Fundamentals of Accommodation & Convergence

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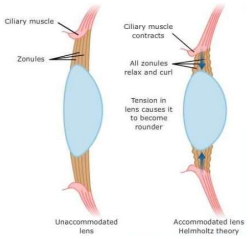
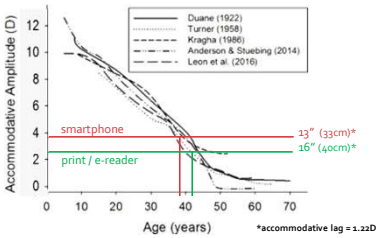
Accommodation

- Accommodation – physiological adjustment of focus
  - thickening of crystalline lens



Accommodation

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



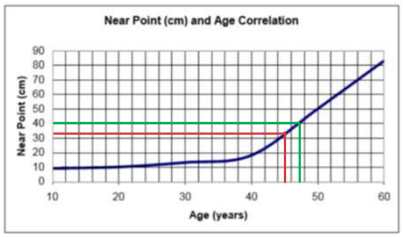
*accommodative lag = 1.22D

[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

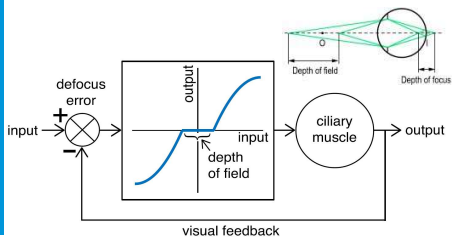
- Near Point of Accommodation
  - closest point of focus with full accommodation[2]



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

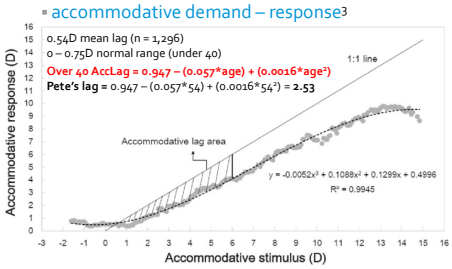
Depth of Field

- **Depth of field** is the range objects remain sharp without change of accommodation.



Accommodative Lag

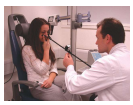
- Accommodative Lag
  - accommodative demand – response[3]



[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

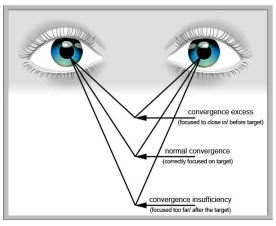
Accommodation Symptoms

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

[5] Ibid.

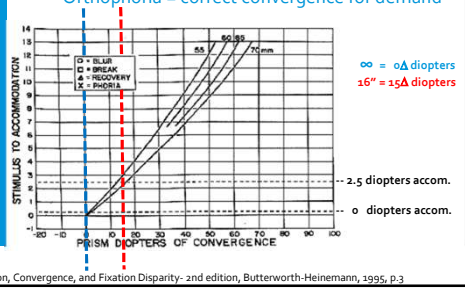
Convergence

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



Convergence

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

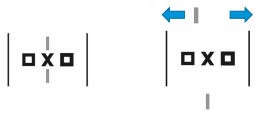


[6] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.3

Convergence

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

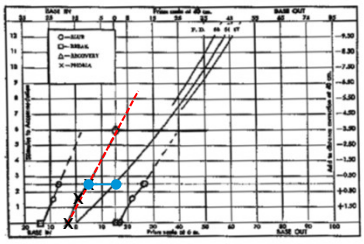
Mallett tests



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

Convergence

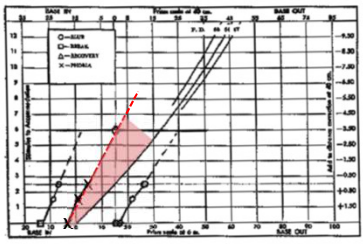
- Exophoria = lack of convergence
  - Associated Phoria = prism required to correct[8]



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

ACA Ratio

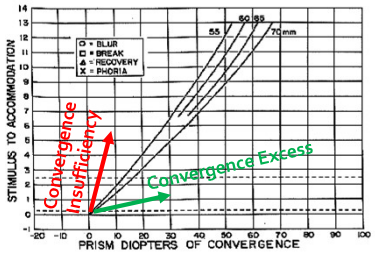
- ACA = accommodative convergence / accommodation
  - Normal = 4-6Δ BO vergence / 1D accommodation[9]



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

ACA Ratio

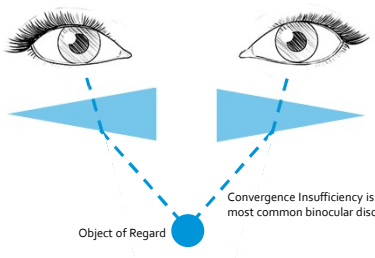
- ACA = steep slope indicates insufficiency[10]



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

Convergence Insufficiency

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

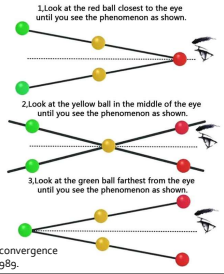


Convergence Insufficiency is the most common binocular disorder

Convergence Insufficiency

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

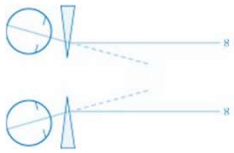
VT is generally the treatment of choice for convergence insufficiency.[11]



[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.

