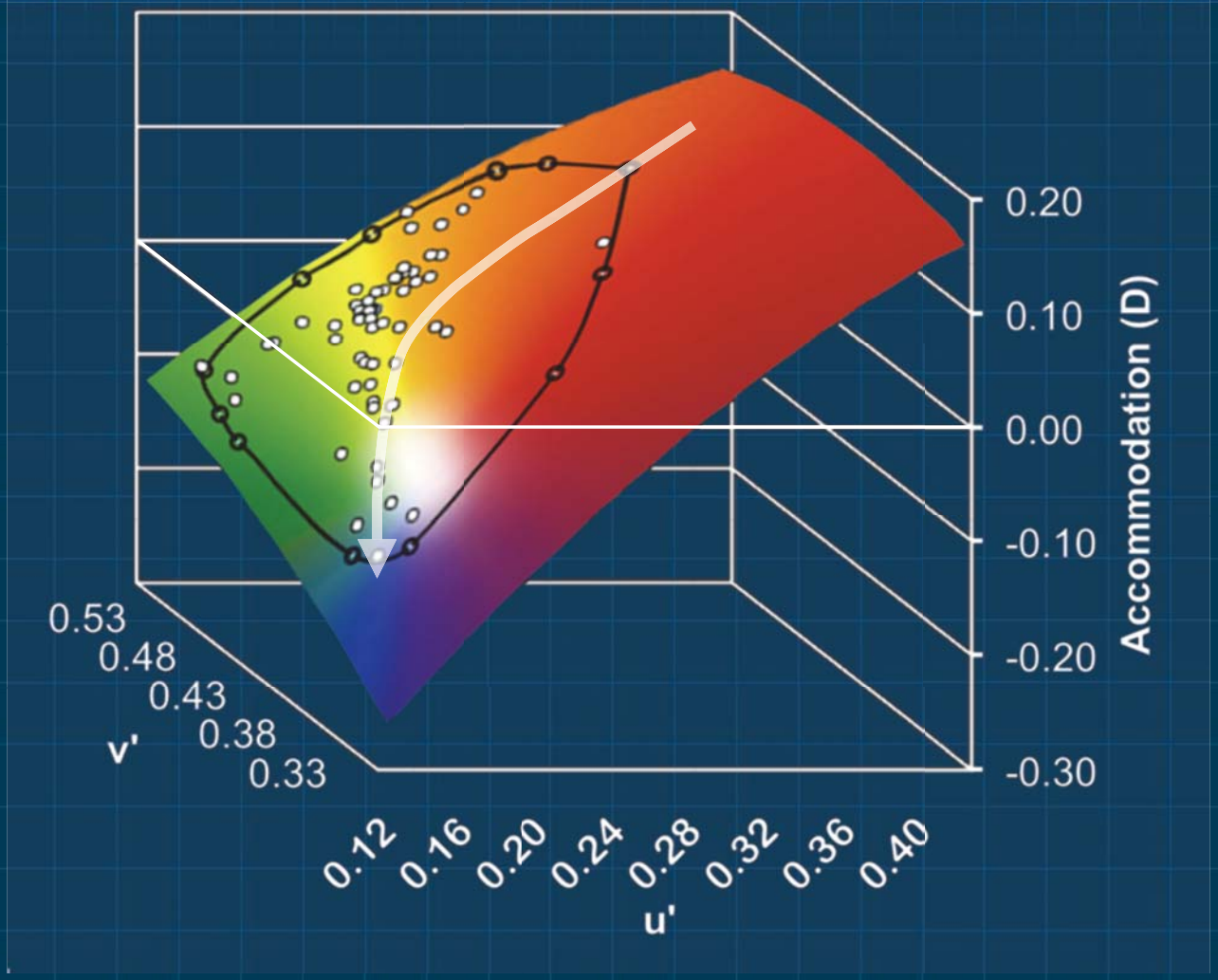
Change of accommodation demand in color space



LCA modeled using Thibos Chromatic Eye.

Colors mapped in CIE Luv with accommodation demand relative to neutral standard lighting in Colorimeter.

