

CONSISTENCY OF DEFOCUS ESTIMATION UNDER PUPIL-SIZE EXTRAPOLATION OF ZERNIKE WAVEFRONT COEFFICIENTS

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Precise quantification of refractive defocus is essential to vision science and in the design of optical correction strategies based on wavefront sensing. Zernike polynomials are widely used to represent ocular aberrations, and extrapolation of Zernike coefficients across different pupil sizes is often carried out without adequate assessment of their physical validity, since the corrections are made over the largest pupil size. Unlike prior works, we therefore analytically evaluated the stability of defocus estimation under pupil-size extrapolation. To this end, the refractive defocus values were varied to correspond to refractive errors ranging from 0 to -5 D at a reference pupil radius of 1.5 mm. The resulting wavefronts were extrapolated to larger pupils with radii ranging from 1.75 to 3.00 mm. The defocus-equivalent (DE) values were then evaluated using the standard Zernike-based conversion. The distribution of DE values shows a linear trend at each pupil radius, with slopes that gradually flatten as pupil size increases. Numerically, the normalized slope decreased from 1.00 at 1.5 mm to 0.54, 0.32, 0.20, 0.13, 0.08, and 0.06 at 1.75, 2.00, 2.25, 2.50, 2.75, and 3.00 mm, respectively. For the first 0.25 mm increase in pupil radius, the results show a reduction of DE of almost 50%. Therefore, for larger pupils, defocus extrapolation across pupil sizes is mathematically ill-conditioned, potentially leading to biased or non-physical estimates. These findings highlighted a critical limitation of Zernike-based methods and emphasized the need for physically consistent, pupil-independent frameworks for precise measurement and correction of refractive error.

Keywords: Defocus equivalent, Extrapolation, Pupil size, Refractive errors, Zernike coefficients