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Refracting the Retina Patient: Contrast Modulation Dioptre Optics and Spatial Acuity

Israel Abramov[1]*, Lawrence R. Stark[2], Robert Ritch[3], Mark Forman[4], Warren W. Ward[5]

[1]Department of Psychology, Applied Vision Institute, Brooklyn College, City University of New York, 2900 Bedford Avenue, Brooklyn, NY 11210, USA
[2]Southern California College of Optometry, Marshall B. Ketchum University, Fullerton, USA
[3]Department of Clinical Ophthalmology, The New York Eye and Ear Infirmary, New York, USA
[4]Long Island Ophthalmic Service, Middletown, United States
[5]Electro-Optical Engineer, Ward Technical Consulting, Jameson, Missouri, United States

***Correspondence:** Israel Abramov, Professor, Department of Psychology, Applied Vision Institute, Brooklyn College, City University of New York, 2900 Bedford Avenue, Brooklyn, NY 11210, USA. Tel: +1 718.951.5454; Email: iabramov@brooklyn.cuny.edu

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Abstract

Clinical refraction to find optimal eyeglass prescription for patients with reduced retinal acuity is fraught with multiple challenges. Not only do standard phoropter methods slow down the eye clinic, but they also cause personal distress to the patient: cascading to economic and public health consequences. The problem is better understood by mathematical visual optics modelling of the targets presented to the eye combined with retinal sensation and contrast discrimination. Diminished ability to distinguish two lens presentations while viewing the acuity characters of the Sloan eye chart presents mainly three challenges to the visual system of the patient: 1) Distinguishing sharpness [loss of high spatial frequency edge data]; 2) Distinguishing clarity [loss of luminance contrast at the primary spatial frequency of the presented letter target]; 3) Temporal comparison [using short-term visual memory recall to compare two successive presentations of lens-induced focusing blur]. In this article, interpolated values of dioptre [0.40 to 4.0 D] and acuity [20/20 to 20/640] are presented as a function of pupil [1 mm to 6 mm] and retinal eccentricity [2 deg to 32 deg]. Washout threshold [67 % decrement of Michelson luminance contrast] also is presented. Results indicate that for retinal acuity lesser than 20/80: sphere lens powers disparate by +1.50 dioptre must be presented. For the low-vision optometrist, this is equivalent to changing the optical target distance from 40 cm (2.50 D) out to 100 cm (1.00 D).

Keywords: Retina; Contrast modulation; Visual optics; Retinal visual contrast; Visual acuity; Refractive lens.

INTRODUCTION

The calendar date 2027 is a 300-year anniversary following the death of Isaac Newton. Early astronomers [like Tyco Brahe] used telescopes designed by men such as Lippershey: of lenses cut and polished by men such as Benedict Spinoza. The post-Renaissance optical sciences literature goes back to the work of Donders, Fourier, Helmholtz, Michelson, Purkinje, Ronchi, and Scheiner: extending across the academic medical landscape of the Rhine river valley of continental Europe [1,2]. Two-dimensional blur had been described pictorially by the nineteenth century but fitting to it a mathematical function that happened only after the Second World War [3].

ACUITY AND VISUAL RESOLUTION

The need for studies on retinal visual resolvability of small detail can mostly be attributed to the needs of maritime navigation [4]. Early pioneering work had been documented [5,6] a few years prior to the establishment of the optometric profession in America. Describing the chromatic difference of focus across the visible spectrum as around 2.0 dioptre, was documented twelve years before the Apollo moon landing [7]. Another six years later, ocular aberration effects on visual acuity [8] were published. The science of optical modulation transfer became known outside of NASA only after year 1974 [9].

CLINICAL VISUAL OPTICS OF RETINA

Consequence for Glaucoma

Visual acuity and ocular refraction became standard knowledge among eye doctors following the 1952 edition of a classic text [10]. More detailed documentation on clinical refraction that included ocular accommodation motility effects was published by 1971 in two volumes [11]. To understand visual optics in a fairly sophisticated

way, a single book chapter [12] from 1995 might suffice. Parallel to clinical refraction arises the need to relax active eye focusing accommodation, which has consequences [13,14] for intraocular pressure: a mainstay for managing glaucoma.

Relation to Point-Spread Function [PSF]

At first glance, PSF Bessel-blur profile of a centrally bright dot-like object such as the Airy disc pattern on the retina can be considered appropriate as a model for clinical refraction. However, the human eye focusing system seems to prefer targets that resemble figure-ground segregated real objects such as a Maltese cross, in comparison to monotonic sinusoid patterns [15]. Even though implicit knowledge of projective geometry is NOT hard-wired in the visual system [16] monocular depth cues are generated by local contrast features compared globally across a larger space [17,18] representing retinal topographic projection as a function of eccentricity from central-of-the-macula fixation.

Relation to Projective Geometry and Cognition

In recent years, topographic analysis of retinal anatomy and point-by-point visual projection has been subjected to mathematical algorithms to develop a robust model utilized for calibration of retinal camera technology [19]. However, the complexity of perceptual psychology of spatial invariants was demonstrated in early pioneering work [20] and much today still remains unresolved. Fortunate for clinical subjective refraction is the fact that simple target geometry with high contrast targets as a function of retinal projective geometry is somewhat easier to bring into prediction by mathematical methods [21] than cognition: the latter being influenced by emotional stimuli [22,23] for which many more historical and contextual cues are needed to prevent being misunderstood when the real mutual objective is interpreting communication for creative collaboration [24,25].