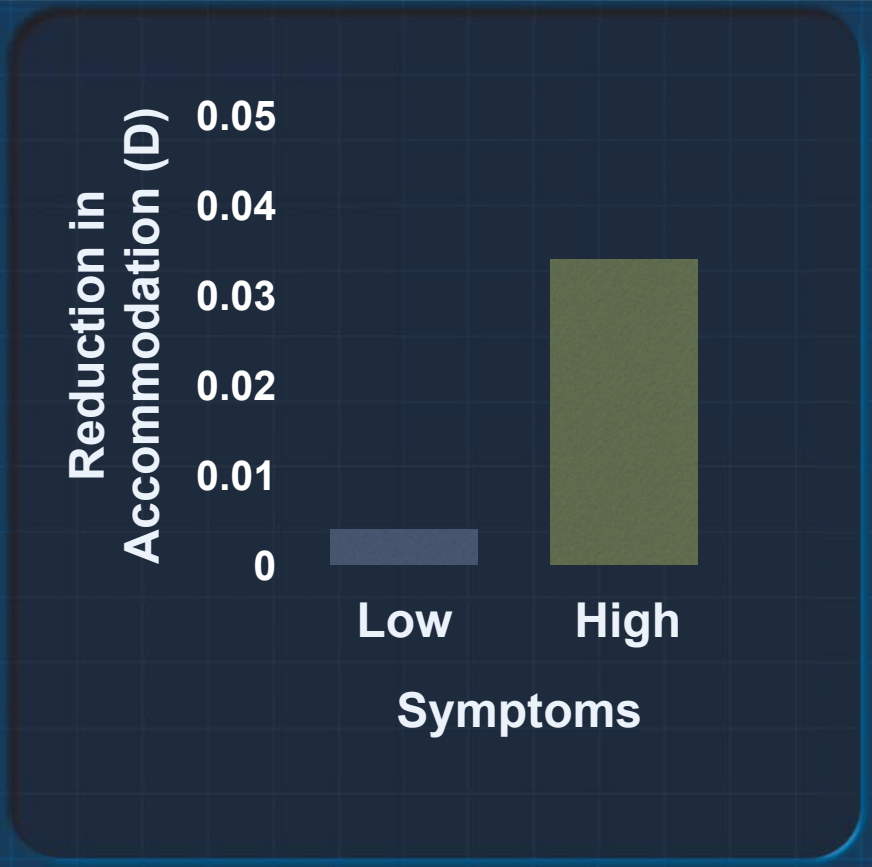
Change of accommodation demand in color space



LCA modeled using Thibos Chromatic Eye.

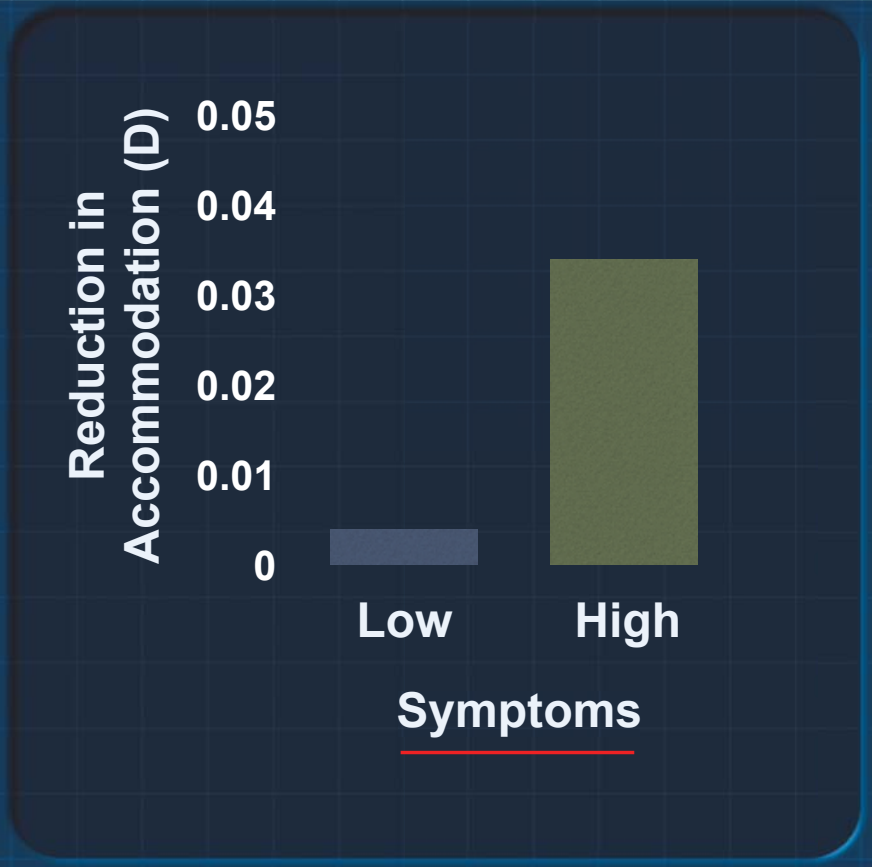
Colors mapped in CIE Luv with accommodation demand relative to neutral standard lighting in Colorimeter.

