6th International Workshop on Adaptive Optics for Industry and Medicine
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Development, calibration and performance of an electromagnetic mirror based adaptive optics system for visual optics

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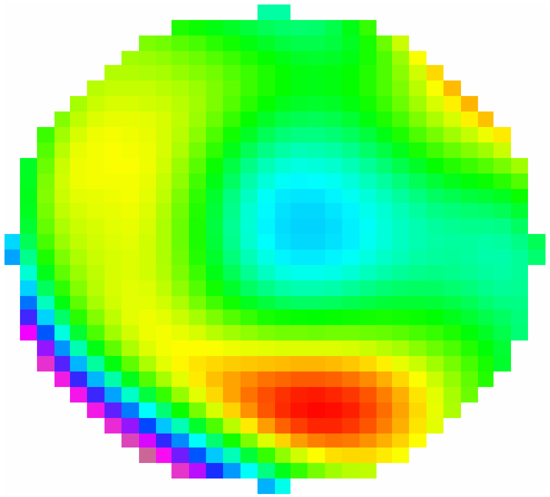
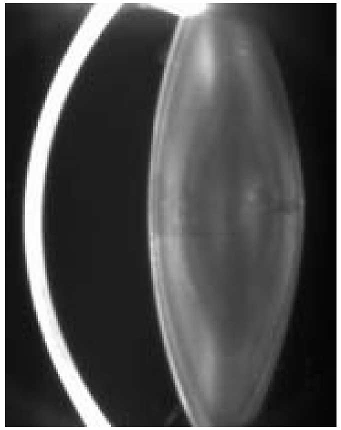
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Goal

Impact of ocular aberrations

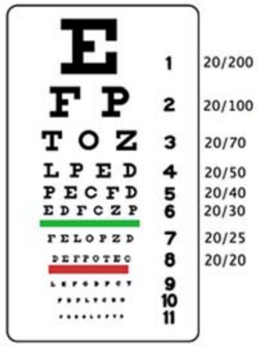


Accommodative response



Rosales et al (2006) Journal of Vision 6, 1057-1067

Visual function



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Motivation

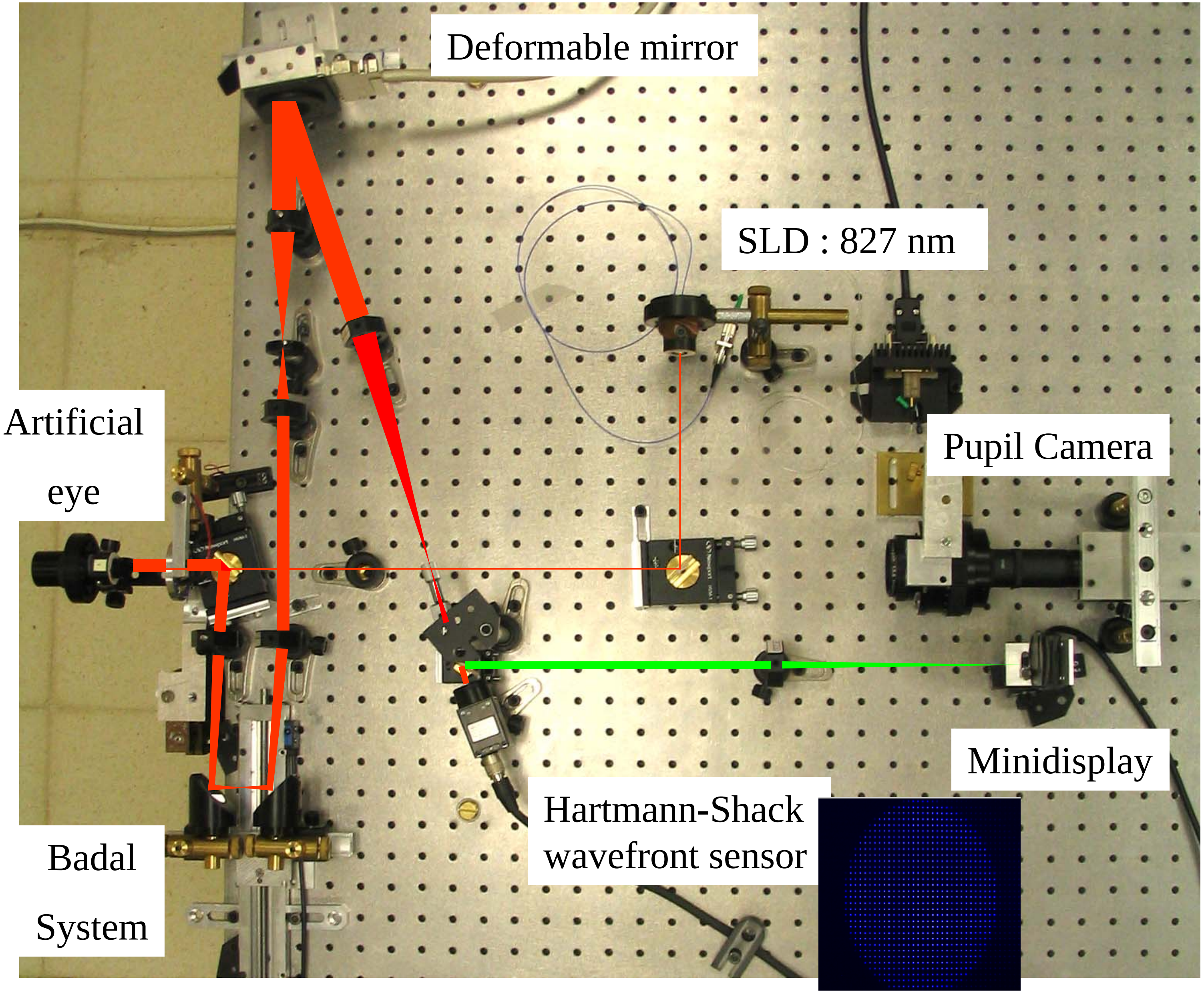
- Aberrations may play a role in:
  - Determining the direction of accommodation
    - References: Chen et al (2006) JOSA 1, 1-8
      Fernández and Artal (2005) JOSA 9, 1732-1738
  - Differences in accommodative lag in emetropes and myopes
    - References: Mutti et al (2006) IOVS 3, 837-846
      He et al (2005) Vision Research 45, 285-290

- The role of ocular aberrations in vision needs better understanding

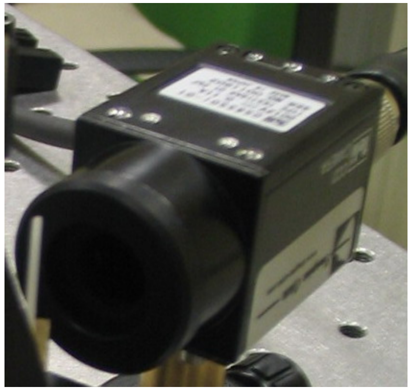
Applications:

- –in refractive and presbyopic corrections
- –visual adaptation
- –tolerance to blur

AO Set-up


Deformable mirror
SLD : 827 nm
Artificial eye
Pupil Camera
Badal System
Hartmann-Shack wavefront sensor
Minidisplay

- Hartmann-Shack Wavefront sensor :
  HASO 32



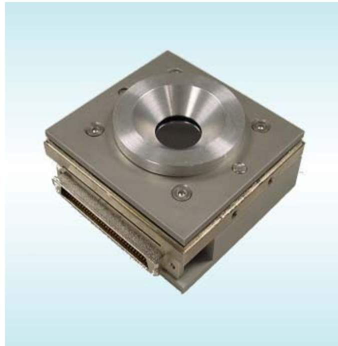
Imagine Eyes Haso 32

Array of 32 x 32 microlenses

Maximum pupil diameter : 3.65 mm

Magnetic deformable mirror

MIRAO32d



Imagine Eyes MIRAO52d deformable mirror

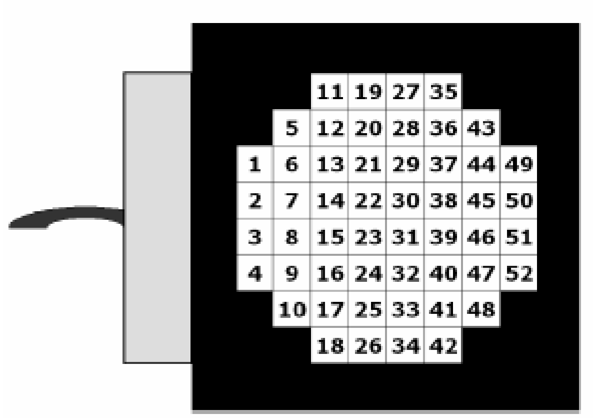
Number of actuators : 52

Effective diameter : 15 mm

Interval between actuator : 2.5 mm

Stroke : up to 50 microns

Bandwith : >200 Hz



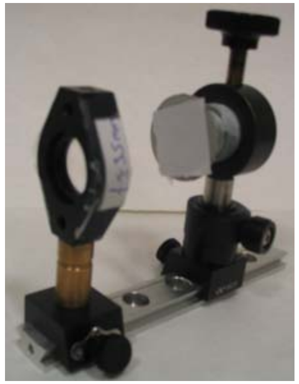
Fernández et al (2006) Opt. Exp. 20, 8900-8918

- Other components:

  - Source: SLD (λ = 827 nm, $P_{máx}$ = 2.5mW) Superlum Ireland
  - Stepping motor controller for Badal system: VXM-1 Velmex
  - Minidisplay 640x480
    - OLED screen for psychophysics
  - Pupil camera. Teli, IC Imaging Control
    - Eye tracker

