Where is the Optimum Far-point for a Presbyopic Eye?

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Dedication

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Inventor of the blur-ratio model of visual acuity in the presence of optical blur.

The emmetropic presbyope's main complaint

Targets don't become more legible when they get closer.
The young man's view

The closer she gets, the better she looks.
The old man's frustration

Increased blur cancels benefit of increased magnification.
Appropriate method of analysis

Eschew Fourier Optics!

- Wavefront analysis is needed only for the quasi-focused eye, for which residual defocus and astigmatism are of the same order of magnitude as higher-order aberrations they interact with (e.g. 0.25 diopters)

- The presbyope is faced with huge amounts of defocus, for which a much, much, much simpler analysis using geometrical optics analysis is sufficient and appropriate.
Stimulus defocus for emmetropic presbyope

Stimulus defocus = Vergence of far point - vergence of object
E = K - L

Stimulus defocus increases as object gets closer to eye and farther from the far point.
Effect of defocus on visual acuity

\[ \beta = \text{blur circle diameter} \]

\[ w = \text{stroke width} \]

\[ \text{Blur ratio} = \frac{\beta}{w} \]

= size of blur circle relative to spatial details of object.

(Smith et al., 1989)
Effect of defocus on visual acuity

At visual threshold for reading letters, average blur ratio $= \beta / w = 4$ (range $= \pm 2$) (Smith, Jacobs, & Chan, *Optometry & Vision Science*, 1989)

<table>
<thead>
<tr>
<th>Blur disk diameter ($\beta$, in arcmin)</th>
<th>Minimum angle of resolution ($w$, in arcmin)</th>
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</thead>
<tbody>
<tr>
<td>b.r.=0</td>
<td>0</td>
</tr>
<tr>
<td>b.r.=1</td>
<td>br=0</td>
</tr>
<tr>
<td>b.r.=2</td>
<td>br=1</td>
</tr>
<tr>
<td>b.r.=4</td>
<td>br=2</td>
</tr>
<tr>
<td>b.r.=6</td>
<td>br=4</td>
</tr>
</tbody>
</table>

Graph showing the relationship between blur disk diameter and minimum angle of resolution.
The emmetropic presbyope's dilemma

Legibility is independent of viewing distance when far-point is at infinity

$$\text{Blur ratio} = \frac{\text{Blur circle dia (radians)}}{\text{Letter size (radians)}} = \frac{\text{Pupil dia (m)}}{\text{Stimulus dist (m)}} \times \frac{\text{Stimulus dist (m)}}{\text{Stimulus dist (m)}}$$

$$\text{Letter size (radians)} = \frac{\text{Letter size (m)}}{\text{Stimulus dist (m)}}$$

$$\text{Blur ratio} = \frac{\text{Blur circle dia (radians)}}{\text{Letter size (radians)}} = \frac{\text{Pupil dia}}{\text{letter size}}$$

$$\Rightarrow \text{Blur ratio is independent of stimulus distance!}$$

Targets are either legible at all viewing distances, or never legible at any viewing distance. Getting closer doesn't help!
Stimulus defocus for myopic presbyope

Stimulus defocus = Vergence of far point - vergence of object

\[ E = \frac{1}{K} - \frac{1}{L} \]

Stimulus defocus first decreases as object gets closer to far point, then increases as object gets closer to eye.
Myopia: the presbyope's friend

Legibility improves when object approaches the far-point.

Depth-of-field (DoF) = range of legible viewing distances = far distance/near distance = near vergence/far vergence
Myopia: the presbyope's friend

Depth-of-field $\approx$ constant for far-points between 0.33 - 2 meters.

Location of the far-point determines the center of the depth-of-field, but not its width.
A simple relationship

Log(Depth-of-field) \approx \frac{\text{Letter height}}{\text{pupil diameter}}

Example:
Upper case letters in 16 point font are 4mm tall. For a 4mm pupil, DoF = 1 log unit, = tenfold range of distances.

Each symbol represents a different combination of pupil diameter, letter height, and far-point vergence.
Conclusions

The presbyope's dilemma, that targets don't become more legible when they get closer, only occurs for the fully-corrected eye.

For the under-corrected, myopic eye:

• Depth-of-field (DoF), specified as the ratio of far to near distances for which text is legible, is largely independent of far-point location.

• The far-point location determines the center of the DoF, but not its width.

• Depth-of-field (DoF) in log-units is approximately equal to the letter size divided by pupil diameter.
Clinical implication

The far-point is a free parameter when prescribing for the presbyope. It can be adjusted to account for factors like:

- habitual pupil size
- habitual reading distance
- text size

to maximize the functional utility of the legible depth-of-field and extend the quality of visual experience.