Symptomatic students reduced accommodation



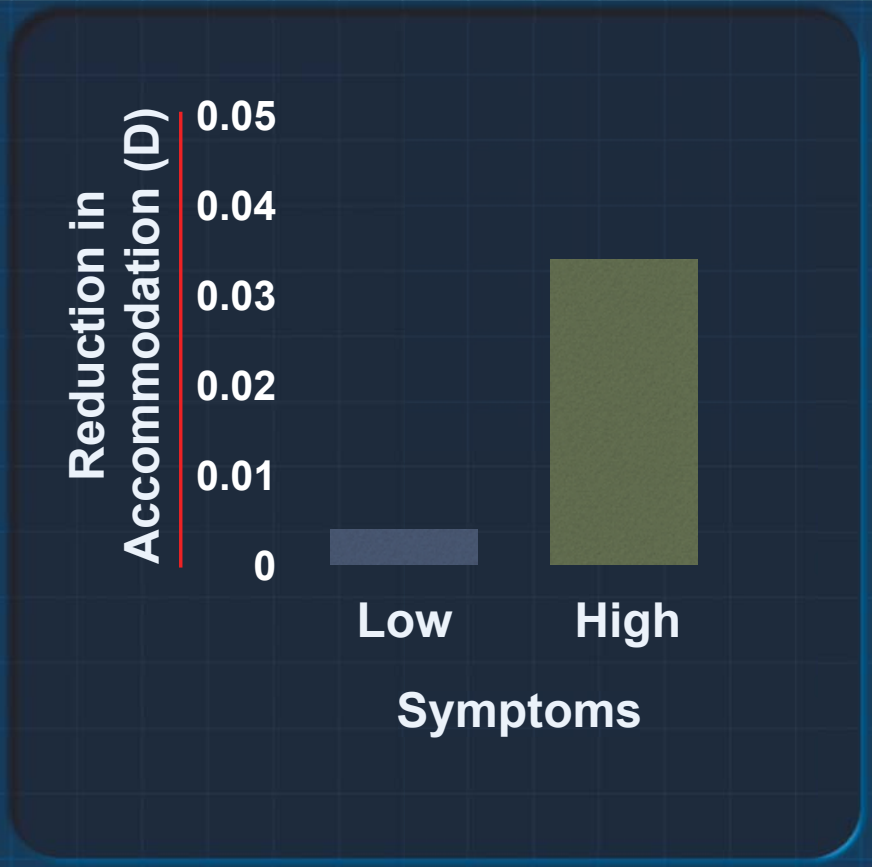
$t(50) = 2.37, p = .01$

Symptomatic students reduced accommodation



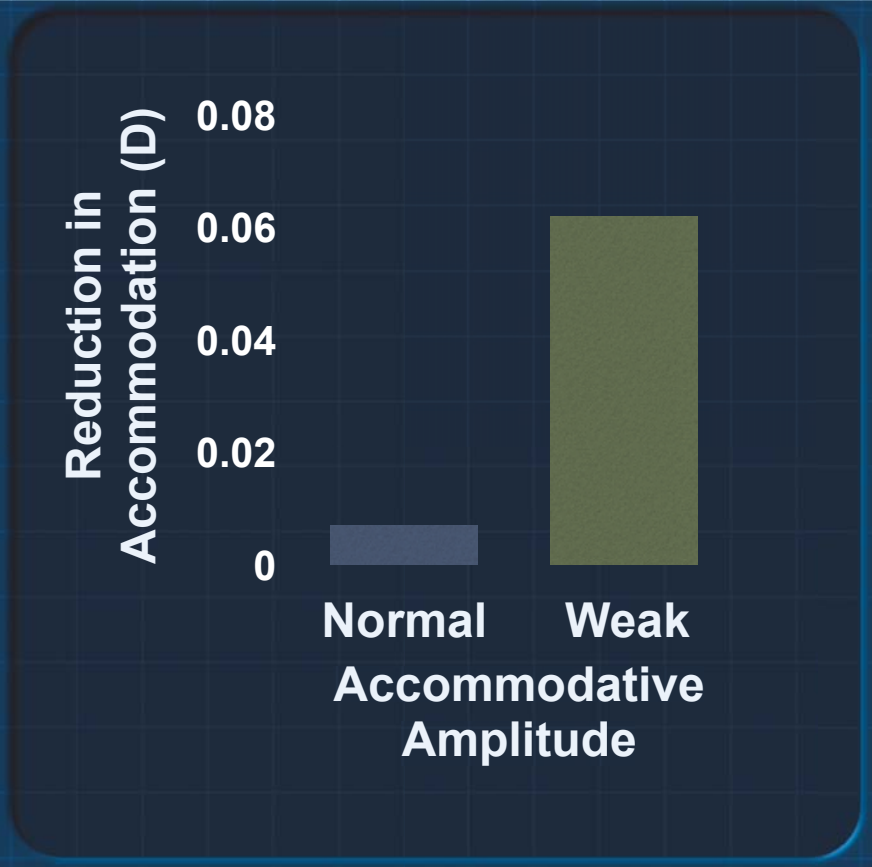
$t(50) = 2.37, p = .01$