System calibration

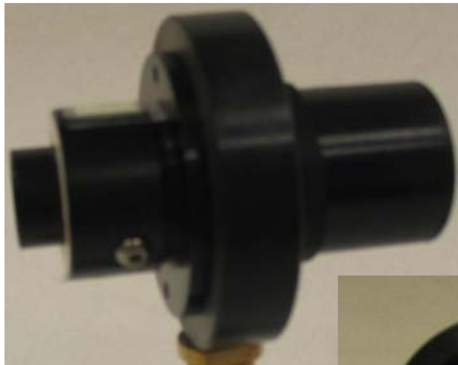
- **Achromatic double lens + diffuser**

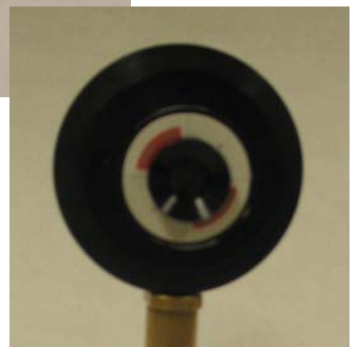


- **Artificial eye #2**

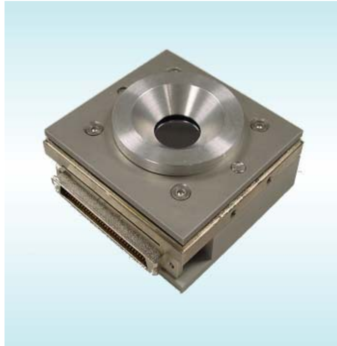
  Aberrations provided by manufacturer (RMS microns)

  - Defocus : 5.17
  - Astigmatism : 0.83
  - Coma : 0.46
  - Spherical aberration : 0.17
  - Other : 0.01

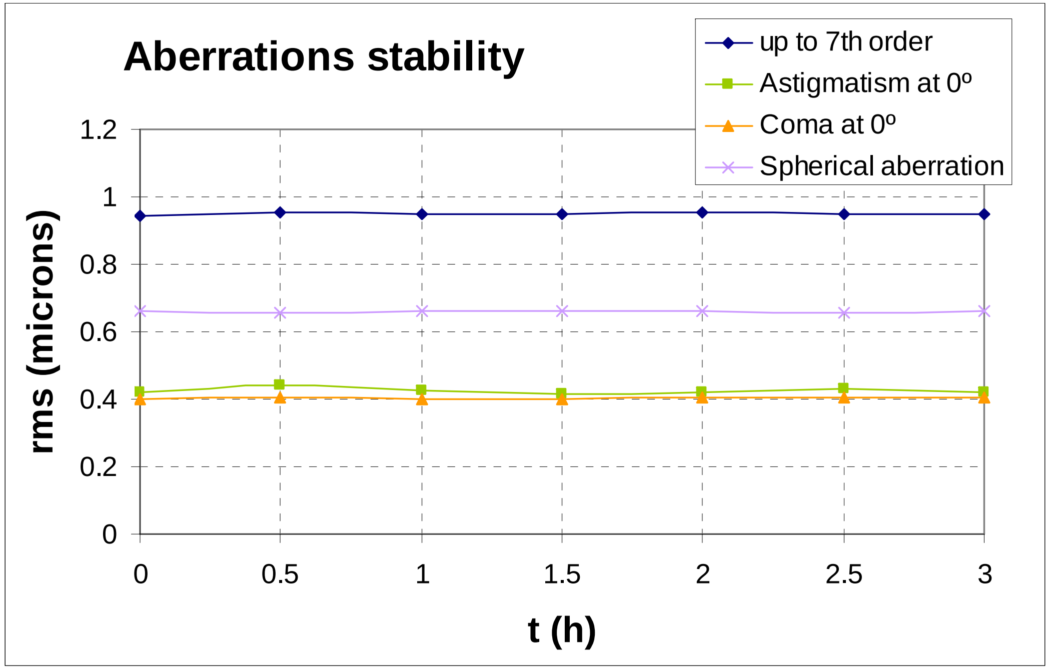




Mirror flatness → **RMS =0.015 μm**



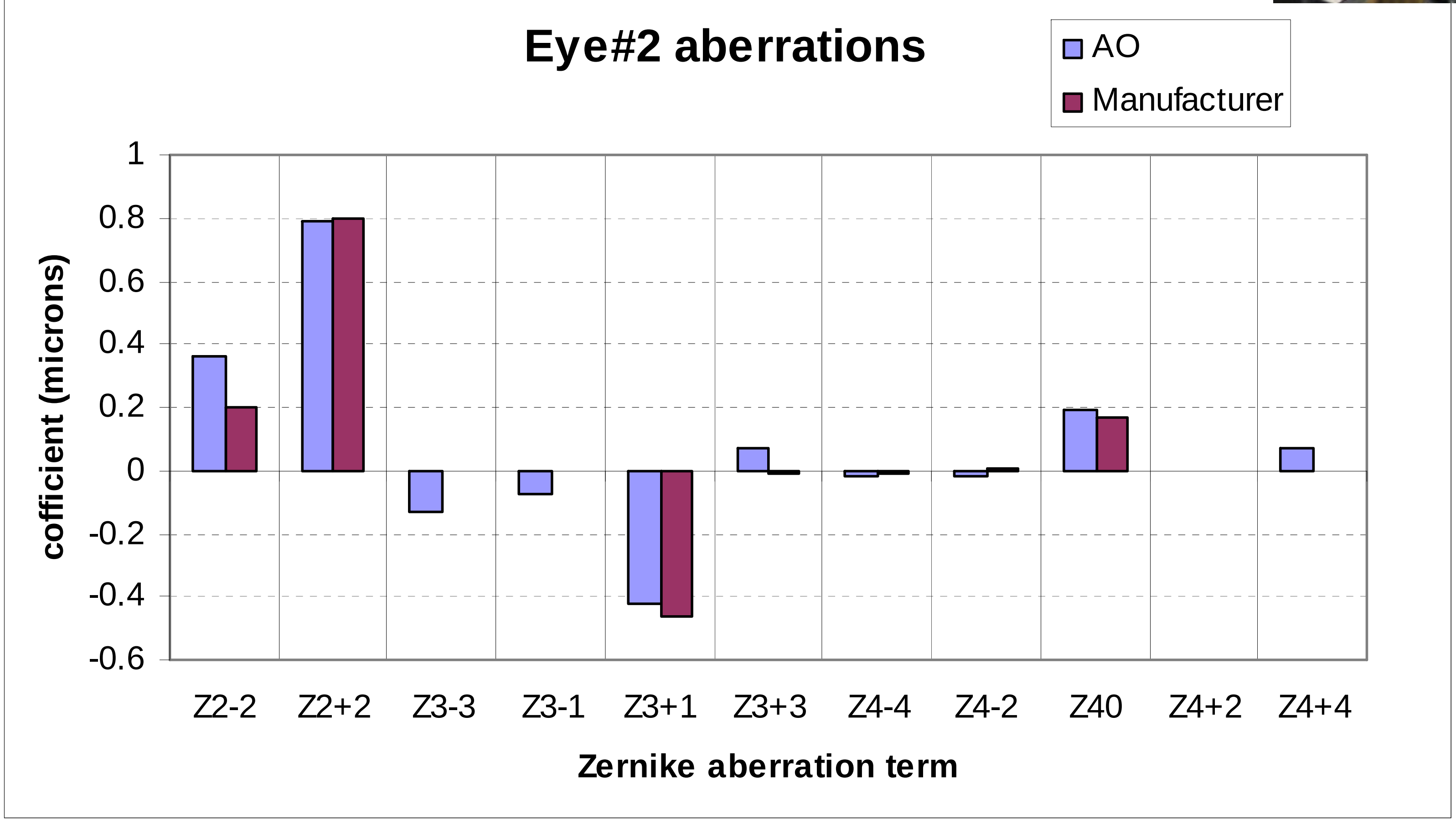
Stability



	Variability(%)
Up to 7th order	0.3
Astgmatism at 0º	2.0
Coma at 0º	0.6
Spherical	0.3

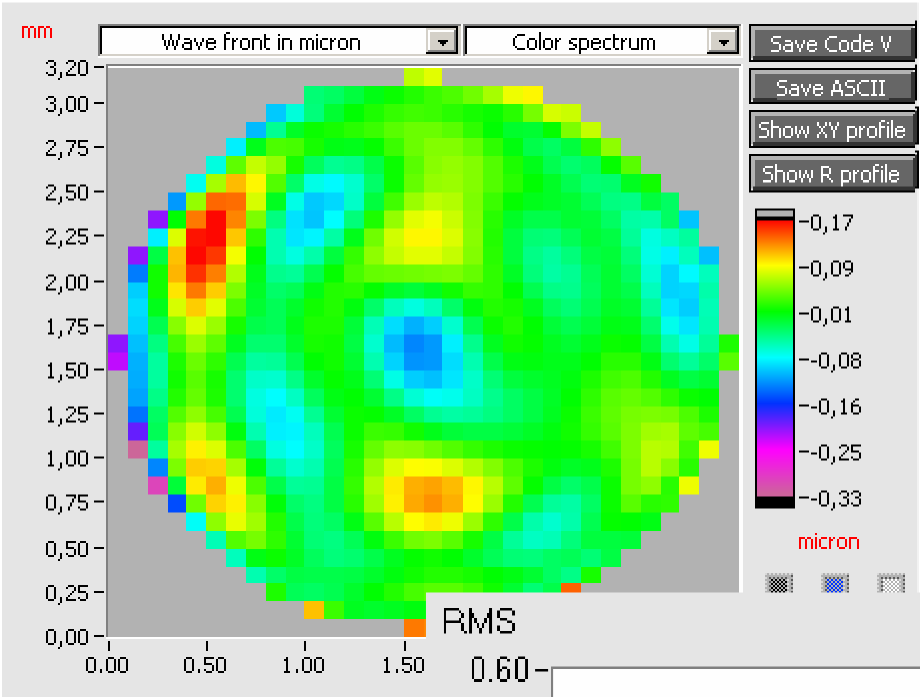
Artificial eye #2:

Comparison with manufacturer data

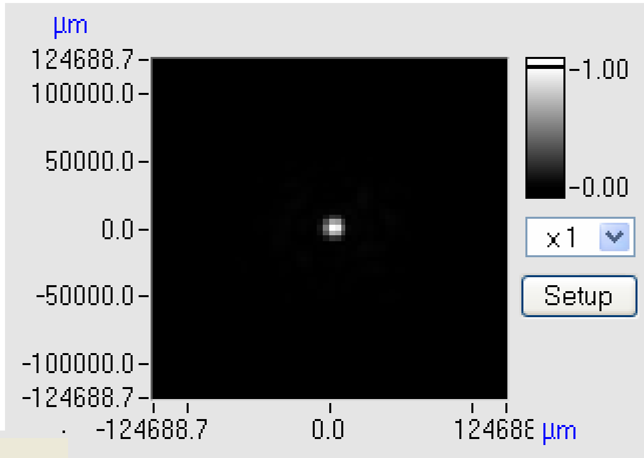


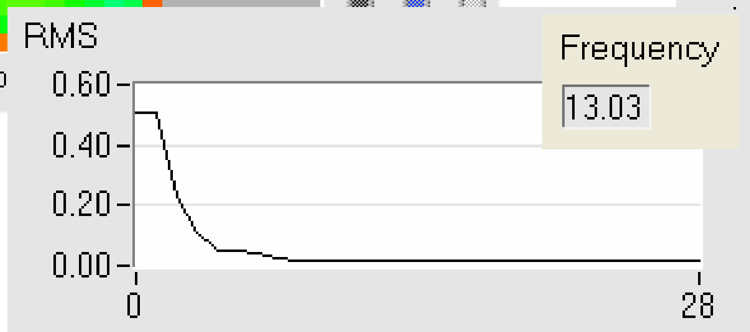
Compensation: Artificial eye #2

Wavefront



PSF

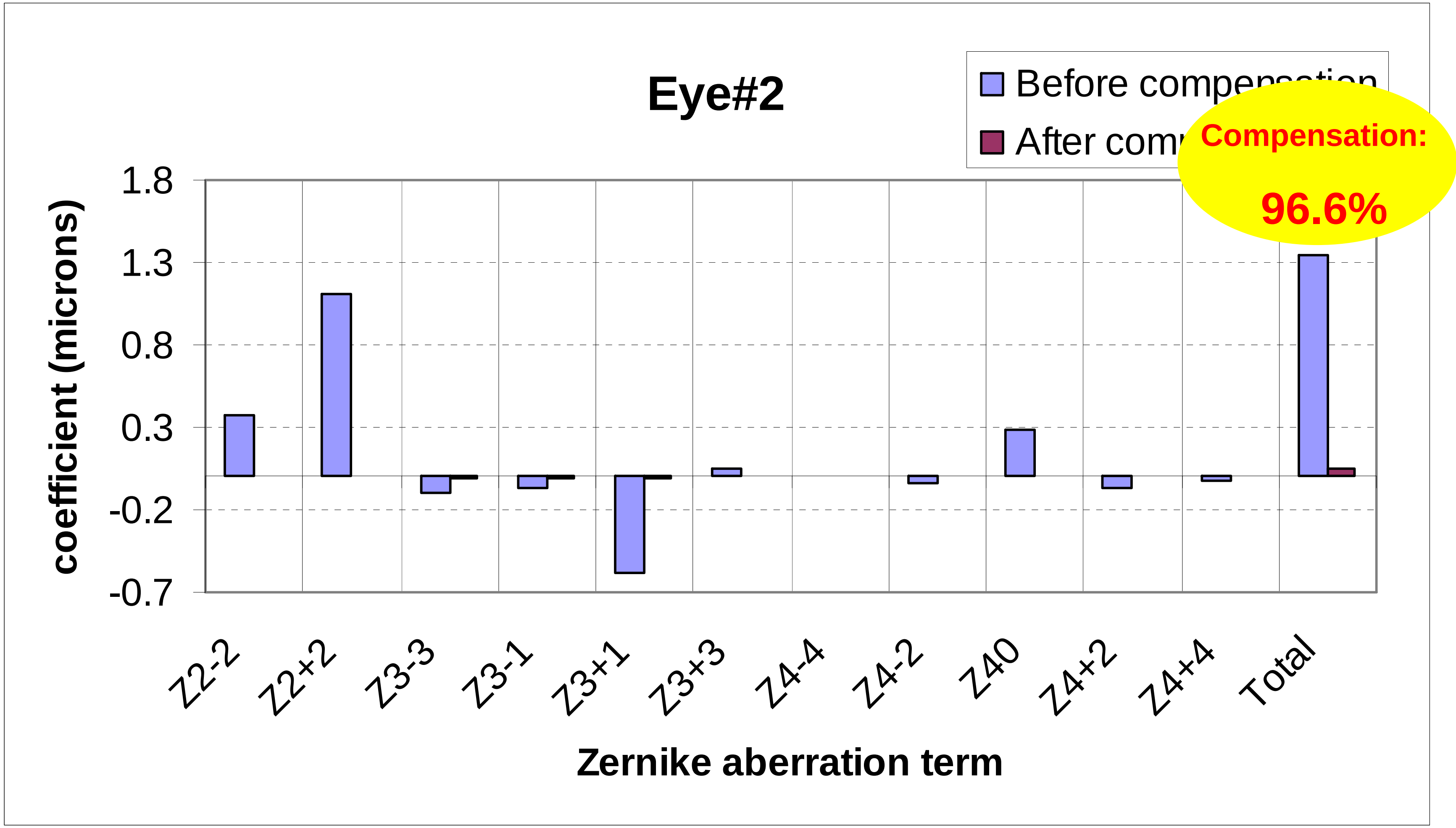




RMS = 1.350 µm

Correction : 96.6 %

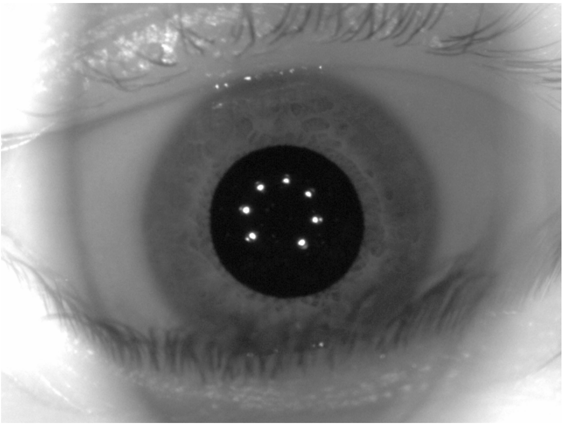
Zernike coefficients before and after close loop correction



Measurements

Real eyes:

- **Bite bar**
- **Natural viewing conditions**
- **Badal system compensating defocus = 0D for subject**



- **4 subjects**

  #1, age 35, sphere +1D

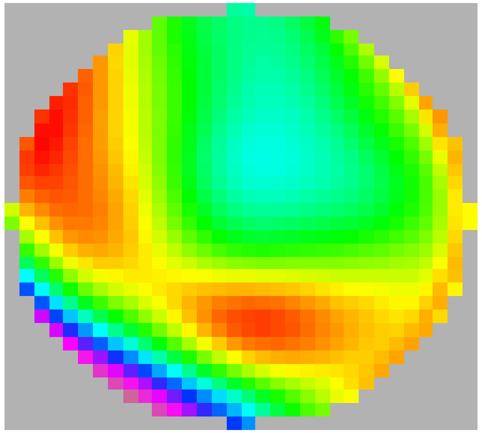
  #2, age 25, sphere – 3.25D

  #3, age 31, cylinder 2.0D

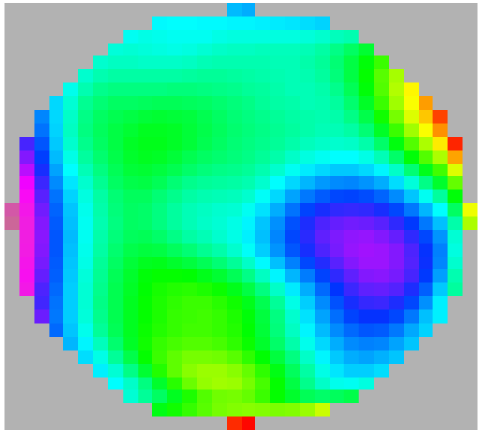
  #4, age 36, sphere – 5.5D, contact lenses

Wave aberrations (defocus corrected, 0D):

