The effect of ocular higher-order aberrations on accommodative response

Sotiris Plainis, MSc, PhD
Harilaos Ginis, PhD
Aris Pallikaris, MSc

Institute of Vision & Optics, UNIVERSITY OF CRETE
Background

• The role of the accommodation mechanism is to obtain and maintain a retinal image of an object in-focus.

• Defocus blur is considered to be the primary stimulus that controls (monocular) accommodative response.

• The accommodative control system exhibits two types of focusing steady-state “errors”:
  • over-accommodation (lead) for far targets
  • under-accommodation (lag) for near targets
  • rapid and continuous changes in focus (microfluctuations)
Background

• The change in the refractive state of the eye is “accompanied” by changes in higher order aberrations:
  • eg. Most eyes suffer from positive spherical aberration at distance which tends to shift towards negative values with increasing accommodation

• Since spherical aberration is the most significant higher-order aberration in refining the equivalent power of the eye, is expected to contribute to the focusing errors.

• Retinal image quality may be differentially affected when accommodating
Aim of the study

To study the effect of ocular higher-order aberrations on the steady-state focusing errors of accommodative response

To investigate the role of these errors on retinal image quality
Methodology

- Monochromatic wavefront aberration (50 recordings) was assessed for a range of target vergences using COAS wavefront sensor and a purposely-designed Badal optometer.
- 7 emmetropic or corrected eyes were measured.
- Accommodation target was a high-contrast letter “E” (1.7°)
- Natural pupils were used.
- Subjects were encouraged to maintain best possible focus at all times.
- Data were analysed offline using custom-written scripts in Matlab and Zemax (chromatic aberration and effectivity were corrected).
Badal optometer

The Badal optometer -COAS sensor set-up allowed recording of the wavefront aberration of the **tested eye while accommodating**
Methodology

• Accommodative response was evaluated using:
  
  – the paraxial focus \( (c_{20}^0) \) and the spherical aberration \( (c_{40}^0) \) Zernike coefficients ("paraxial curvature matching" – Thibos et al., 2004)

\[
M = \frac{-c_{20}^0 4\sqrt{3} + c_{40}^0 12\sqrt{5}}{r^2}
\]

  – a computational method which calculates the power of a focusing lens needed to optimise retinal image quality of the accommodating eye (the “optimised” MTF)
The “optimised” MTF

- Peaks at 18 c/deg. ("it is the high spatial frequencies or edges that refine the accuracy of the accommodative response" Charman & Tucker, 1977)

- A high frequency tuned MTF is expected to be more effective in detecting small changes in focus
Accommodation-induced pupillary miosis

• The higher the accommodative response, the greater the degree of miosis, with the relationship being fairly linear.

• When averaged across subjects, each diopter of accommodation elicits 0.18mm of pupil constriction.
Results - Accuracy of accommodation

• Over-accommodation (lead) for distant targets
• Under-accommodation (lag) for near targets

• Response equals stimulus vergence at about -1.75D
Results - Changes in higher order terms

- Spherical aberration \((c_4^0)\) moves to negative values with accommodation (but there is significant inter-subject variation).

- Coma-like aberrations \((c_3^{-1}) (c_3^1)\) on average change to positive values.

- These are probably attributed to changes in lens shape and lens position during accommodation (Drexler et al., 1997; Roorda & Glasser, 2004)
There is a considerable variation in the wavefront patterns from individual to individual at each accommodation level.

Subject SP: higher order wavefront error is minimised at intermediate level
Subject AT: higher order wavefront error is minimal at distance
Subject IK: higher order wavefront error is minimal for the nearest target.
Image quality when accommodating

• “Optimised” MTF for:
  • the recorded accommodative response (top)
  • the "ideal" 1:1 response (middle)
  • the dioptric response which maximises the “optimised” MTF (bottom).

• An accommodative lag equal to 1.05D (compared to the overall 2.66D) can be attributed to the high negative $c_4^0$ when accommodating

• the one-to-one stimulus/response relationship is not necessarily the ideal.
Errors in focus attributed to spherical aberration

Errors in focus

= "ideal" 1:1 response – "optimised" MTF response

\[ c_4^0 \] is the main higher-order aberration that contributes to image quality changes during accommodation.
Fluctuations in Accommodative Response

- Rapid changes in response
- Highest stability at infinity - more powerful as accommodation effort increases
- Considerable variation among subjects, in both the magnitude and in their changes with target vergence
Fluctuations in Accommodative Response

• For most of the subjects, fluctuations are higher at intermediate target vergences (decreasing at higher accommodative demands).

• Results agree with previous hypothesis (Miege and Denieul, 1988), which suggested maximal activity near the centre of accommodative range.
The role of fluctuations

Target vergence: 4.0 D,
Average response: 3.55 D (range between 3.23 and 4.02D)

...fluctuations probably maintain the system at high levels of response by temporarily searching for the best focus.
Conclusions

• Although focusing errors of accommodation response increase when viewing near targets, the change in higher order aberrations may influence the accuracy of the resulting response.

• The one-to-one stimulus/response relationship should not necessarily be considered as the ideal: for a spherical aberration shifting from positive to negative values with increasing accommodation, a “lag” for near targets, and a “lead” for far targets can be predicted.
Conclusions

• Fluctuations in accommodation seem to play an important role in providing a feedback mechanism in accommodative response.

• Their increased amplitude preserves image quality, when errors of accommodation are moderate, by temporarily bringing the image into the best focus.

• Population averaged data may lead to erroneous results as a consequence of the significant inter-subject variability (in the pattern of aberrations, pupil size, accommodative amplitude)
Acknowledgments

The “SHARP-EYE: Adaptive Optics for Retinal Imaging and Improved Vision”, Research Training Network (RTN) (http://www.sharpeye.org)

Sotiris Plainis was funded by the Greek State Scholarship Foundation (IKY).