Symptomatic students reduced accommodation



$t(50) = 2.37, p = .01$

Weak accommodators reduced demand

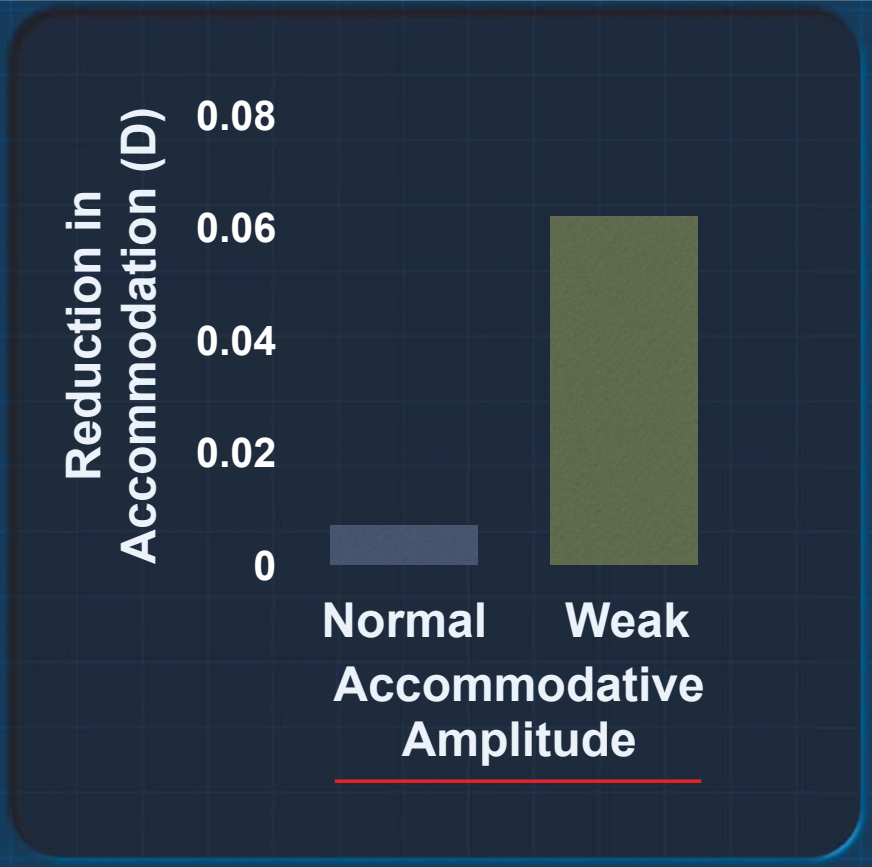


t(47) = 3.76, p = .0002

Hofstetter's formula = 15 - .25*Age, or for 20-year olds = 10D.
2D below = 8 cut-off.