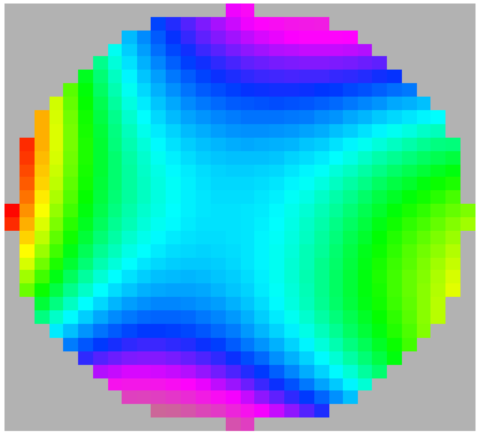
Subject #1:
rms=0.858μm
Pupil: 6.9mm



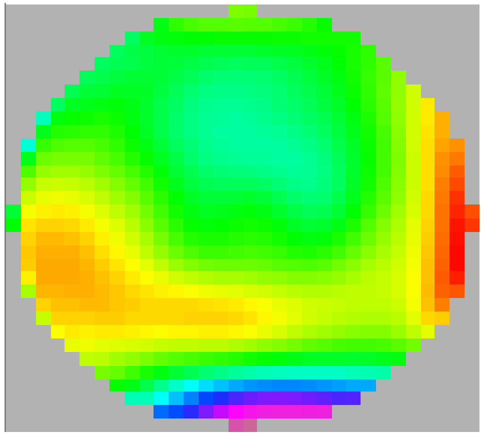
Subject #2:
rms=0.260μm
pupil: 5.0mm



Subject #3:
rms=2.542μm
pupil: 5.9mm

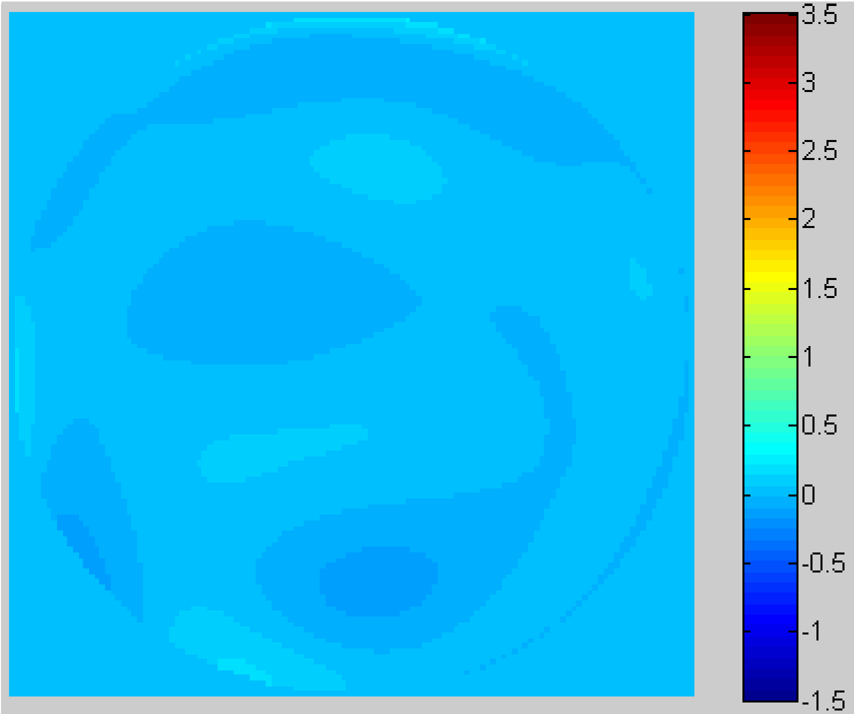


Subject #4:
rms=0.907μm
pupil: 5.7mm



Close loop compensation. Subject #1

Wavefront

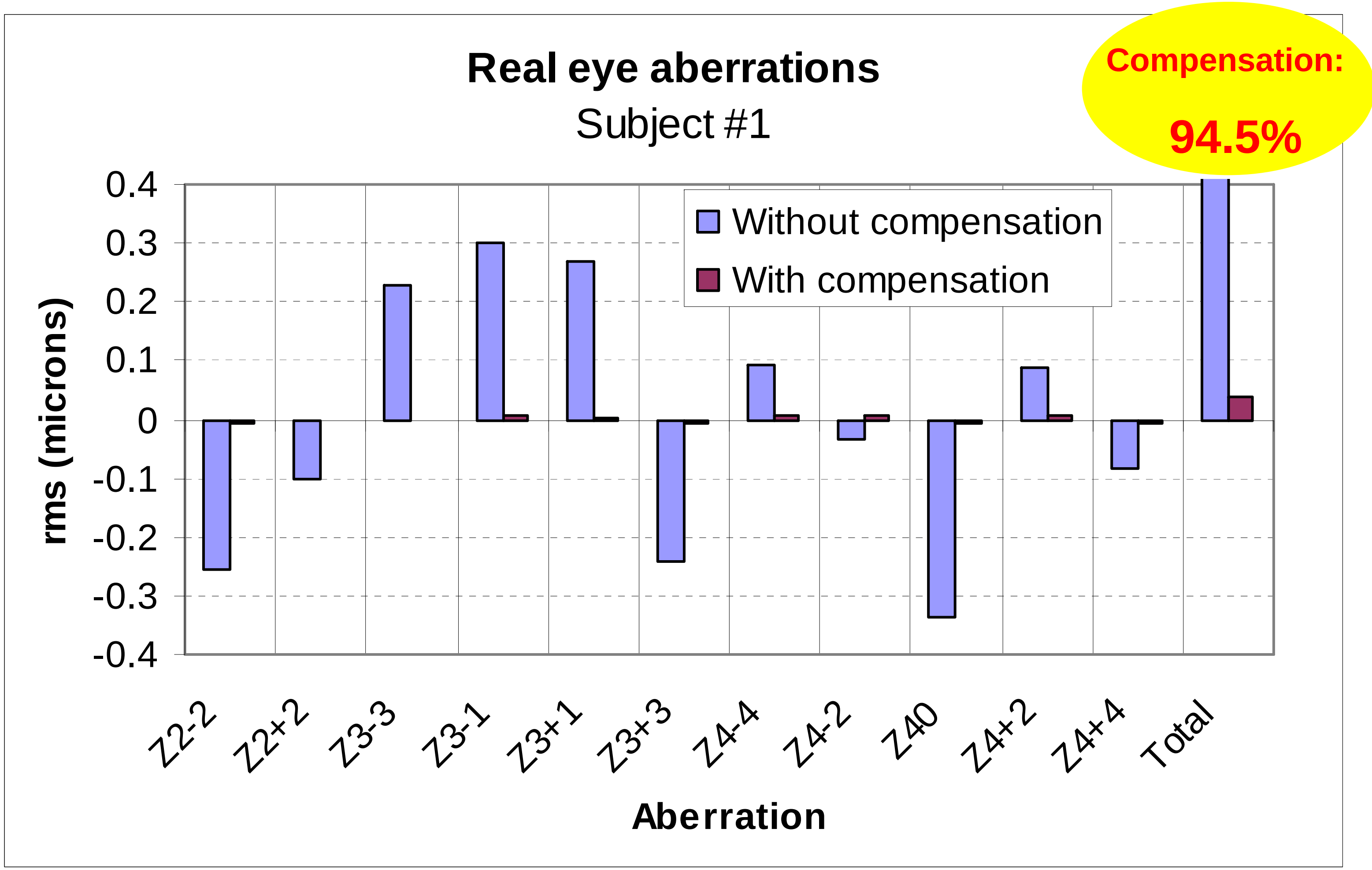


RMS = 0.710 μm → **RMS =0.039 μm**

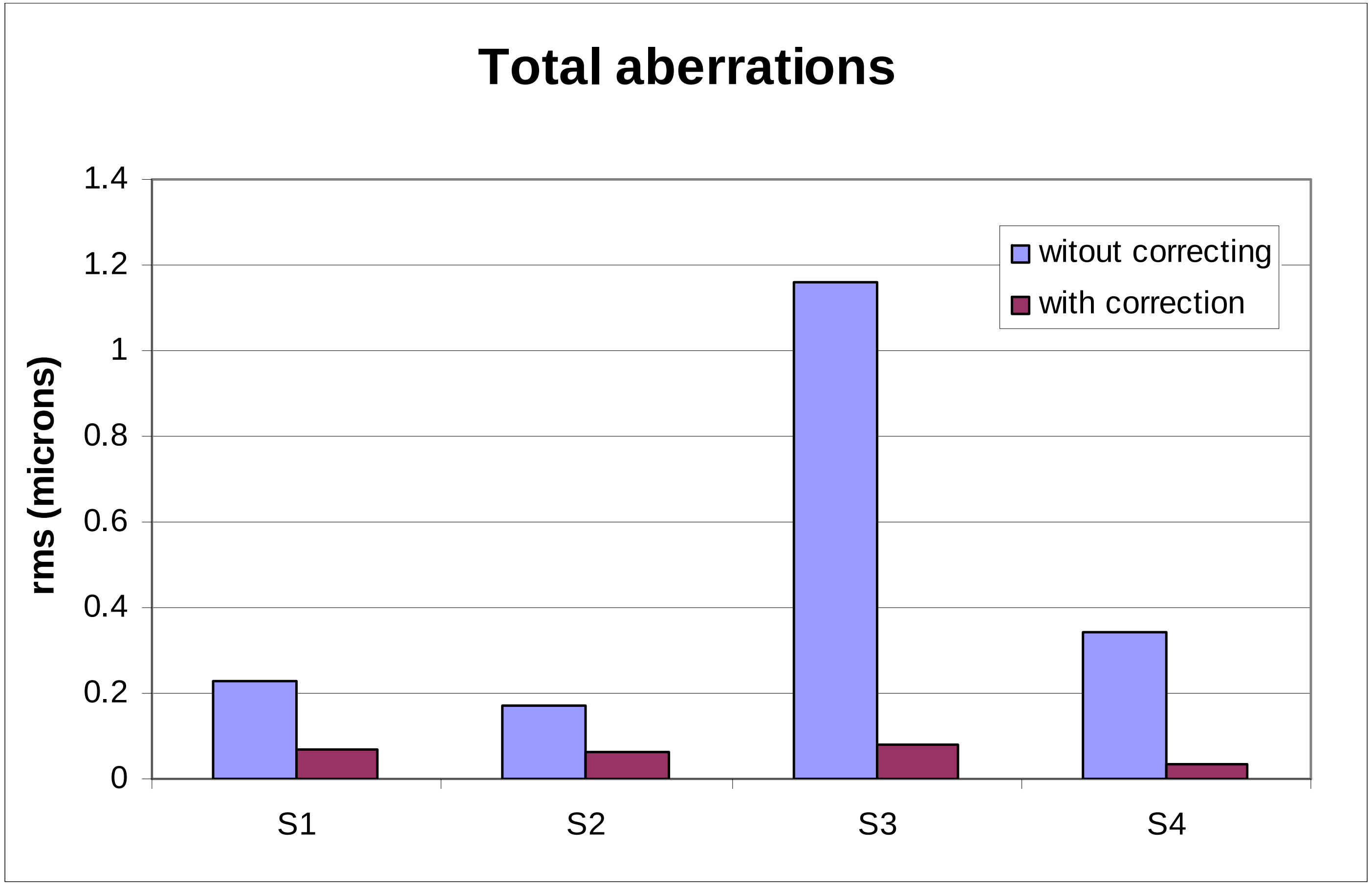
Pupil diameter: 6.6 mm

Close loop compensation.

