# Effects of higher-order wavefront aberrations on the eye's depth of focus

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## Purpose

To evaluate the impact of individual Zernike coefficients (higher-order aberrations) on depth of focus using an adaptive optics visual simulator.

*<u>Underlying question</u>: Can we improve depth of focus, by adding controlled aberrations to the "natural" aberrations, of a (presbyopic) subject ?*

## Methods: Subjects

- 10 subjects
- Dominant eye
- Inclusion criteria:
  - clear intraocular media
  - no ocular diseases / no previous surgeries
  - between 25 and 35 years old

## Methods : Subjects

- Accommodation
  * Freezed (Tropicamide 1% drops)
- Wavefront Analysis:
  (irx3 aberrometer, Imagine Eyes)
  6-mm pupil / up to the 10th Zernike order

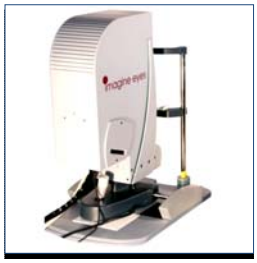
| Subjects (N) | Age (years) | Gender | SE (D) | HOA RMS | Trefoil µm | Coma µm | Sph Ab µm |
|---|---|---|---|---|---|---|---|
| 10 | 30±2 | 8 male<br>2 female | -1.05±1.5 | 0.34±0.10 | -0.15±0.14 | 0.07±0.14 | 0.11±0.10 |

** 6-mm pupil*

## Methods: crx1 Adaptive Optics Visual Simulator

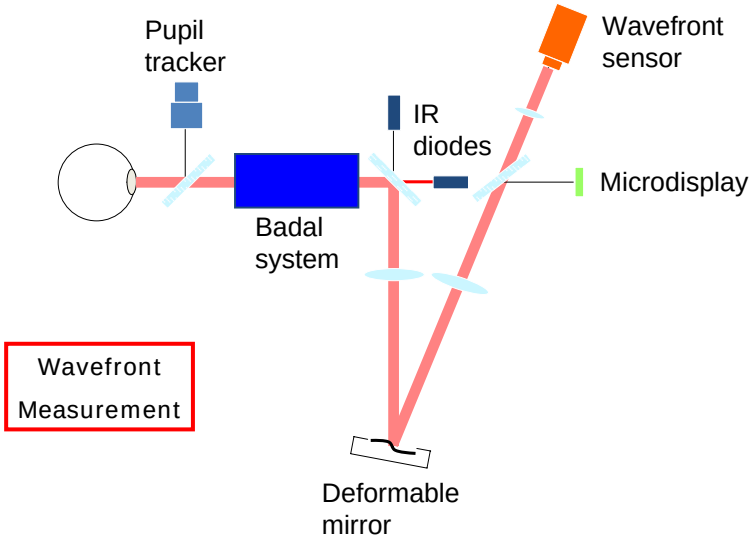
Shack-Hartmann based Wavefront Aberrometer:
32x32 subpupils

Electromagnetic Deformable Mirror:
52 actuators
large stroke (±50µm tilt p/v)
voltage range: -1.0 to +1.0 V