Low group (N=11) < 8.0
Normal (N=38) >=8.0

Weak accommodators reduced demand

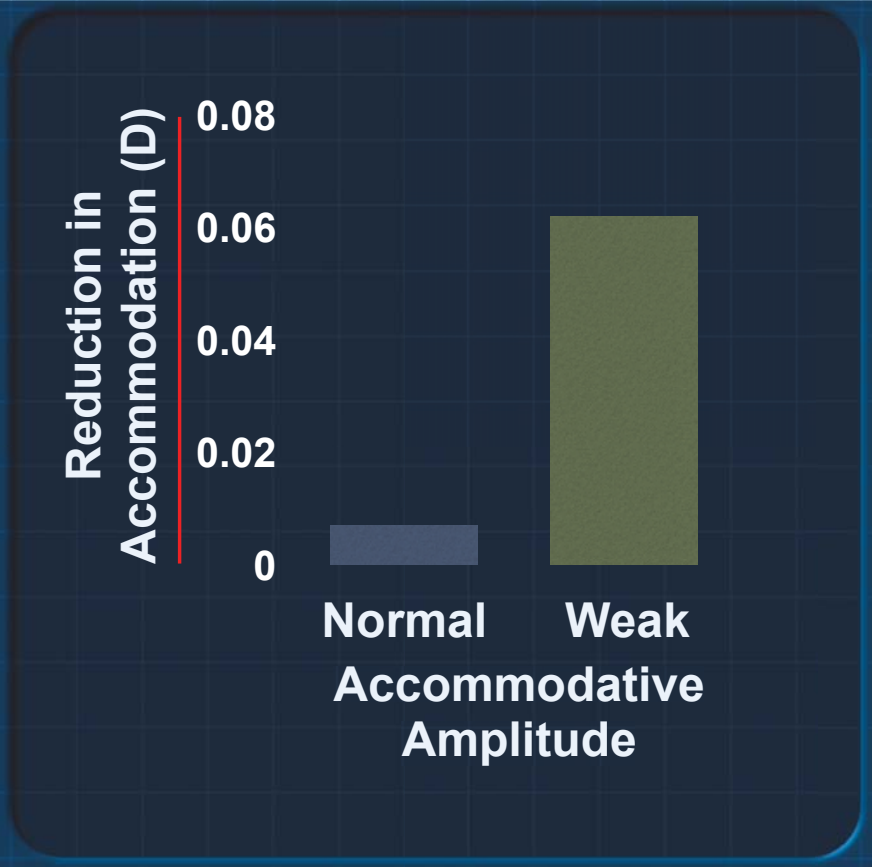


t(47) = 3.76, p = .0002

Hofstetter's formula = 15 - .25*Age, or for 20-year olds = 10D.
2D below = 8 cut-off.

Low group (N=11) < 8.0
Normal (N=38) >=8.0

Weak accommodators reduced demand



t(47) = 3.76, p = .0002

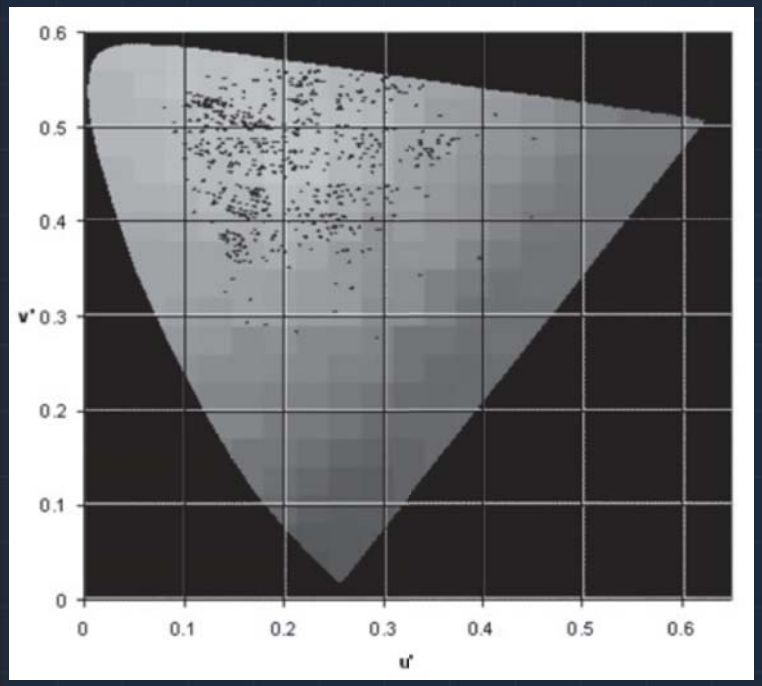
Hofstetter's formula = 15 - .25*Age, or for 20-year olds = 10D.
2D below = 8 cut-off.

