Optical performance with multi-zone multifocal designs with natural and corrected ocular aberrations

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Background

Multifocal simultaneous vision corrections are increasingly used solutions to correct for presbyopia, by producing different foci for far, near and intermediate vision [1] or expanding the depth-of-focus by increasing spherical aberration or different combinations of optical aberrations [2].

In a recent study we explored computationally through-focus optical performance of multi-zone phase patterns, distributed either angularly or radially, and found that, in diffraction limited eyes, angular zone designs provided better multifocal performance [3]. Moreover we have studied the optical quality and visual perception with different pupil segmentation patterns using a Simultaneous Vision simulator [4].

Goal

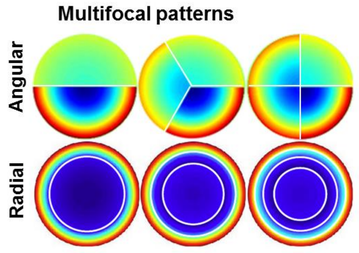
To further explore quality of vision of multi-zone multifocal designs in real eyes, simulated with Adaptive Optics (AO).

We have investigated perceived optical quality with angular and radially segmented multifocal patterns, in the presence or absence of natural aberrations.

Predictions of thru-focus optical quality with multifocal designs

Through-focus optical quality was computed for different multi-zone multifocal phase designs Radial & Angular zone designs with 2 to 4 zones.

Multifocal patterns



C_0^2 ➔ −0.45 & −3.89 µm in a 6 mm pupil (+0.35 D for far to +3.0 D for near)

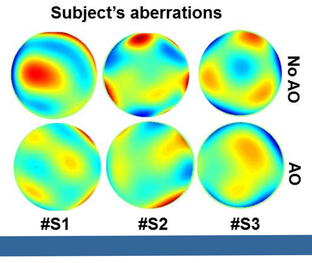
The area of each zone was constant in all cases

Through-focus Visual Strehl (VSOTF) was computed w/wo natural aberrations.

$$VSOTF = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} CSF_N(f_x,f_y)\cdot OTF(f_x,f_y)df_xdf_y}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} CSF_N(f_x,f_y)\cdot OTF_{DL}(f_x,f_y)df_xdf_y}$$ [5]

Visual Strehl-based optical performance metric [DOF<threshold (0.06) vs. area under the Visual Strehl through-focus curve] was used for multifocality, and given relative to multifocality of the 2-segmented angular (NoAO) design.

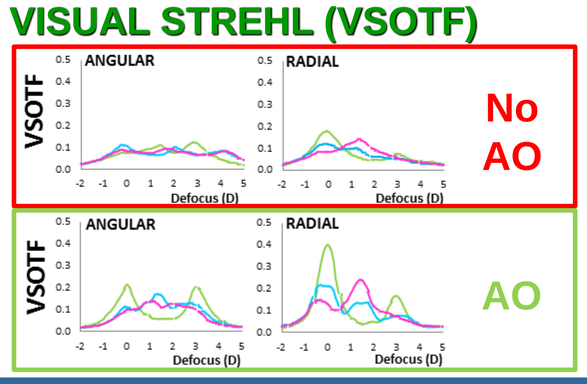
SUBJECT'S ABERRATIONS



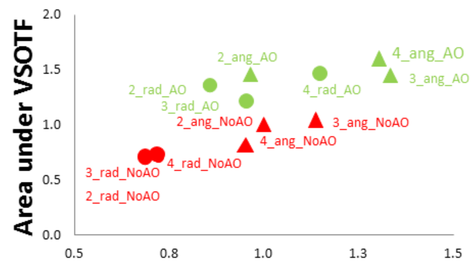
	NoAO	AO
#S1	0.4132	0.0236
#S2	0.6847	0.1508
#S3	0.1567	0.0234

RMS (µm) for all subjects with/without AO

VISUAL STREHL (VSOTF)

