Simulation of higher order aberrations using adaptive optics

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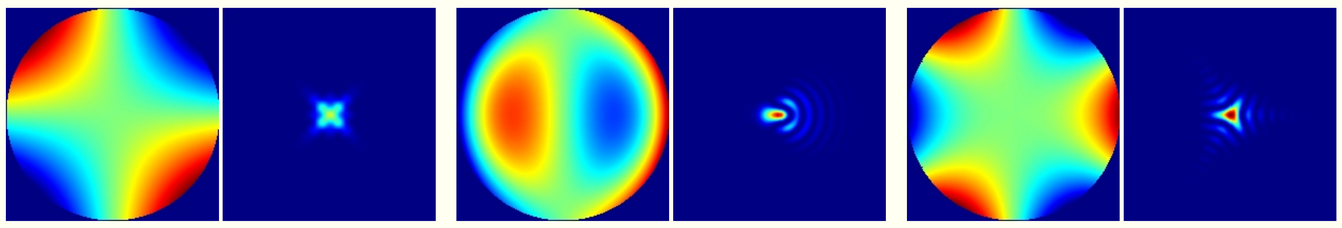
With the help of adaptive optics it is possible to correct aberrations of the human eye in real-time as well as to induce aberrations. An “adaptive optics visual simulator” (AOVS, Fig. 1) was used as technical setup for a study in cooperation between the IAO and the University of Applied Sciences Jena. The goal was to determine the just-noticeable difference (JND) of higher order aberrations (HOA). The simulated aberrations were the coma, the trefoil and the lower order aberration astigmatism. The study was conducted with 28 healthy subjects with non-cyclopleged eyes. To get comparable results, a fixed pupil was put in front of the deformable mirror (DM) to get an effective pupil of 5 mm for all subjects.

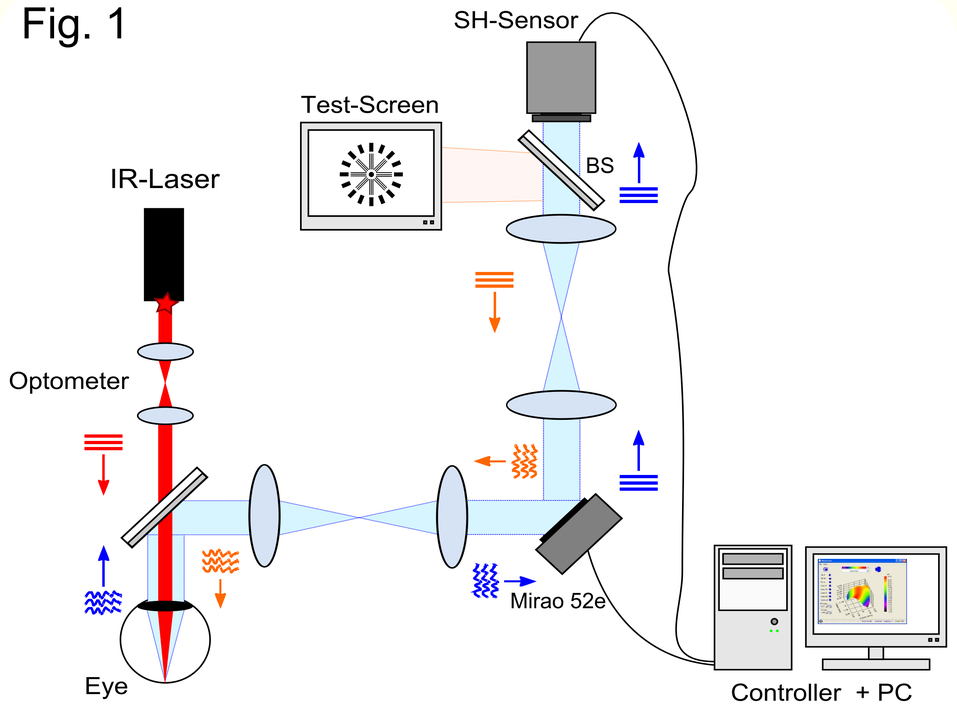
Study:
- 28 subjects
- fixed 5mm pupil
- radial test-pattern (Ø 1°) (Fig. 2 a/b)
- “BestPEST” staircase procedure



Wavefront and resulting point spread function of astigmatism (left), coma (middle) and trefoil (right), each with an RMS-value of 0.5 µm.

AOVS - Setup

Fig. 1



A spot is created on the subjects retina by an IR-Laser (858 nm) (red lines). From there, the light is scattered and propagates through the pupil of the eye (blue lines). The resulting wavefront is deformated by the aberrations of the eye. The pupil plane is imaged onto the deformable mirror Mirao 52e (Imagine Eyes, France) by a 4f-system. A second 4f-system then restores the wavefront on the Shack-Hartmann-sensor. Finally, a test-screen is integrated to the system by a beam-splitter BS (orange lines). Its image can be observed after passing the DM.

