Fundamentals of Accommodation & Convergence

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Accommodation

- Accommodation – physiological adjustment of focus
  - decreases with age[1]

smartphone — 13" (33cm)*
print / e-reader — 16" (40cm)*

*accommodative lag = 1.22D

[1]James S. Wolffsohn, Leon N. Davies, Presbyopia: Effectiveness of correction strategies,
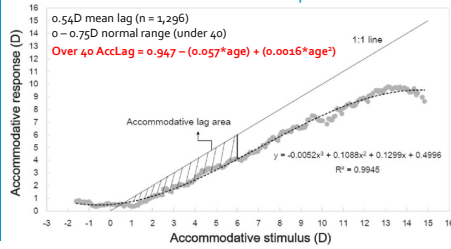Progress in Retinal and Eye Research, Volume 68, 2019, Pages 124-143

Accommodation

$d(m) = 1/D$

- Near Point of Accommodation
  - closest point of focus with full accommodation[2]

Near Point (cm) and Age Correlation

[2]https://media.pearsoncmg.com/bc/bc_marieb_ehap_10/art_activities/figure_8.4a/figure_8.4a.html

Accommodative Lag
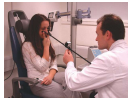
- Accommodative Lag
  - accommodative demand – response[3]

0.54D mean lag (n = 1,296)
0 – 0.75D normal range (under 40)
Over 40 AccLag = 0.947 – (0.057*age) + (0.0016*age²)

$y = -0.0052x^3 + 0.1088x^2 + 0.1299x + 0.4996$
$R^2 = 0.9945$

1:1 line
Accommodative lag area

[3] Alejandro L, Rosenfeld M, Estrada JM, Medrano SM, Marquez MM. Lag of accommodation between 5 and 60 years of age. Optom Vis Perf 2017;5(3):103-8.

Accommodation Measurements

- Measurements of Accommodative Function[4]
  - Amplitude (how much)
    - ✔ measured as a function of near point
    - ✔ push-up test
  - Facility (how fast)
    - ✔ lens rock test (+2.00/-2.00)
    - ✔ 8 cycles / minute (binocular)
  - Lag (how deficient)
    - ✔ MEM / Nott dynamic retinoscopy

[4] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.135

Accommodation Symptoms
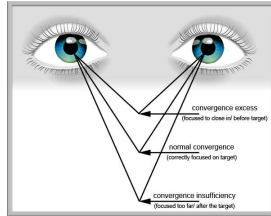
- Accommodative disorder symptoms[5]
  - blurred vision
 - headaches
  - ocular discomfort

[5] Ibid.

Convergence

- **Convergence** – simultaneous movement of both eyes towards each other, normally occurring in near vision
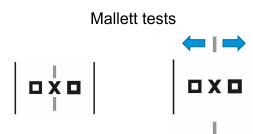

convergence excess
(focused to close in/ before target)

normal convergence
(correctly focused on target)

convergence insufficiency
(focused too far/ after the target)

Convergence

- Convergence is expressed in prism diopters[6]
  - Orthophoria = correct convergence for demand

∞ = 0Δ diopters
16" = 15Δ diopters

-- 2.5 diopters accom.

-- 0 diopters accom.
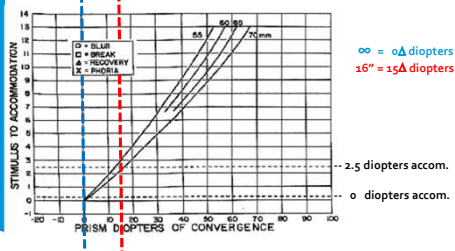
[6] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.3
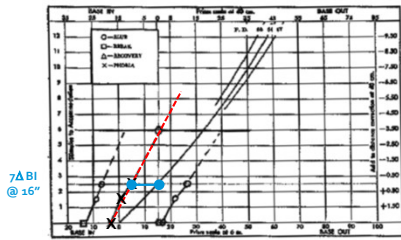

Convergence

- Convergence errors (fixation disparities) are commonly measured by subjective alignment of two small lines or bars.[7]

Mallett tests

[7] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.67

Convergence

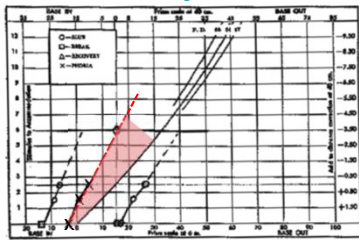- Exophoria = lack of convergence
  - Associated Phoria = prism required to correct[8]

7Δ BI @ 16"

[8] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.70
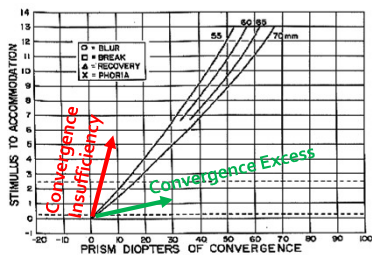
ACA Ratio