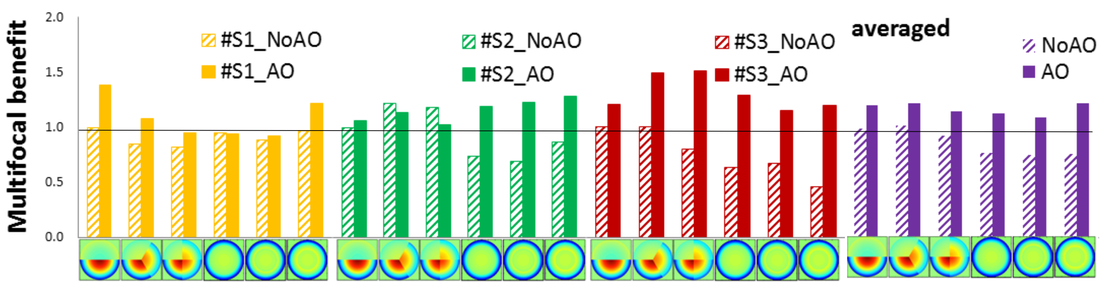


MULTIFOCAL BENEFIT RESULTS



Best optical multifocal performance (as described by the selected metrics) is achieved with 3/4 angular designs (both with and without natural aberrations).

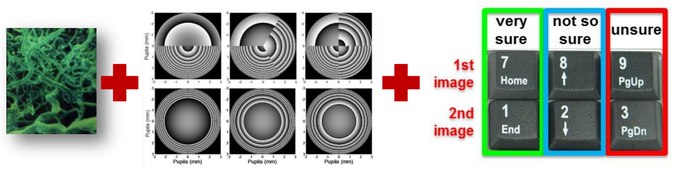
The relative differences of multifocal benefit across patterns increase when natural aberrations are present.



Psychophysical experiment

6 multi-zone multifocal patterns were tested in a polychromatic AO set-up, using a Spatial Light Modulator (SLM) to generate the patterns and an AO-loop to control the aberrations.

PSYCHOPHYSICAL TEST

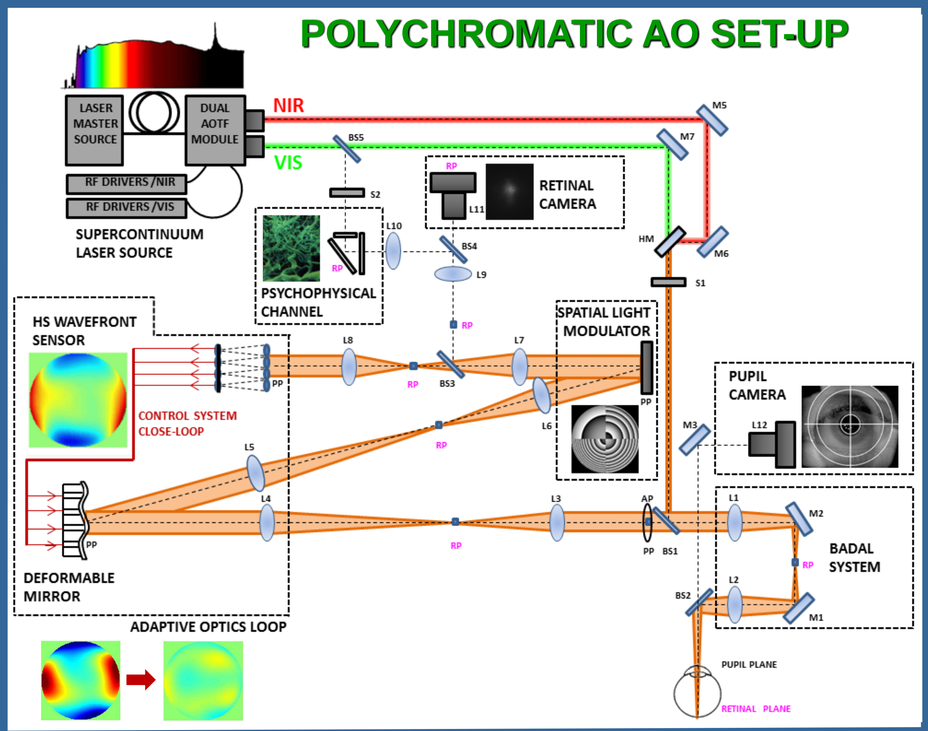


- ❑ Stimulus: natural image
  Back-illuminated: 555nm (monochromatic)
- ❑ 6 patterns: angular&radial (2, 3 & 4 segmented)
- ❑ 60 pairs of patterns (120 images, random)
  4 trials (240 pairs of images)
- ❑ Score: 10, 5 & 1 (very sure, not so sure, unsure)