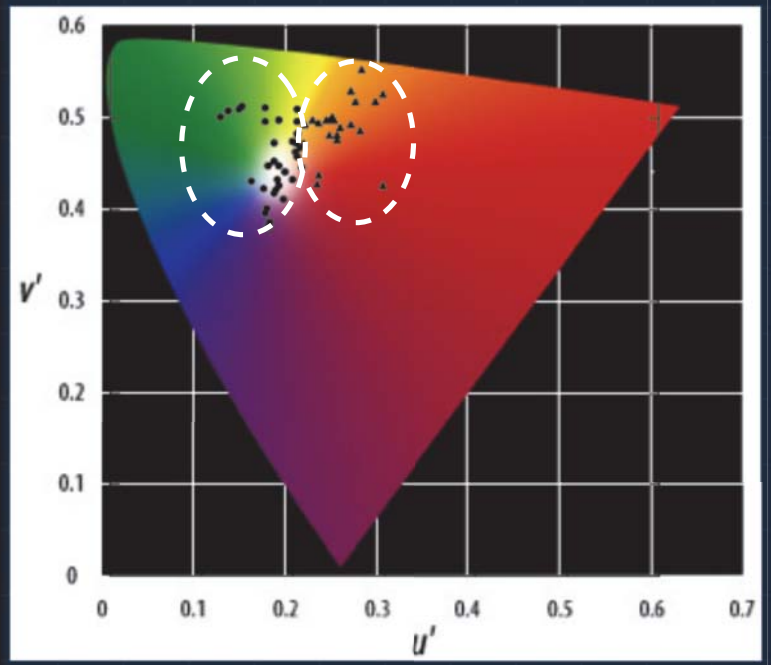
Low group (N=11) < 8.0
Normal (N=38) >=8.0

Summary

- Symptomatic students reduce accommodation demand with greens and blues that reduce L/M cone-contrast ratios.
- Weak accommodators do the same.
- Color may be a way to reduce eyestrain by relieving accommodation demand.