- ACA = accommodative convergence / accommodation
  - Normal = 4-6Δ BO vergence / 1D accommodation[9]

[9] Schor CM, Ciuffreda KJ, eds. *Vergence Eye Movements: Basic and Clinical Aspects.* Boston, MA: Butterworth-Heinemann; 1983:15-21
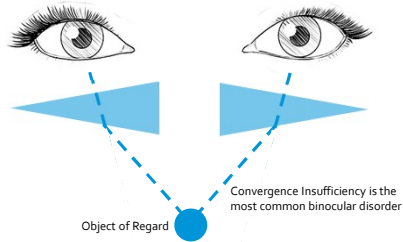
ACA Ratio

- ACA = steep slope indicates insufficiency[10]

[10] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.15

Slide 1

Convergence Insufficiency

- Convergence Insufficiency (exophoria @near)
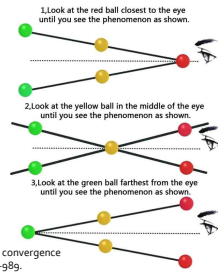 - BI prism restores binocular vision, however...

Convergence Insufficiency is the most common binocular disorder

Object of Regard

Slide 2

Convergence Insufficiency

- Convergence Insufficiency (exophoria @near) usually responds well to vision therapy (VT)

VT is generally the treatment of choice for convergence insufficiency.[11]

1. Look at the red ball closest to the eye until you see the phenomenon as shown.

2. Look at the yellow ball in the middle of the eye until you see the phenomenon as shown.

3. Look at the green ball farthest from the eye until you see the phenomenon as shown.

[11] Cooper, J, Selenow A, Ciuffreda KJ, et al. Reduction of asthenopia in patients with convergence insufficiency after fusional vergence training. *Am J Optom Physiol Opt*. 1983;60:982-989.

Slide 3

Convergence Excess

- Convergence Excess (esophoria)
  - Treatment of choice at distance is BO Δ[12]
    - ✓ Resolves alignment with the visual axes
  - Treatment of choice at near is ADD power[13]
    - ✓ Reduces the convergence signal
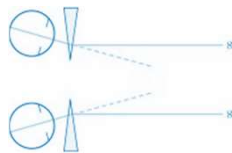
[12,13] Amos JF, ed. *Diagnosis and Management in Vision Care*. Boston, MA: Butterworth-Heinemann; 1987:461-510

ZCSBV

- **ZCSBV** = zone of clear single binocular vision[14]
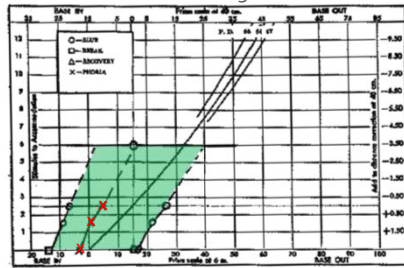
[14] Fry GA. Further experiments on the accommodation-convergence relationship. *Am J Optom Arch Am Acad Optom.* 1939;16:325-336

Morgan's Norms

- Dr. Merideth Morgan established "normal" phorias in the 1940-60s[15]

Tests	Expected	Standard Deviation
Distance Lateral Phoria	1 exophoria	+/-2 prism diopters
Base In (Distance) - Blur	n/a	n/a
Base In (Distance) - Break	7 prism diopters	+/-3 prism diopters
Base In (Distance) - Recovery	4 prism diopters	+/-2 prism diopters
Base Out (Distance) - Blur	9 prism diopters	+/-4 prism diopters
Base Out (Distance) - Break	19 prism diopters	+/-8 prism diopters
Base Out (Distance) - Recovery	10 prism diopters	+/-4 prism diopters
Near Lateral Phoria	3 exophoria	+/-3 prism diopters
Base In (Near) - Blur	13 prism diopters	+/-4 prism diopters
Base In (Near) - Break	21 prism diopters	+/-4 prism diopters
Base In (Near) - Recovery	13 prism diopters	+/-5 prism diopters
Base Out (Near) - Blur	17 prism diopters	+/-5 prism diopters
Base Out (Near) - Break	21 prism diopters	+/-6 prism diopters
Base Out (Near) - Recovery	11 prism diopters	+/-7.00 prism diopters
AC/A ratio	4:1	+/-2.00 prism diopters
Accommodation: Push Up	18 - (1/3) x age	+/-2.00 D
Accommodation: Fused Cross Cylinder	+0.50 D	+/-0.50 D
Accommodation: NRA	+2.00	+/-0.50 D
Accommodation: PRA	-2.37	+/-1.00 D

[15] Morgan MW. The analysis of clinical data. *Optom Weekly.* 1964;55:27-34;55:23-25

