Using Adaptive Optics Vision Simulation to Explore the Effect of Higher Order Aberrations on Depth of Focus

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The Adaptive Optics Technology

What is Adaptive Optics?

It is a technology to improve the performance of optical systems by reducing the effects of optical distortions (Aberrations).
The Adaptive Optics Technology

The Adaptive Optics Main Components

- Aberrometer
- Deformable Mirror

Communication and the tracking of satellites;
The Adaptive Optics Technology

Correct wavefront using deformable optics

Calculate control parameters

Measure residual wavefront using a sensor

Observer
Deformable Mirror

Imagine Eyes

Gemini 8-meter Telescope Mirror Blank
The Adaptive Optics Technology

The nuclear region of the nearby galaxy NGC 7469, with and without AO (from CFHT)
Effects of Zernike Wavefront Aberrations on Visual Acuity Measured Using Electromagnetic Adaptive Optics Technology

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Clinical Use of AO Technology

Not all Zernike Terms are Weighted Equally. The more peripheral terms have lesser impact on visual performance, while the more centrally located ones have a greater contribution.
Purpose

To evaluate the impact of individual Zernike coefficients (HOA) on depth of focus using an adaptive optics visual simulator.
Methods

• 10 subjects
• Dominant Eye
• Inclusion Criteria:
  clear intraocular media
  no ocular diseases / no previous surgeries
  age ranged from 25 to 35 years
Methods

- **Wavefront Analysis:**
  - *irx3 aberrometer*, Imagine Eyes, Orsay, France
  - 6-mm pupil / up to the 10th Zernike order;

- **Accommodation measurement**
  - *from -0.5 to +4.0 D, 8 stimulus presentation*
  - tropicamide 1% drops 15 minutes
Physiologic changes

True Accommodation

Young Subject
Accommodation - check
Methods

- crx1 Adaptive Optics Visual Simulator

Electromagnetic Deformable Mirror:

52 actuators
effective diameter: 15 mm
voltage range: -1.0 to +1.0 V
- Coma $Z(3, -1)$
- Trefoil $Z(3, -3)$
- Sph Aber. $Z(4, 0)$
Experimental Procedure

- **Sphero-cylinder (SC) correction**
- **Higher-order aberration generation:**
  
  * SC + single Zernike modes
  
  Spherical Aberration: +/- 0.3, 0.6 and 0.9 μm
  
  Vertical Coma  $Z(3,-1)$
  Trefoil  $Z(3,-3)$  $+/- 0.3$
Deformable Mirror: Spherical Aberration - 0.6 µm
Experimental Procedure

- How did we measure Depth of Focus?

Psychometric functions for the identification of each of the 10 Sloan letters:

- Letters: 12 c/d° (or 20/50) at 40 cm
- Presented in random order
- Gray-scale display – Photopic conditions
- Number of read letters as a function of defocus
## Subjects

<table>
<thead>
<tr>
<th>Subjects (N)</th>
<th>Age (years)</th>
<th>Gender</th>
<th>SE (D)</th>
<th>HOA RMS</th>
<th>Trefoil µm</th>
<th>Coma µm</th>
<th>Sph Ab µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>30±2</td>
<td>8 male 2 female</td>
<td>-1.05±1.5</td>
<td>0.34±0.10</td>
<td>-0.15±0.14</td>
<td>0.07±0.14</td>
<td>0.11±0.10</td>
</tr>
</tbody>
</table>

* 6-mm pupil
Results

- Depth of Focus curves:
Results

- **Depth of Focus:**

![Graph showing depth of focus](image)

- Number of letters induced by defocus
- Three curves: corr, Trefoil+0.3, Coma+0.3
Results

- Depth of Focus curves:
• **Depth of Focus curves:**

- 3.7D Baseline (sphere corr.)
- 4.0D 0.3µm coma
- 3.5D 0.3µm trefoil
- 4.5D 0.3µm SA
- 6.0D 0.6µm SA
- 5.9D 0.9µm SA
- -0.3µm SA 5.2D
- -0.6µm SA 3.0D
- -0.9µm SA 5.2D

(D)
The depth of focus curve (blue curve) strongly increased (up to 2D), but there are a maximum before a decrease for strong values (0.9µm).
The best focus point (pink curve) was continuously shifted (~2.7D/µm).
Conclusion

- Coma and Trefoil did not increase DOF or shift the curves
- We observed an increase of the DOF from 0 to 0.6 μm of Spherical Aberration
- For higher values, the DOF do not increase but becomes stable or decreases
Summary

- Systematic induction of targeted amounts of spherical aberration can improve depth-of-focus

- Further studies: determine the optimal spherical aberration values necessary to increase depth of focus X pupil diameter X image quality

- Future Applications: restore pseudoaccommodation
Thank you !!!

Wavefront Presbyopic Refractive Corrections
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