Distribution of preferred colors raises questions

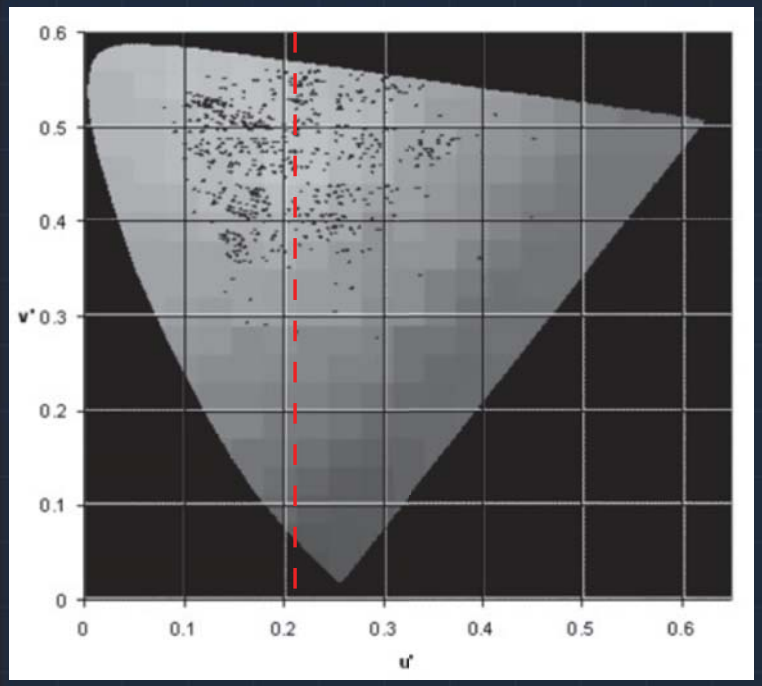


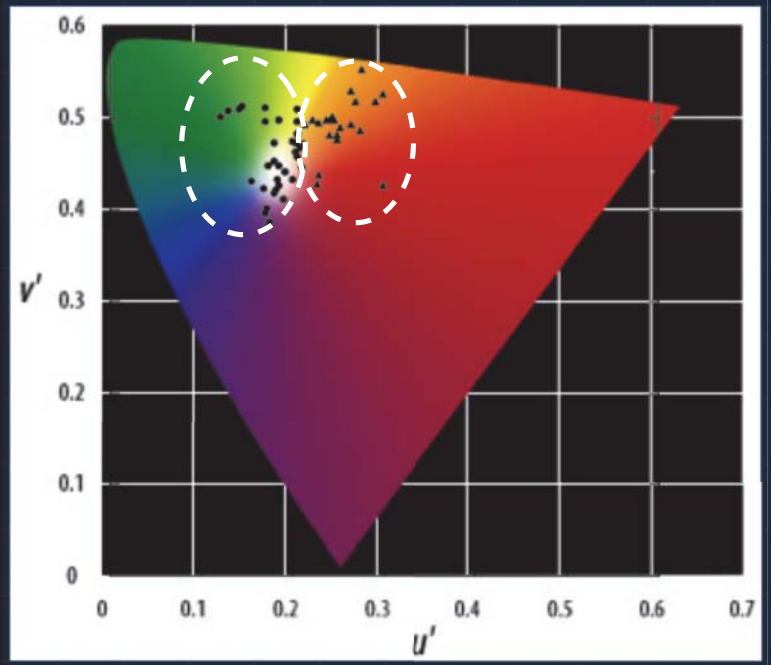


From Wilkins 2003

1. Patients are choosing a variety of colors, many that increase L/M ratios, but some do not.

Distribution of preferred colors raises questions

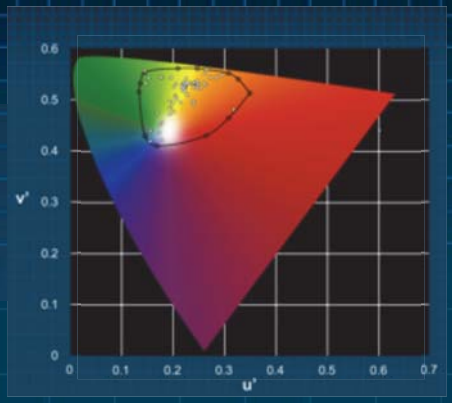




From Wilkins 2003

1. Patients are choosing a variety of colors, many that increase L/M ratios, but some do not.

Why so many colors?



- Other abnormalities besides accommodation.
- Balancing cone L/M ratio variation.
- Stimulating sluggish accommodation response with orange/red.
- Bad choices.

Several possibilities:

a. Accommodative weakness only a subtype and the color variation reflects other types of abnormalities.

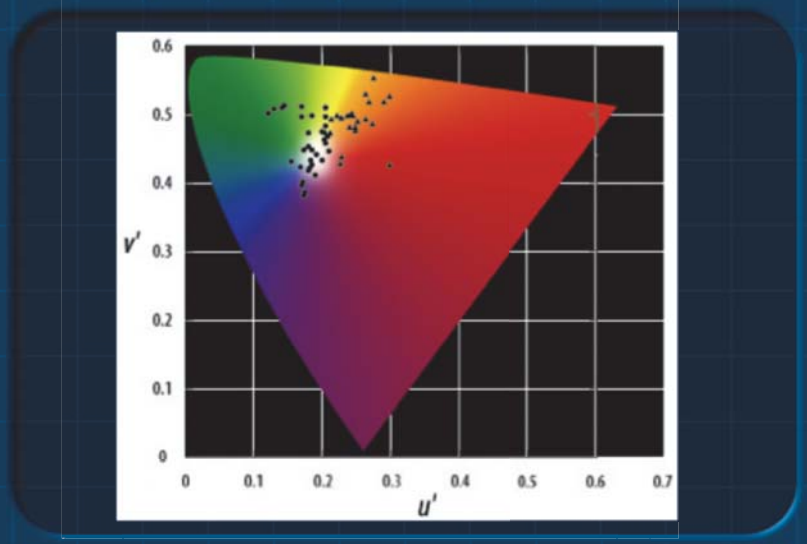
b. Individuals who choose colors that increase L/M ratios are off-setting biological variation in L/M-cone contrast sensitivity to create a balance.

c. Patients have chosen suboptimal colors and really would do better with low-pass filters.

d. Accommodation is just fine and chosen color doesn't improve reading speed. The red/orange was selected to stimulate accommodation in a sluggish but responsive system

e. Results from these studies are based on college students who are good readers, and they are not representative of the general population shown here.