Zernike coefficients



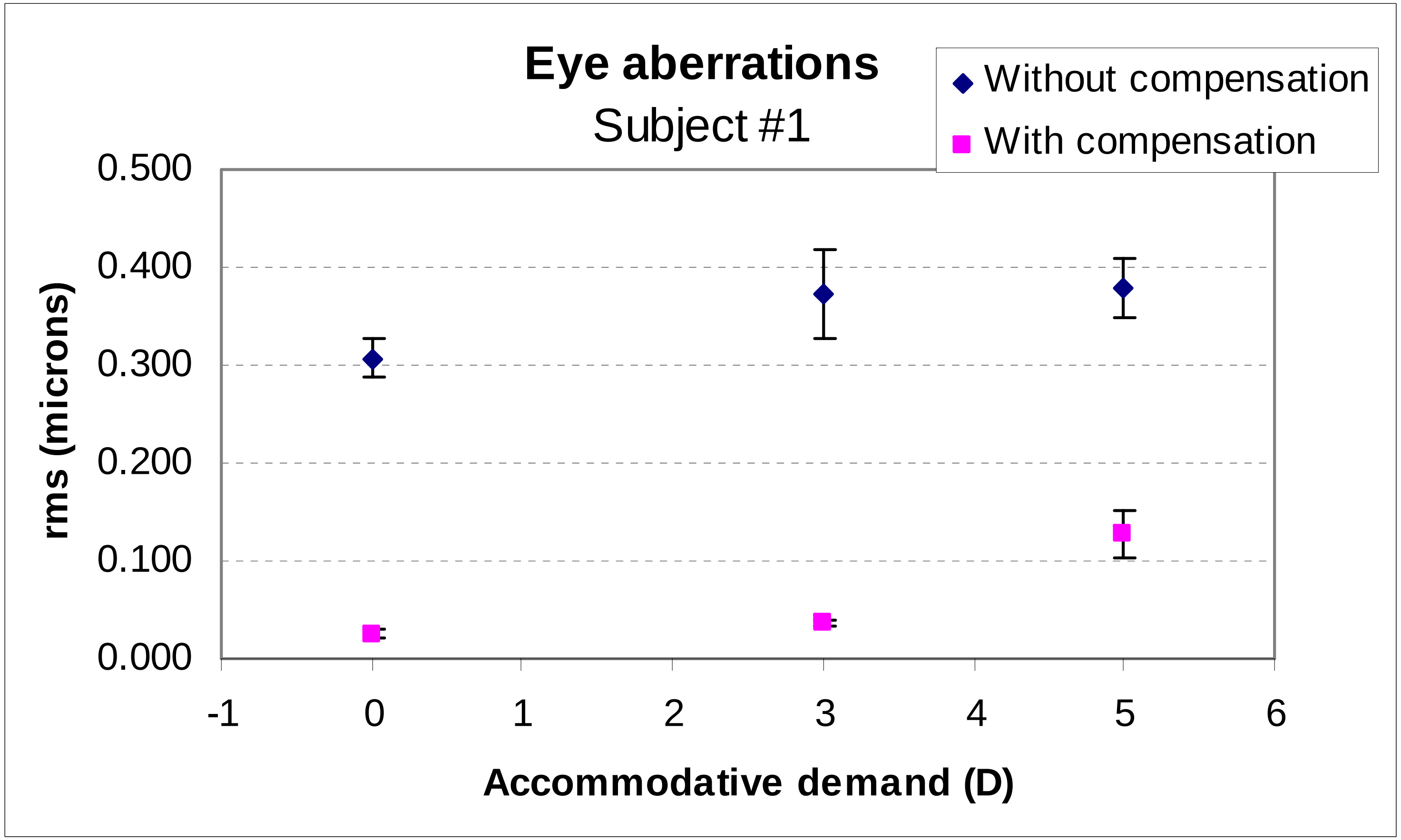
Close loop compensation.



Pupil diameter = 4.8 mm

Close loop compensation.

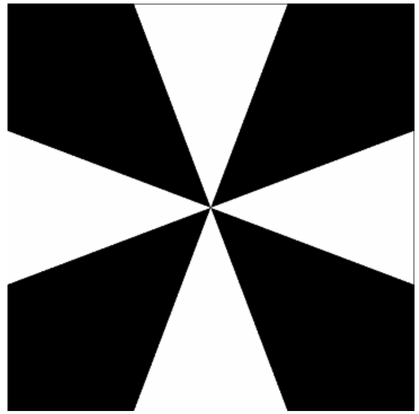
Different accommodative demands



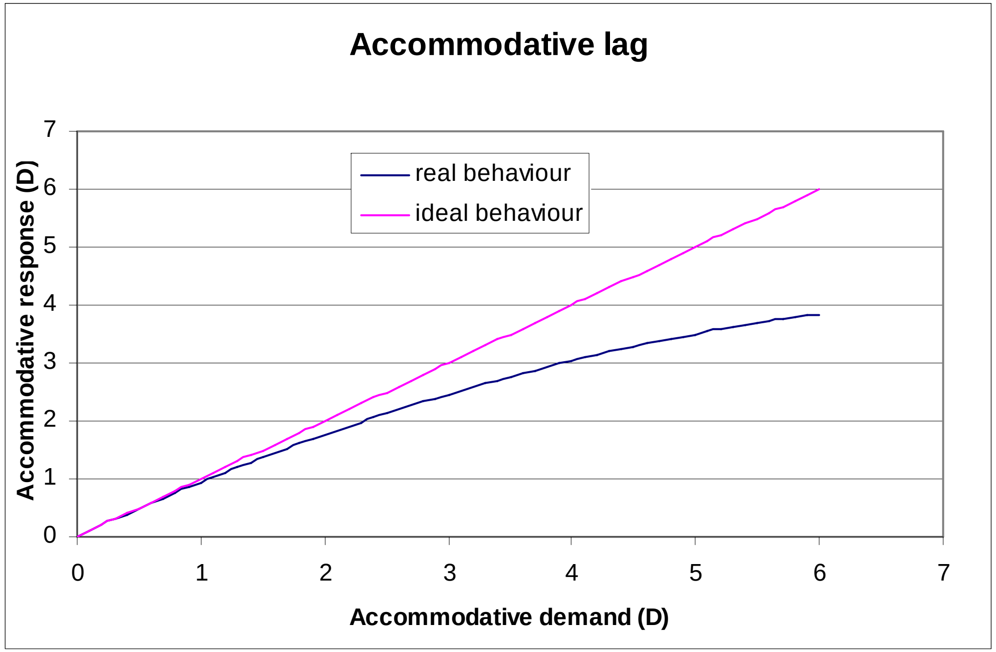
Pupil diameter = 4.8 mm

Effect of aberrations on accommodative response

- **0D, 3D and 5D accommodative demand measurements**
  - **All aberrations**
  - **Compensating all aberrations for 0D**
  - **Inducing spherical and residual defocus for 0D**