Morgan's Norms

- General observations
  - A small amount of exophoria is normal
    - ✓ 1Δ up to 3Δ at distance
    - ✓ 3Δ up to 6Δ at near
  - Normally, it takes considerable prism to create blur at near
    - ✓ 13 ΔBI
    - ✓ 17 ΔBO
  - ACA Ratios can fall between 2-6Δ/1 diopter of accommodation

Slide 1

Sheard's Criterion

- Asthenopia –
  - weakness or rapid fatigue of the eyes often accompanied by pain and headache (Webster)
- Dr. Charles Sheard's criterion
  - Fusional reserve should be at least 2x the demand
  - Does the patient require prism?
    $\Delta = 2/3\ D - 1/3\ R$
    - Δ = prism required
    - D = diopters of phoria
    - R = diopters of reserve

Dr. Charles Sheard
1883-1963

[16] Sheard C. *The Sheard Volume – Selected Writings in Visual and Ophthalmic Optics*. Philadelphia, PA: Chilton; 1957:267-285.

Slide 2

Case Study - 43 year old wearing 1st PAL

- Returns to office complaining of
  - Headache & asthenopia
  - Occasional blur
- Re-dotting the lenses reveals
  - FRP is <u>perfectly</u> placed
  - Lenses are straight, well-mounted
  - Frame fit is good (8 panto, 7 wrap, 12mm vertex)
- Recheck reveals 20/15 distance, so ADD is "bumped"
  - Symptoms become worse
  - New lenses are "unusable"
- What is a *possible* explanation?

Slide 3

Case Study - 43 year old wearing 1st PAL

- If the patient has insufficient convergence…
  - The ADD power further reduces convergence
    - ✓ A +1.00 ADD reduces convergence signal by the ACA Ratio
      (ACA = accommodative convergence / diopter of accommodation)
    - ✓ If the patient is already exophoric at near, the ADD increases exophoria
      - If ACA Ratio = 3, patient has 3 more diopters of exophoria at near
    - ✓ If fusional reserve is insufficient, symptoms may be the result
  - Increasing the ADD actually makes the situation worse
    - ✓ Because it's not a problem of accommodation…
    - ✓ …it's a problem of convergence
- Note: this is the realm of an optometrist
  - The first line of investigation is **lens fitment**
  - Refer back to the OD with your observations
- **What simple test could an <u>OD</u> perform to see if convergence may be the issue?**

ALL PALs Require Adaptation

- Providing an ADD power alters the wearer's near phoria
- At least one study confirms successful adaption to PALs requires phoria elasticity[20]
 - "Successful PAL adapters become more esophoric with PAL wear."
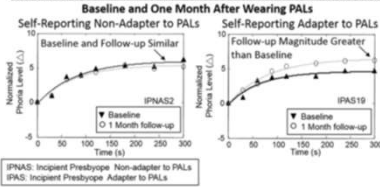
[20]Alvarez TL, Kim EH, Granger-Donetti B. Adaptation to Progressive Additive Lenses: Potential Factors to Consider. Sci Rep. 2017;7(1):2529. Published 2017 May 31. doi:10.1038/s41598-017-02851-5

HOAs Challenge Accommodation

- Higher order aberration (HOA) is known to increase accommodative lag[21]
  - "Accommodative lag increased in all subjects when coma and positive spherical aberration were induced."
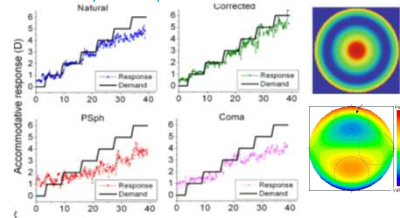
[21]Gambra E, Sawides L, Dorronsoro C, Marcos S. Accommodative lag and fluctuations when optical aberrations are manipulated. J Vis. 2009 Jun 9;9(6):4.1-15. doi: 10.1167/9.6.4. PMID: 19761295.
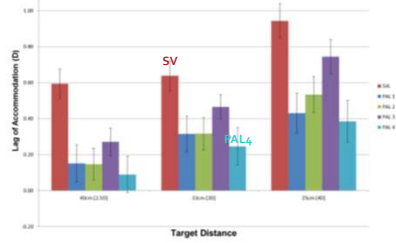
HOAs Challenge Accommodation

- Progressive surfaces create HOAs
  - HOAs reduce image sharpness...
  - ...which increases accommodative lag
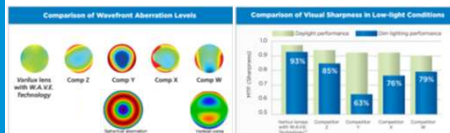
[22]Data on File – Essilor of America

Myopia & Accommodation

- PALs with a higher negative horizontal mean power gradient were more efficient at reducing accommodative lag[28]

[28] Tim Schilling; Arne Ohlendorf; Saulius R. Varnas; Siegfried Wahl Peripheral Design of Progressive Addition Lenses and the Lag of Accommodation in Myopes. *Investigative Ophthalmology & Visual Science* July 2017, Vol.58, 3319-3324.