Convergence Excess

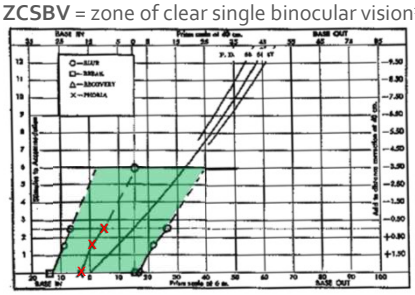
- Convergence Excess (esophoria)
  - Treatment of choice at distance is BO Δ[12]
    - ✓Resolves alignment with the visual axes
  - Treatment of choice at near is ADD power[13]
    - ✓Reduces the convergence signal



[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

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?
    Δ= 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.

Sheard's Criterion

- For example:
  - Patient has 10Δ exophoria at near
  - Fusional reserve (blur) occurs at 12Δ BO

    2/3 (10Δ) – 1/3 (12Δ) = 6.67 – 4 = **2.67ΔBI**

    Patient will likely have asthenopia w/o prism.

    (Or VT could be used to increase reserve to 20Δ BO)
  - Does the patient require prism?

    Δ= 2/3 D – 1/3 R

    Δ = prism required

    D = diopters of phoria

    R = diopters of reserve

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

Sheard's Criterion

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  - Patient has 10Δ exophoria at near
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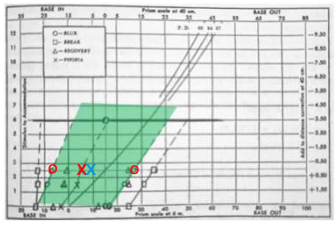
2.67Δ BI



[17] Goss, David A. Ocular Accommodation, Convergence, and Fixation Disparity- 2nd edition, Butterworth-Heinemann, 1995, p.49

Case Study - 43 year old wearing 1st PAL

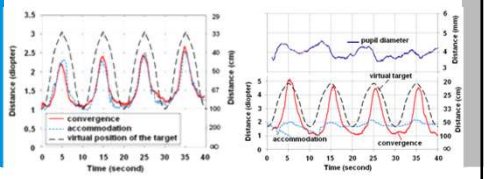
- Returns to office complaining of
  - Headache & asthenopia
  - Occasional blur
- Re-dotting the lenses reveals
  - FRP is perfectly placed
  - Lenses are straight, well-mounted
  - Frame fit is good (8 panto, 7 wrap, 12mm vertex)
- Recheck reveals 20/15 distance, so ADD is "bumped"
  - Symptoms become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

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 OD perform to see if convergence may be the issue?**

Visual Process of Near Vision

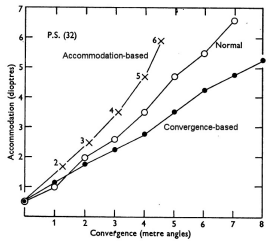
- The elements of near vision are
  - Accommodation (change of focus)
  - Convergence (change of visual axis)
  - Pupil constriction (increase in depth of field)
- These elements are all inter-related[18]



[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.

Visual Process of Near Vision

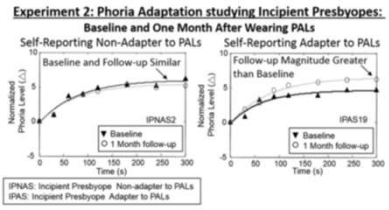
- When each element is triggered independently, near vision is challenged[19]



[19]Finchim, EF & Walton, J. The Reciprocal Actions of Accommodation and Convergence. From the Institute of Ophthalmology, Judd Street Lond and the Northampton Polytechnic St John Street London, 1957.

ALL PALs Require Adaptation

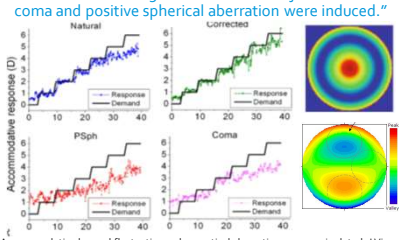
- Providing an ADD power alters the wearer's near phoria
- At least one study confirms successful adaption to PALs requires phoria elasticity[20]
  - "Successful PAL adapters become more esophoric with PAL wear."



[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

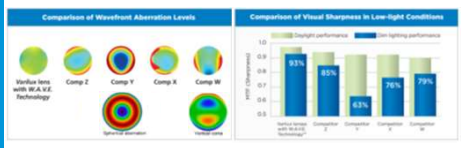
- Higher order aberration (HOA) is known to increase accommodative lag[21]
  - "Accommodative lag increased in all subjects when coma and positive spherical aberration were induced."



[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

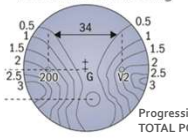
Low Light Challenges Accommodation

- Accommodation requires light
  - "…at an illumination of 0.0117 foot-candle, **the average error for accommodation alone is 1/23** of the standard distance and that for **accommodation plus convergence is 1/58** of the standard distance"[23]
  - "At a point near the lower visual threshold **accommodation alone breaks down while convergence shows little change** in the rate of increase in error." [24]
  - "These findings were interpreted as indicating that **convergence is a more important distance cue than accommodation under low illumination** and that the physiological resting states of convergence and accommodation are relatively independent."[25]

[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.

Myopia & Accommodation

Studies demonstrate PALs have a significant, if small, impact on myopic progression.[26] The impact becomes considerable for children with higher accommodative lag and esophoria.[27]



	SV lenses	PAL lenses
Progression @ 3 yrs TOTAL POPULATION	-1.48±0.06D	-1.28±0.06D [26]
Progression @ 3 yrs hi-lag & near esophoria	-1.75	-0.98 [27] (+2.00 ADD)

[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.

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

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.