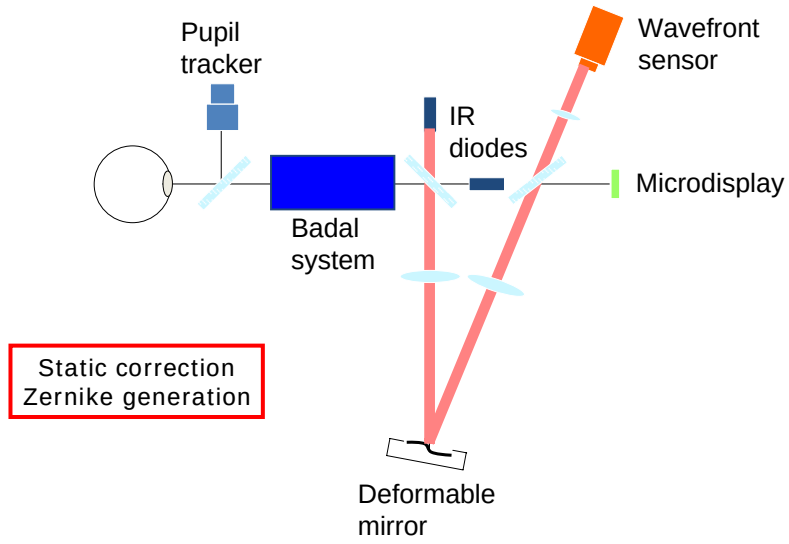


*crx1 (Imagine Eyes)*

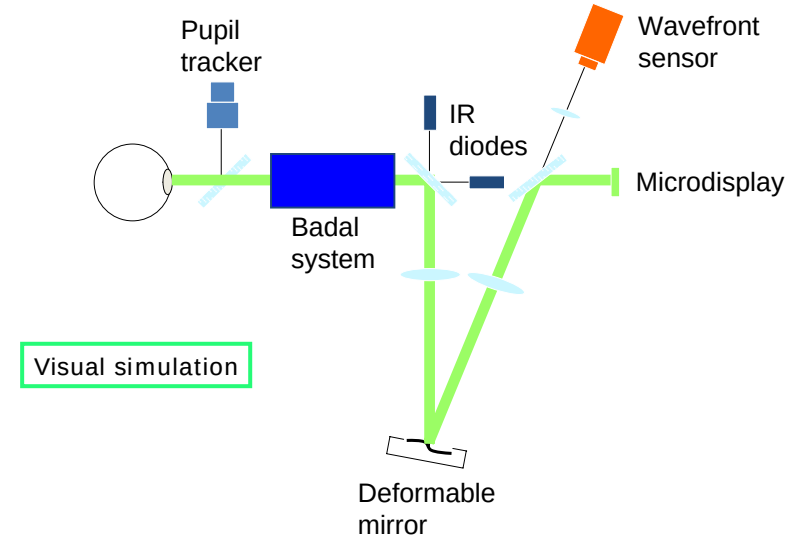
## Methods: Visual simulator principle



## Methods: Visual simulator principle




## Methods: Visual simulator principle



## Methods: Experimental procedure

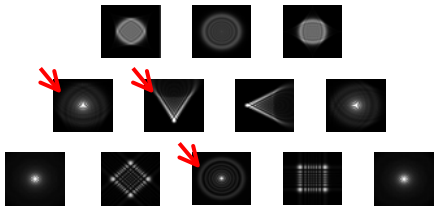
- Sphere correction (SC) (Badal system)
- Higher-order aberration generation (deformable mirror):

SC + single Zernike modes

Spherical Aberration: ±0.3, 0.6 and 0.9 µm

Trefoil Z (3, -3) ±0.3 µm

Vertical Coma Z(3,-1) ±0.3 µm

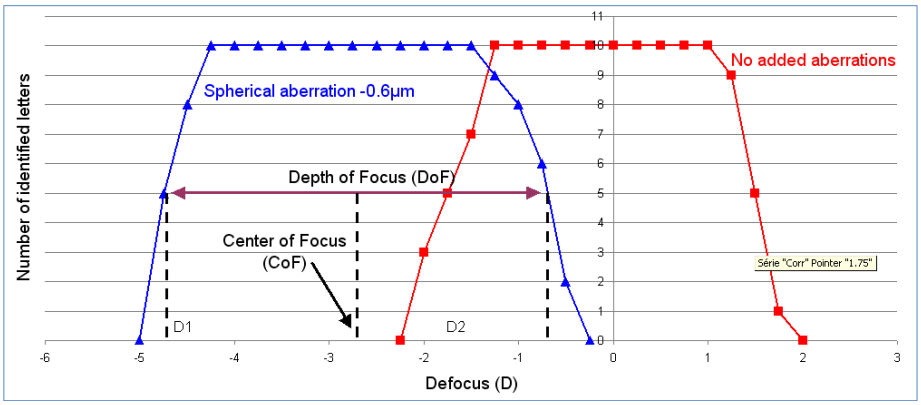


## How did we measure Through Focus Response ?

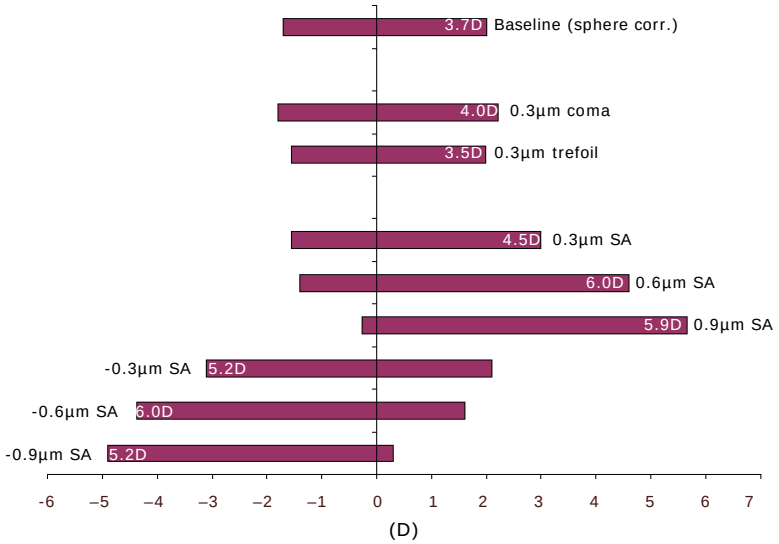
Psychometric functions for the identification of each of the 10 *Sloan letters*:

* Pupil size : 6mm
* Letters: 12 c/d° (or 20/50)
* Presented in random order
* Grayscale display – Photopic conditions
* Number of read letters as a function of defocus

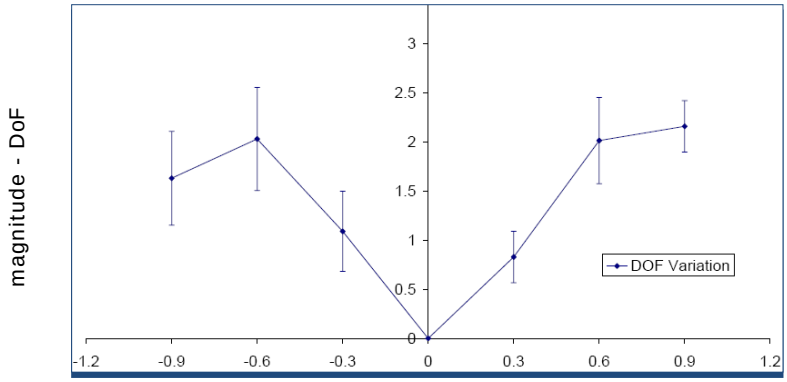
## Through Focus Response curves




## Results

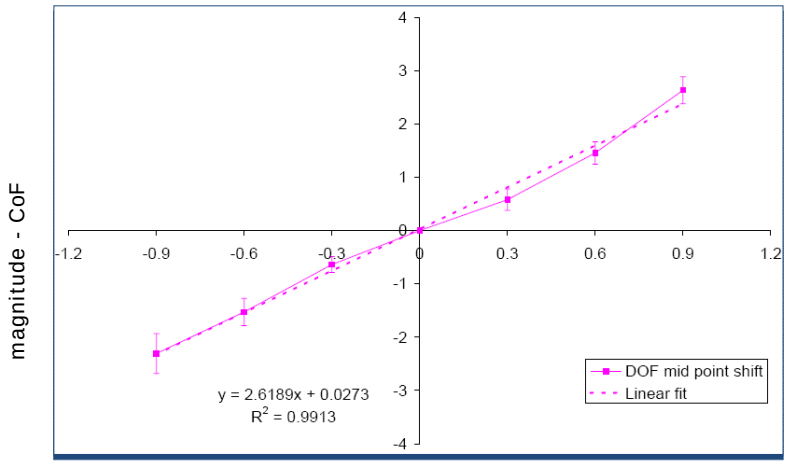


## DoF as a function of the added Spherical Aberration




DoF strongly increased (up to 2D), but there is a maximum before a decrease for strong values (0.9µm).

## CoF as a function of the added Spherical Aberration




The CoF is continuously shifted (~2.6 D/µm).

## Summary

- Coma and Trefoil did not increase DoF or shift the CoF
- 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
- 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

# Thank you !

## Effects of Zernike Wavefront Aberrations on Visual Acuity Measured Using Electromagnetic Adaptive Optics Technology

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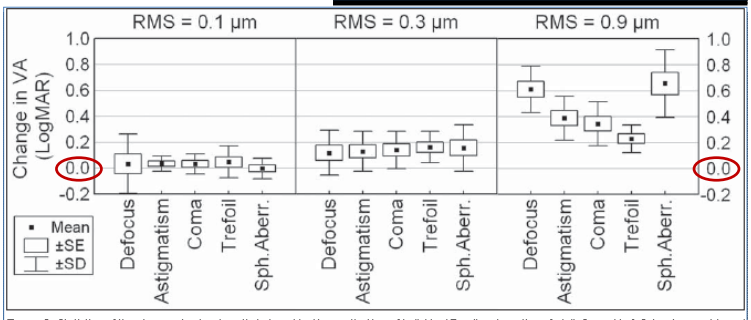


**Figure 3.** Statistics of the changes in visual acuity induced by the application of individual Zernike aberrations 0.1 (left graph), 0.3 (center graph), and 0.9 (right graph) µm. For each patient, the changes in visual acuity were computed by subtracting a baseline visual acuity value, measured with the best possible wavefront correction, from the visual acuity findings obtained while adding individual Zernike aberrations.

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