Summary

- Accommodation
  - Triggered by convergence
  - Refined by blur
    - ✓ Performs best with high contrast
  - Typically settles on the edge of focus depth
- Convergence
  - Triggered by accommodation
  - Refined by fixation disparities
- ADD powers shift phorias exo
  - Successful PAL wearers become more eso
- Asthenopia occurs when convergence is challenged
  - Blur occurs when accommodation takes vision outside of depth of focus

Questions?

THANK YOU

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EOA Customer Development Group

Citations

[1] James S. Wolffsohn, Leon N. Davies, *Presbyopia: Effectiveness of correction strategies, Progress in Retinal and Eye Research*, Volume 68, 2019, Pages 124-143
[2] https://media.pearsoncmg.com/bc/bc_marieb_ehap_10/art_activities/figure_8.4a/figure_8.4a.html
[3] Alejandro L, Rosenfeld M, Estrada JM, Medrano SM, Marquez MM. *Lag of accommodation between 5 and 60 years of age.* Optom Vis Perf 2017;5(3):103-8.
[4] Goss, David A. *Ocular Accommodation, Convergence, and Fixation Disparity-* 2nd edition, Butterworth-Heinemann, 1995, p.135
[5] Ibid
[6] Ibid, p.3
[7] Ibid, p.67
[8] Ibid, p.70
[9] Schor CM, Ciuffreda KJ, eds. *Vergence Eye Movements: Basic and Clinical Aspects.* Boston, MA: Butterworth-Heinemann; 1983:15-21
[10] Goss, p.15
[11] Cooper, J, Selenow A, Ciuffreda KJ, et al. *Reduction of asthenopia in patients with convergence insufficiency after fusional vergence training.* Am J Optom Physiol Opt. 1983;60:982-989.
[12] Amos JF, ed. *Diagnosis and Management in Vision Care.* Boston, MA: Butterworth-Heinemann; 1987:461-510
[13] Ibid
[14] Fry GA. *Further experiments on the accommodation-convergence relationship.* Am J Optom Arch Am Acad Optom. 1939;16:325-336
[15] Morgan MW. *The analysis of clinical data.* Optom Weekly. 1964;55:27-34;55:23-25
[16] Sheard C. *The Sheard Volume – Selected Writings in Visual and Ophthalmic Optics.* Philadelphia, PA: Chilton; 1957:267-285.

Citations

[17] Goss, pg. 49
[18] Miyao, Masaru & Shiomi, T. & Kojima, Takehito & Uemoto, K. & Ishio, Hiromu & Takada, Hiroki. (2012). *While viewing 3D video-clips, accommodative focus and convergence are in harmony.* Proceedings of the International Display Workshops. 2. 1208-1211.
[19] Finchim, EF & Walton, J. *The Reciprocal Actions of Accommodation and Convergence.* From the Institute of Ophthalmology, Judd Street London and the Northampton Polytechnic St John Street London, 1957.
[20] Alvarez TL, Kim EH, Granger-Donetti B. *Adaptation to Progressive Additive Lenses: Potential Factors to Consider.* Sci Rep. 2017;7(1):2529.
[21] Gambra E, Sawides L, Dorronsoro C, Marcos S. *Accommodative lag and fluctuations when optical aberrations are manipulated.* J Vis.2009 Jun 9;9(6):4.1-15.
[22] Data on File – Essilor of America
[23] Israel, H. E. (1923). *Accommodation and Convergence under Low Illumination.* Journal of Experimental Psychology, 6(3), 223–233.
[24] Ibid.
[25] Owens DA, Liebowitz HW. *Accommodation, convergence, and distance perception in low illumination.* Am J Optom Physiol Opt. 1980 Sep;57(9):540-50.
[26] Gwiazda J, et.al. *A randomized clinical trial of progressive addition lenses versus single vision lenses on the progression of myopia in children.* Invest Ophthalmol Vis Sci. 2003 Apr;44(4):1492-500
[27] Gwiazda J, et.al. *Accommodation and related risk factors associated with myopia progression and their interaction with treatment in COMET children.* Invest Ophthal Vis Sci. July 2004, Vol.45, 2143-2151.
[28] Tim Schilling; Arne Ohlendorf; Saulius R. Varnas; Siegfried Wahl *Peripheral Design of Progressive Addition Lenses and the Lag of Accommodation in Myopes.* Investigative Ophthalmology & Visual Science July 2017, Vol.58, 3319-3324.