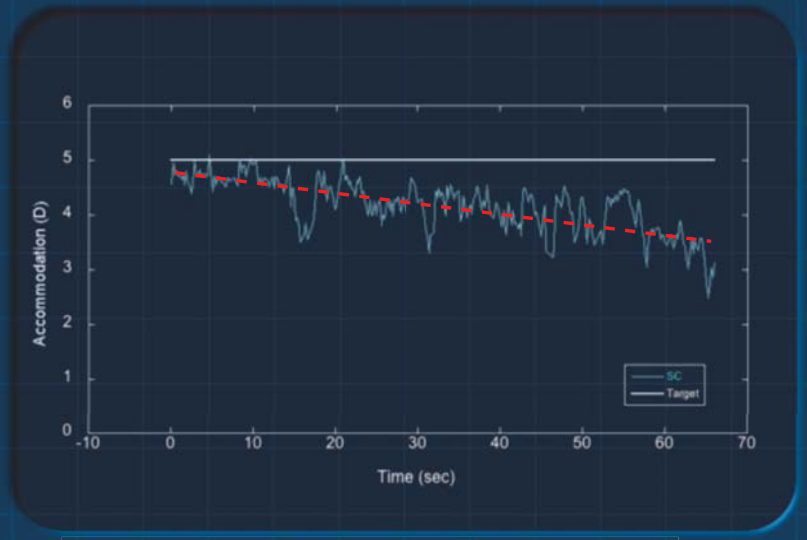
Conclusions

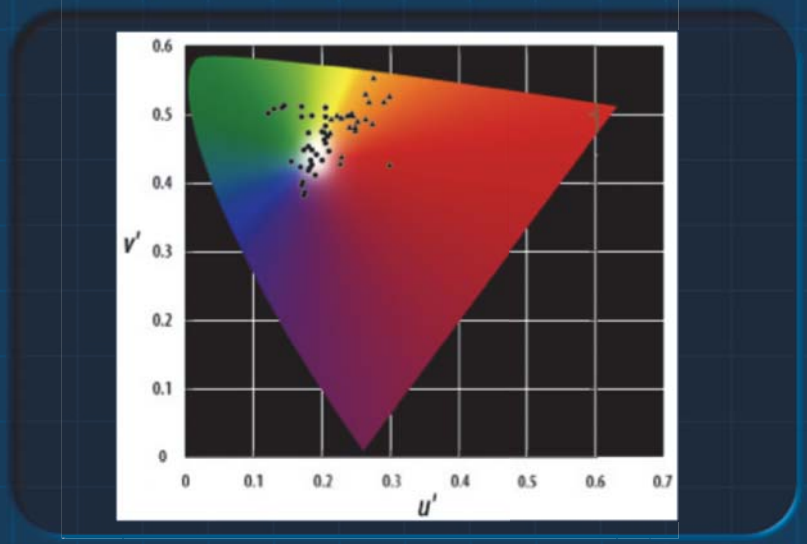


- Further study of accommodation and color.
- Objective measures of accommodation, particularly over time.
- Relationship between color (L/M ratio) and accommodation demand.

1. Need to measure color in terms of relative L/M-cone contrast sensitivity.
2. Objectively measure accommodative function under color choices.
3. Treatment comparison plus-lenses to relieve accommodative demand and color.
4. Study of presbyopic individuals (older) and emmetropes (younger) who both have visual stress. If treated with reading glasses, do symptoms subside?

Conclusions





- Further study of accommodation and color.
- Objective measures of accommodation, particularly over time.
- Relationship between color (L/M ratio) and accommodation demand.

1. Need to measure color in terms of relative L/M-cone contrast sensitivity.
2. Objectively measure accommodative function under color choices.
3. Treatment comparison plus-lenses to relieve accommodative demand and color.
4. Study of presbyopic individuals (older) and emmetropes (younger) who both have visual stress. If treated with reading glasses, do symptoms subside?