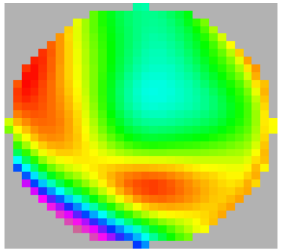
Measurements

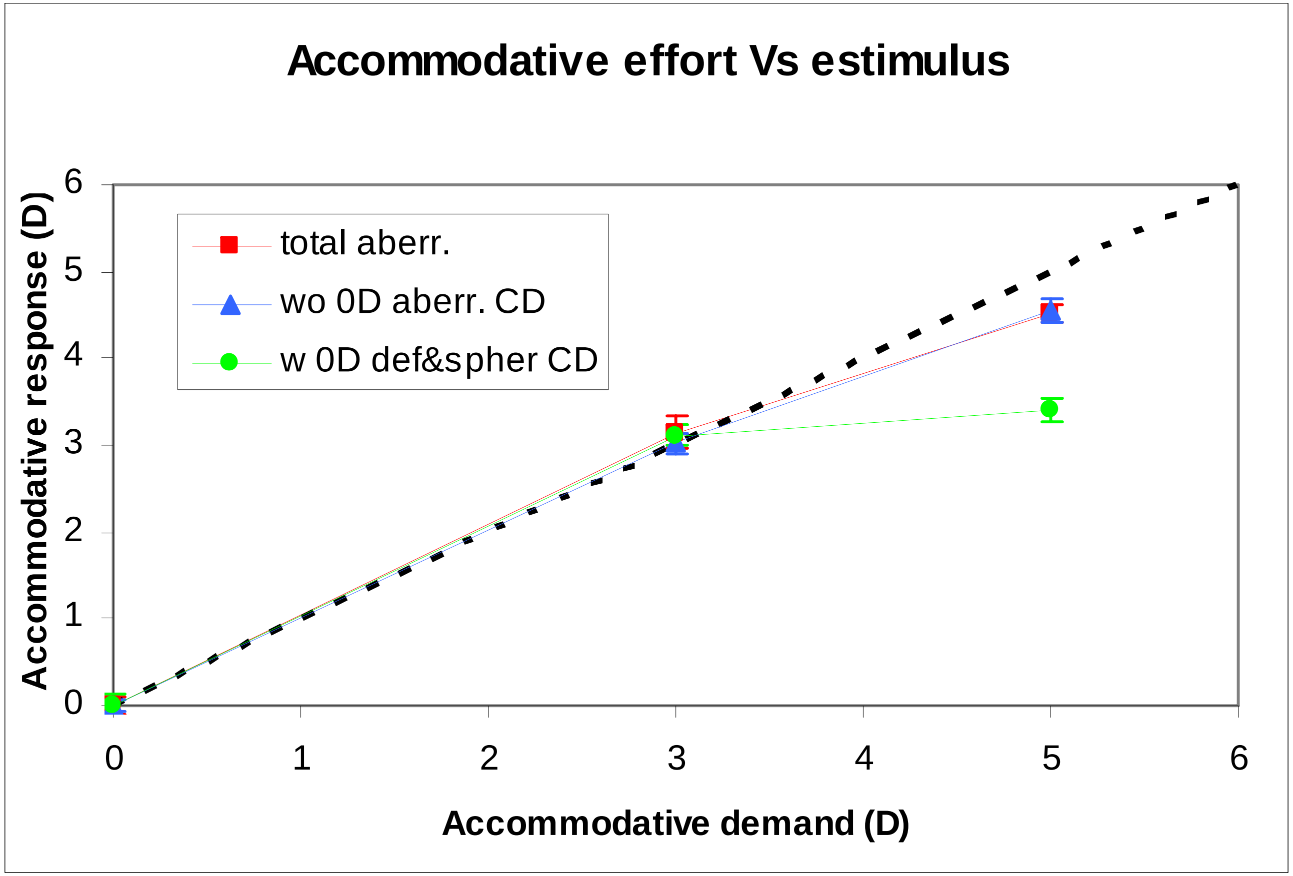


Measurements

S#1, Age: 35

Sphere: +1D



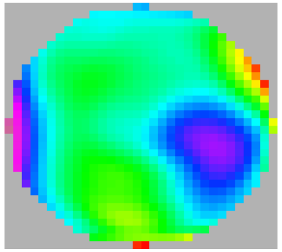


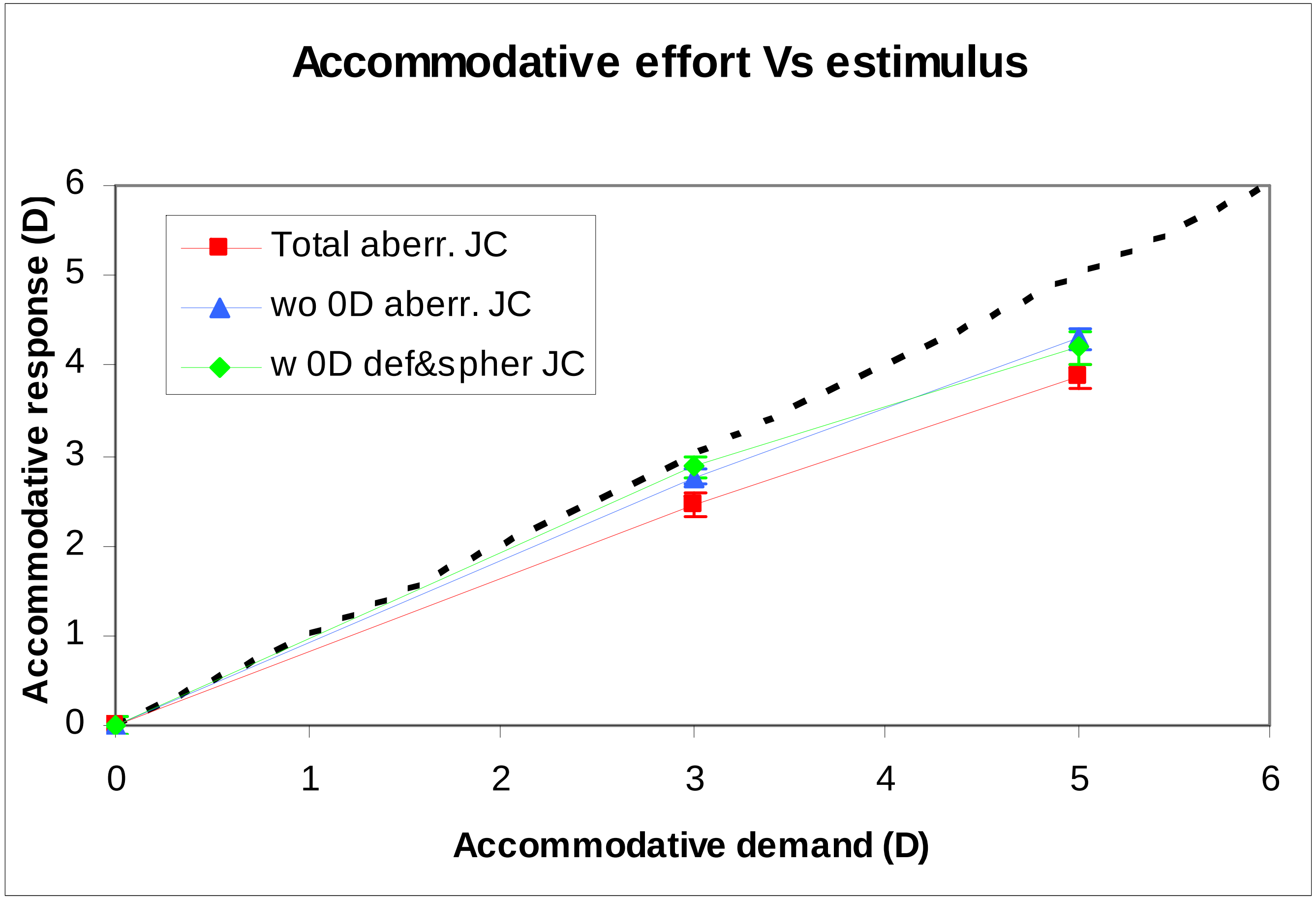
S#1 show worse response for the higher accommodative demand when spherical aberration is induced

Measurements

S#2, Age: 25

Sphere: - 3.25D



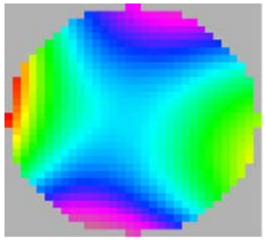


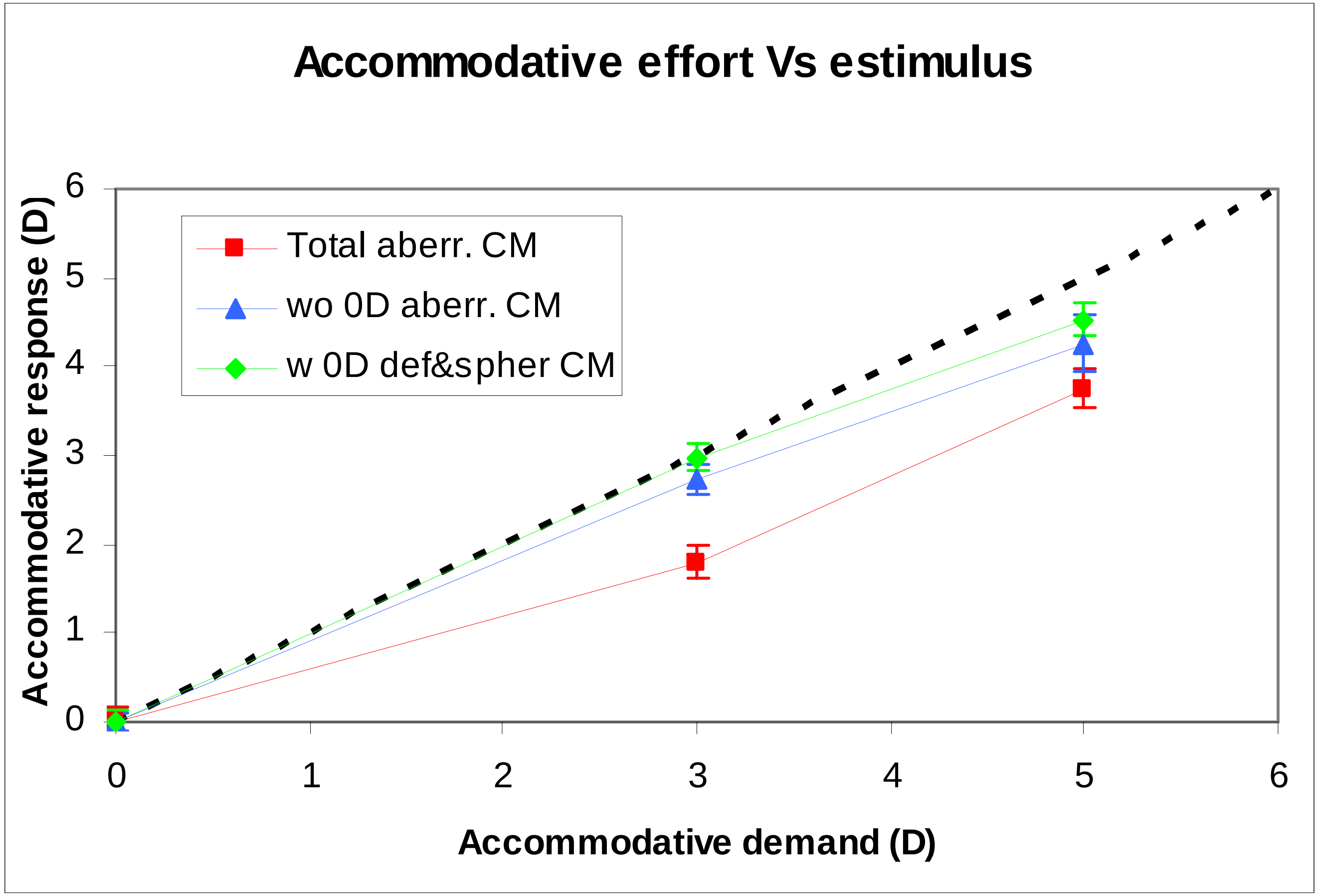
S#2 takes advantage of both correcting all aberrations and keeping spherical aberration free