Fig. 2

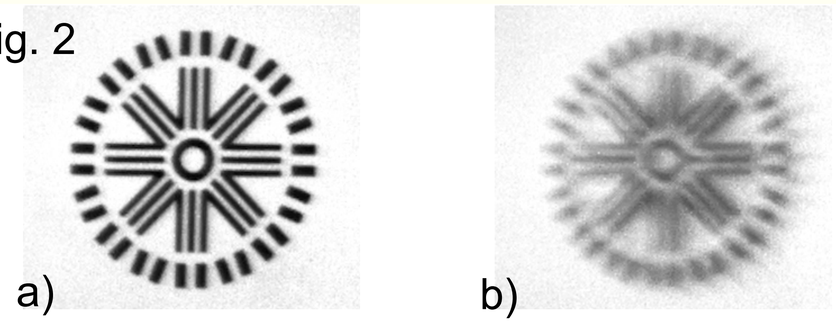
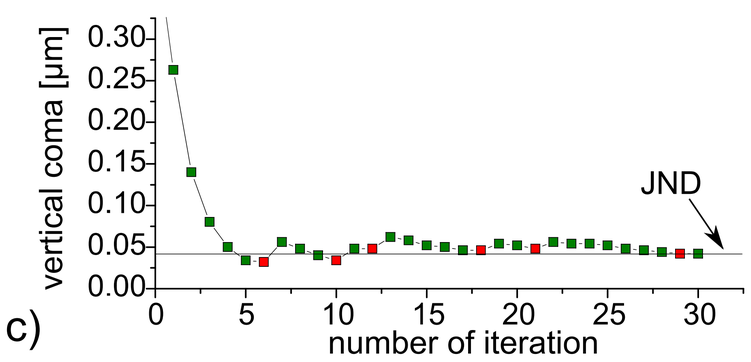


Photo of a test image after passing the AOVS. a) aberration free, b) vertical coma (0.5 µm RMS)



c) Sample of a BestPEST-test. Correct answers are green, wrong Answers red.

28 subjects were tested to determine the JND. Through the AOVS, the subjects had to observe a test-pattern under full correction (Fig. 2.a) as well as superposed by aberrations (Fig 2.b). The order was randomized, so they did not know which was the aberrated one. Then they had to choose the image with the - to their opinion - higher image quality. The value of the aberration was varied by the BestPest-method [3] (Fig 2.c), starting at 0.5µm with 30 iterations. If the subjects chose the fully corrected image, the value of the aberration was reduced. If they chose the aberrated one the value of the aberration was increased. The last value is equivalent to the JND.

course of action:

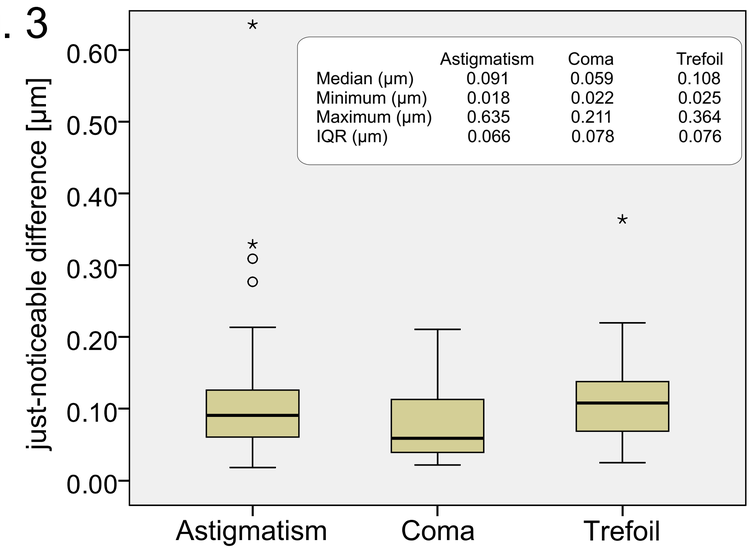
- WASCA measurement
- subjective alignment

measurements at the AOVS
- correction A: all aberrations up to the 6th order zernike polynomials
- correction B: all aberrations up to 6th order zernike polynomials + astigmatism/coma/trefoil induced by the deformable mirror
- test-pattern was presented and the subject had to compare correction A and B
- value of the aberration was varied according to the “BestPEST” staircase procedure (forced choice)

Discussion

The median of the JND of all 28 subjects was in the case of astigamtism 0.09 µm, while the coma caused 0.06 µm and the trefoil 0.11 µm. Hence, the coma disturbes vision already at lower values than the other two aberrations. The JND of the coma is significantly below the JND of the astigmatism. The IQR (the range in which 50% of all measured values are) was between 0.07 µm (astigmatism) and 0.08 µm (trefoil). Due to this spreading, a correction of these aberrations (e. g. LASIKs) based on the measurements of the wavefronts only does not seem to be appropriate. Instead, it might be useful to evaluate the best correction with a subjective refraction at an AOVS.

Fig. 3



Comparison of the JNDs of the three chosen aberrations. 50% of all values are inside the coloured rectangles.

[1] H. Jungnickel, H. Babovsky, A. Kiessling, M. Gebhardt, H.J.Grein, R. Kowarschik.,"Effects on Vision With Glare After Correction of Monochromatic Wavefront Aberrations," Journal of Refractive Surgery 27, 602-612 (2011)
[2] H. Babovsky, H. Jungnickel, A. Kiessling, R. Kowarschik.,“Wellenfrontkorrektion menschlicher Augen”, DGaO-Proceedings 2010
[3] H.R.Lieberman, A.P. Pentland (1982) “Microcomputer-based estimation of psychophysical thresholds: The Best PEST”. Behavior Research Methods & Instrumentation,14, 21-25 (1982)

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