EXPERIMENTAL PROCEDURE

- ➔ Best subjective focus, adjusted by the subject with the Badal system
- ➔ Psychophysical measurement
- ➔ Wave aberrations checked immediately before and after measurement
- ➔ Psychophysical measurement repeated under full AO correction

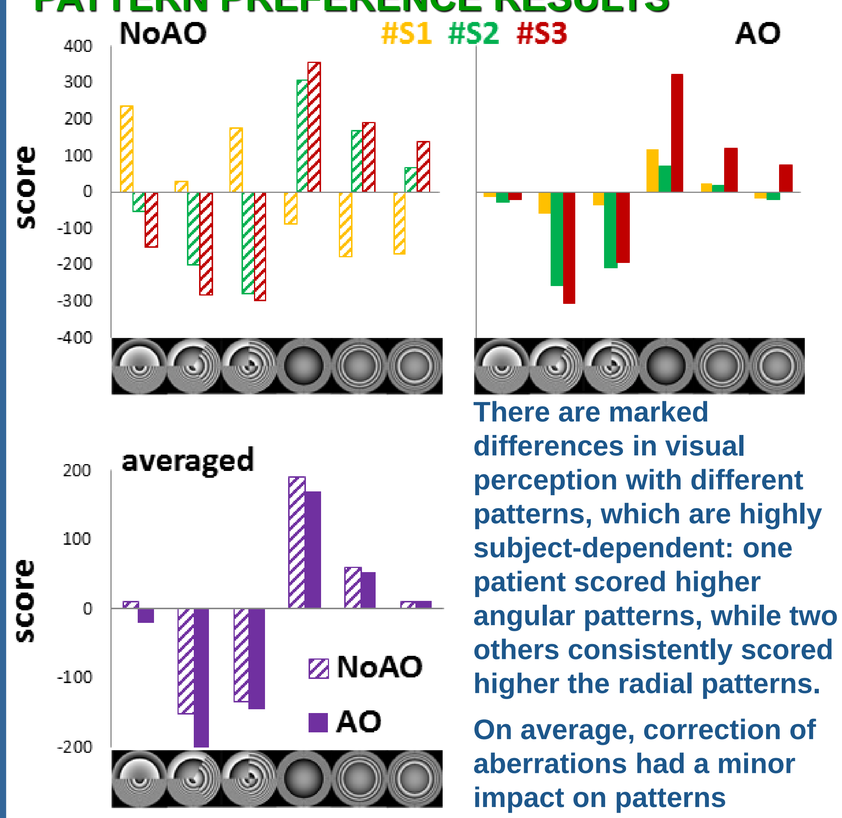
POLYCHROMATIC AO SET-UP



SAMPLE

- ❑ 3 subjects (28.60 ± 3.3 yrs);
- ❑ Rx: Sph < 0.25 D & Cyl < 0.25 D
- ❑ 6-mm artificial pupil

PATTERN PREFERENCE RESULTS



There are marked differences in visual perception with different patterns, which are highly subject-dependent: one patient scored higher angular patterns, while two others consistently scored higher the radial patterns.

On average, correction of aberrations had a minor impact on patterns preference.

Conclusions

1. We studied optical performance & visual perception with different radial and angular designs, by means of optical simulations and psychophysical tests on patients using an AO system, in the presence/absence of optical aberrations.
2. Adaptive Optics (combining deformable electromagnetic mirror and spatial light modulator technologies) in combination with a psychophysical channel allowed us real simulations of 3-4 zone angular and radial multifocal patterns.
3. Optical simulations predict, on average, higher quality with angular designs. Measurements on patients reveal a high intersubject variability in multifocal pattern visual preference, relatively little affected by the presence/absence of aberrations.

References

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