S#3, Age: 31

Sphere: - 2.25D

Cylinder:





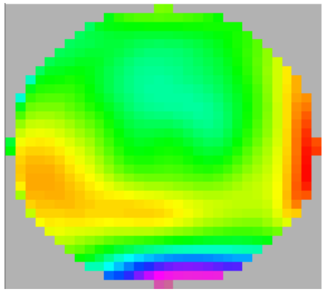
S#3 also takes advantage of both correcting all aberrations and keeping spherical aberration without compensation

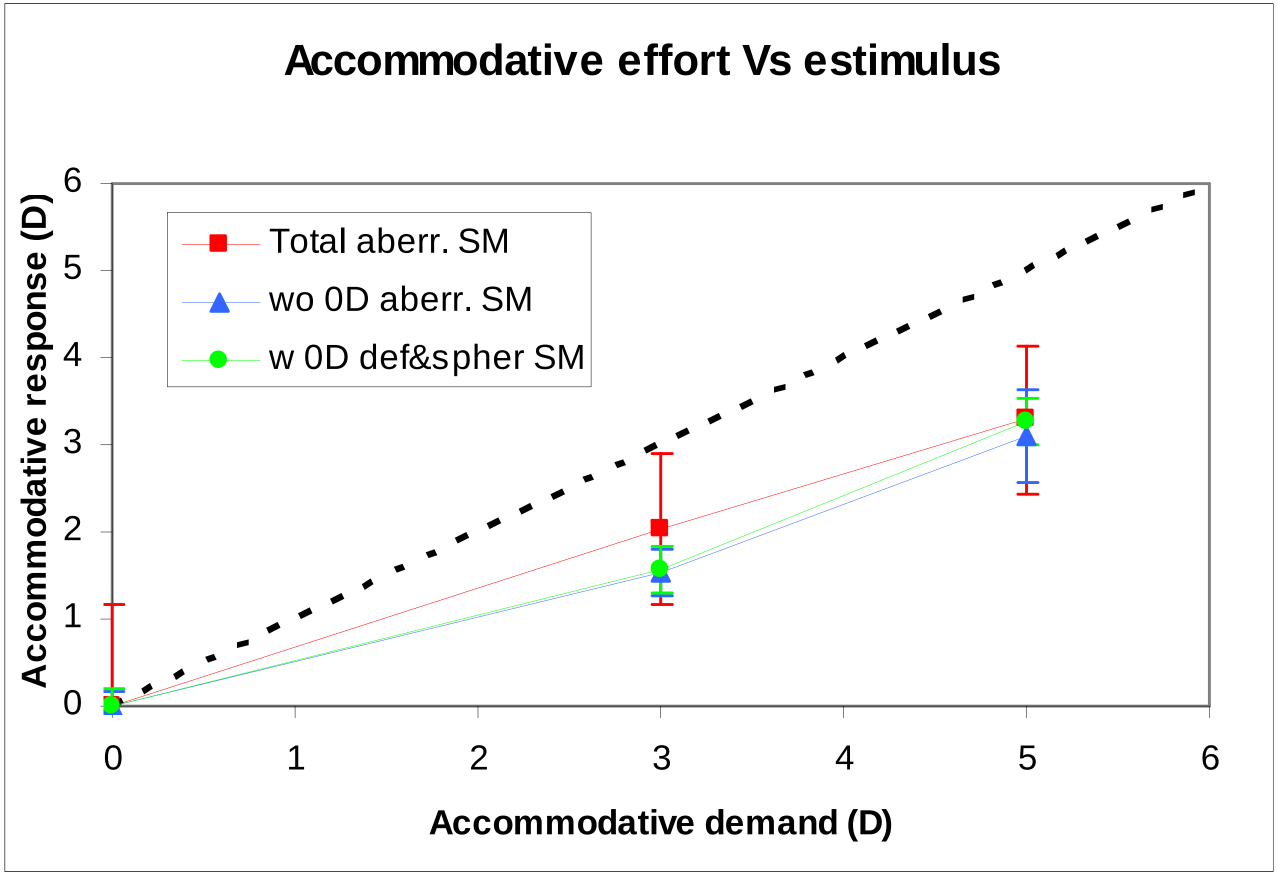
Measurements

S#4, Age: 37

Sphere: - 5.5D

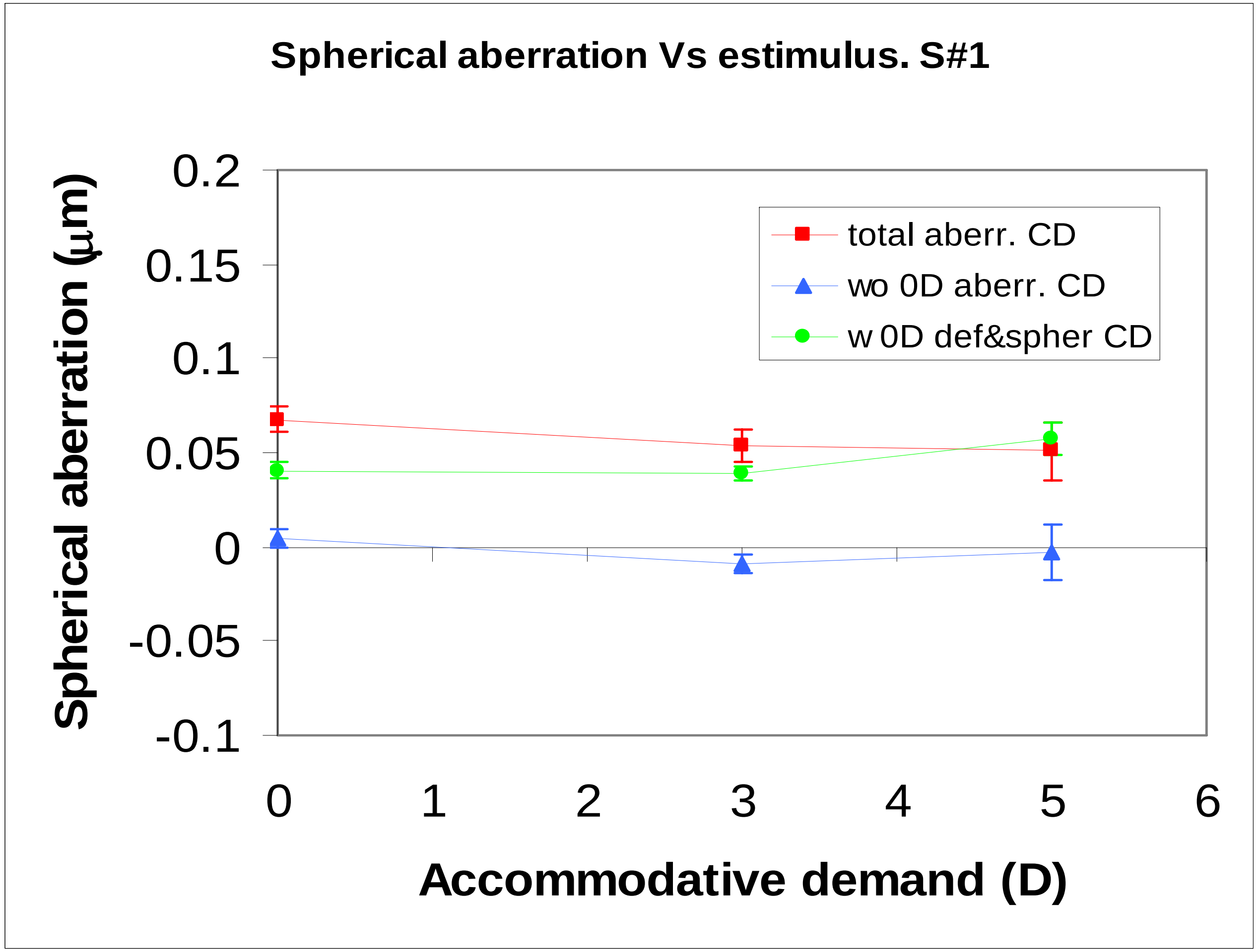
Corrected with contact lenses



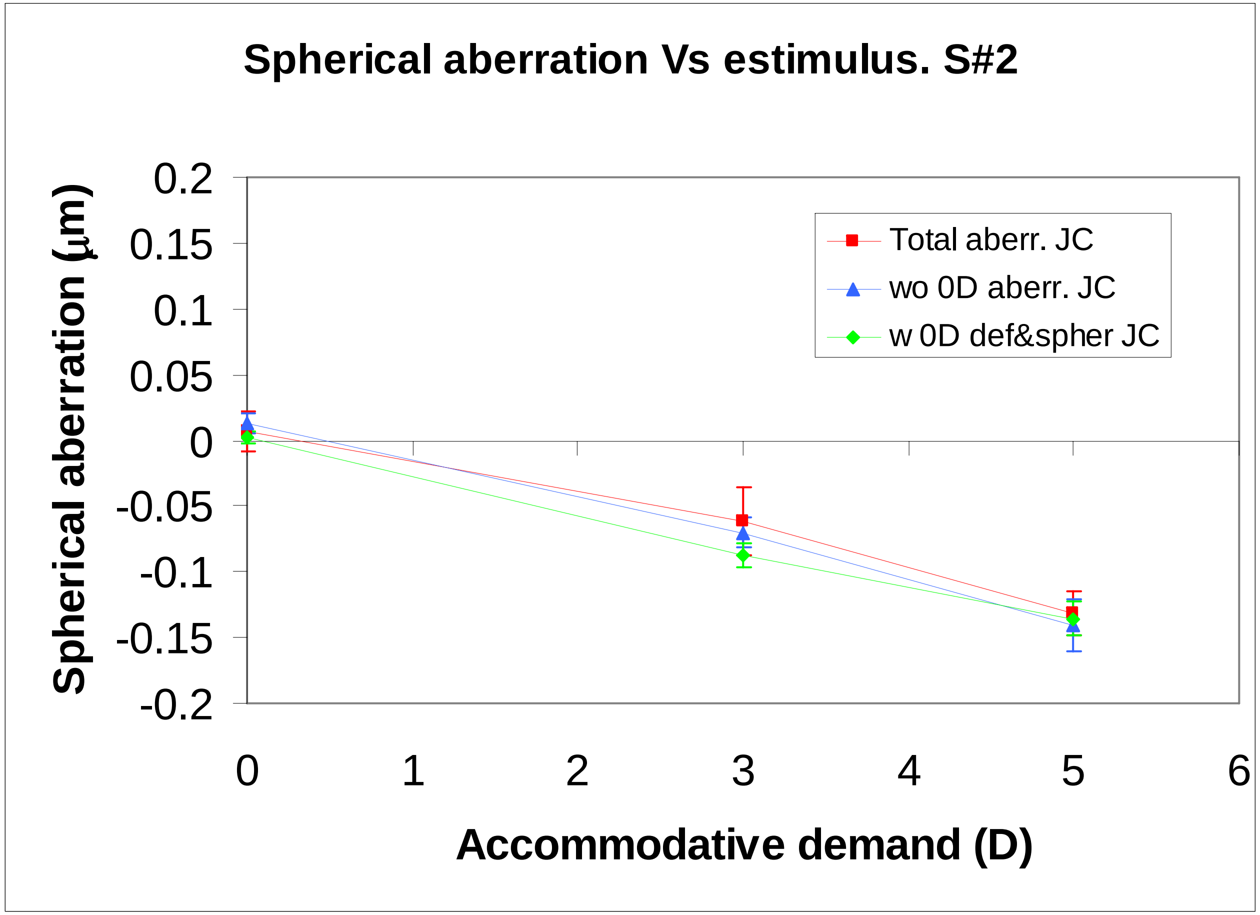


However, S#4's better response occurs with his own aberrations

Spherical aberration



Measurements



Visual Experiments

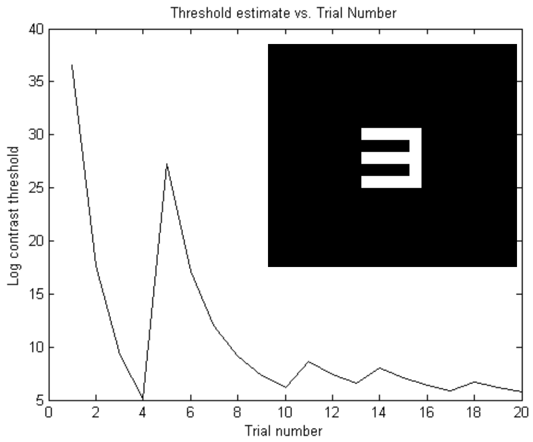
Thru – Luminance visual Acuity: Snellen E

- **High resolution and high brightness minidisplay (LiteEye)**
- **Optical bench with badal system**
  (changes vergence without affecting the magnification).

- **4 alternative forced choice paradigm (Snellen E)**
- **QUEST algorithm for threshold estimation using Psychtoolbox + MatLab.**
- **Stimulus: One E each 0.5 seconds.**

- **50 trials per luminance position (Using neutral density filters).**

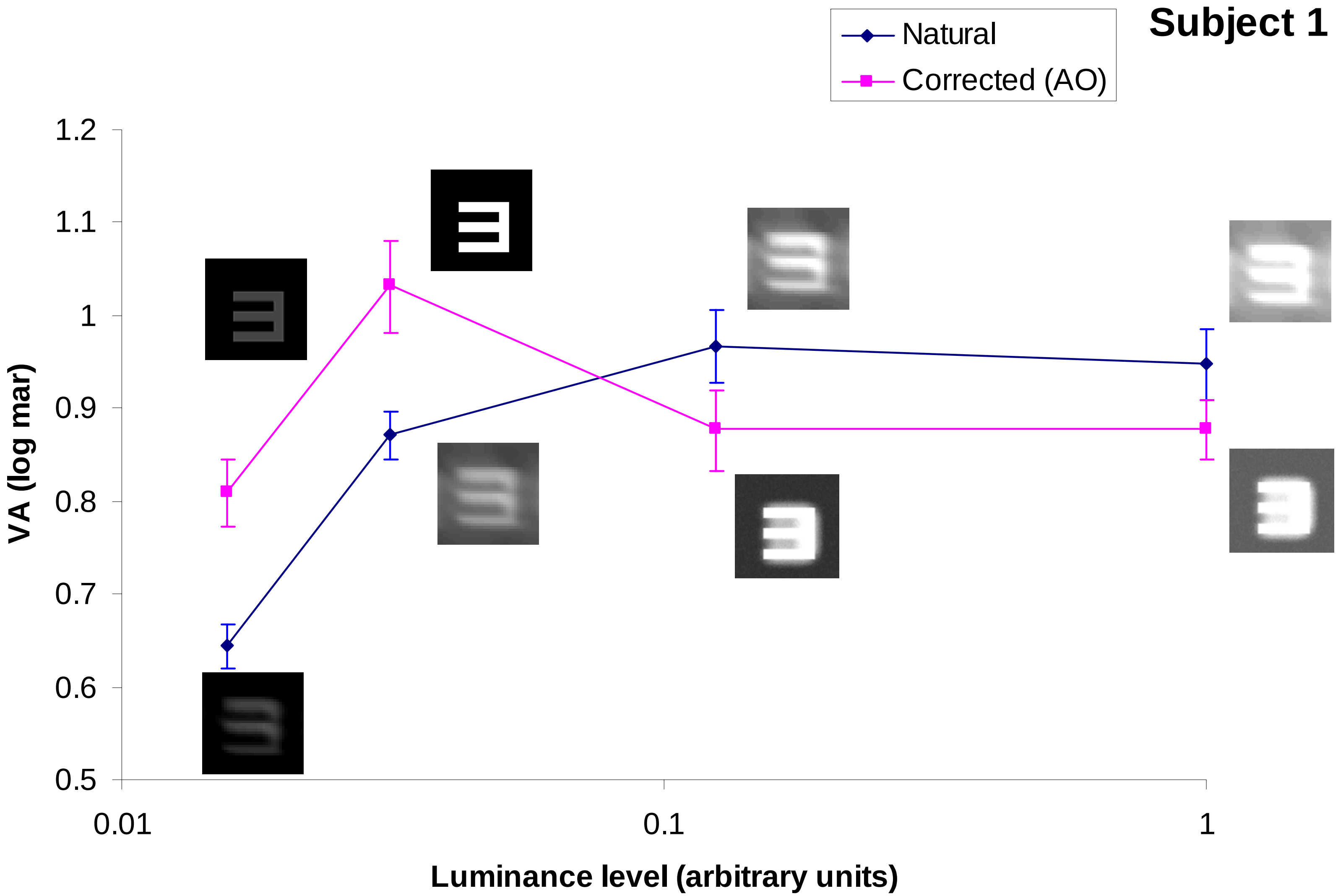
- **With and without adaptive optics correction**



Brainard, D. H., Spatial Vision 10:433-436 (1997)

Pelli, D. G., Spatial Vision 10:437-442 (1997)

Thru – Luminance Visual Acuity



Conclusions

- A new AO system has been presented
- We have calibrated the system with two artificial eyes
- We have achieved a close loop compensation higher than 90% in both artificial and real eyes
- Some subjects seem to use some aberrations clues (spherical) for better accomodating, while others take advantage of correcting their aberrations to focus more accurately.
- Phycophysics…

Future work

- To evaluate the effects of the aberrations on visual performance
- Test relationships between optical & visual quality
- To evaluate the effects of dynamic aberrations on accomodation
- Simulation of refractive and multifocal corrections