Relation to Spectrally Delimited [Monochromatic] Targets

The difference of focus position along the viewing axis through the eye pupil [7] of red [610 nanometer] versus green [530 nm] color background of the duochrome test is around 0.5 dioptre. The design of this test [26] and its widely accepted usage by dispensing opticians, technicians, optometrists, and ophthalmologists: has assumed for more than sixty years past, that eye focusing internal lens accommodation remains equally stable for a black versus white pattern compared to a black versus green or a black versus red pattern. Such assumed stability and assumed equal control of eye muscle focusing dynamics [despite diverse illumination spectra] has been demonstrated patently false [27-30]. Much of the experimental monochromatic visual target evidence [for instability of active focus changing and maintaining feedback retinal control of internal biological lens curvature] is derived from studies published between 1951 and 1993 [15,31]. It is interesting that spatially superposed [2-channel] red plus green monochromatic illumination of an alternating consequent yellow-black linear grating pattern of black plus white cross section appearing across the central six (6) degrees centre on the fovea pit provides synchronous stimulus to accommodative eye muscle action: with progressive dependence [32] upon normal values of axial chromatic focus displacement.

CLINICAL RELATIONS TO RETINAL SPACE PROJECTION OF EDGES

Analytical Substrate for Edge and Linear Contours

Edges appearing as perceived by the brain can be formed by real and continuous uninterrupted contours and also by interrupted contours. Such latter perceived but unreal edges are the result the brain's assumption that mostly all real objects possess the property of being delimited in space by a closed external contour envelope. Linear narrow rectangles possess the attribute of orientation when projected across the eye pupil to x-y coordinate system at the retinal surface. Although such oriented linearly extended objects require larger spatial local interactions than have [thus far] been experimentally demonstrated by single unit neuronal recordings from the retina, it might be premature to assume zero encoding of oriented narrow rectangles in the pre-cortical neurology.

Lighted Vision Versus Dim-Light Vision

Dotted with photoreceptor cells of mostly photopic [cone] and mostly scotopic [rod] visual sensitivity, the retina possesses associated functional significance for sky daylight ambient illumination versus moonlit ambient illumination, respectively. Excitation of bipolar and ganglion cells is NOT NECESSARILY THE ONLY DIRECT PATH through the optic nerve to lateral geniculate for sensory and motor visual mechanisms. Further elucidation could be relevant for diagnostic application development to evaluate and quantify reading disability and normal departures from reading comprehension. In between, the medulla oblongata motor neuron controllers of the eye pupil and eye muscles participate alongside the lateral geniculate and other nuclear complexes. Top-down effects from the cognizing brain to the locally interpreting retina, are not well documented.

INNOVATION OPPORTUNITY

Comparison Lens Magnitude and Letter/Pupil Size

Magnitude of lens for subjective discrimination must follow established physics of optical modulation transfer and physiology of contrast detection as it changes by spatial scale. Patients with reduced retinal function are difficult to refract partly because smaller Sloan letters get washed out. Even for letter as large as 20/120, focus alteration comparison lens magnitude of one dioptre [sphere or cylinder] might not be detectable if diabetic changes have altered photoreceptor geometry and synapse integrity in the central (macular) retina with consequential elevated detection threshold for contrast decrement. Comparison lens magnitude must be increased for smaller pupil diameter, and matched with target spatial scale. Lowest discriminated lens that enables faster patient response would perhaps be of 50 percent greater dioptre value than psychophysically determined depth of focus.

Target According to Optic Array Pattern and Retinal Sensation

The polar coordinate object-plane orientations of letter target components have muddled linear and curved contour elements that are difficult to analyze and quantify by Fourier and Fractal methods. This can be overcome by using high contrast targets or mid-contrast targets with specified Michelson numerator [being L: Max minus L: Min] division by denominator [being L: Max plus L: Min] luminance contrast ratio [as static flux or as dynamic flux].

Contrast transferred from the ambient optic array incident upon the anterior cornea, traversing through the aqueous humour onward intercepted at the eye pupil margin: is affected also by polarizing properties of the collagen composition and shape and spacing of precisely inter-spaced lamellae of the middle layer stroma. Such aggregated collagen sheets enable constructive phase propagation with minimal attenuation. Retinal sensation depends on many factors: some of them metabolic. For any given size and shape of eye pupil, mathematical model approximation for specified eccentricity is considered feasible with certain limitations. This requires convolution of the aperture function with 2-D size [33] and retinal interactions by eccentricity [34]: both being sensitive to retinal spatial sensitivity to contrast decrement from focus blur.

Plus, to Blur Determines Hyperfocal Endpoint for Eye Refraction

Clinical protocol for subjective eye refraction did not alter much at year 2019 compared to textbook methods [35] from the year 1979: through a span of 40 years. Refraction endpoint is most often mandated to be "Hyperfocal," as a standard of care protocol for licensed optometry practice. The hyperfocal refractive endpoint requires that plus power added by sudden lens increment necessarily decreases perceived sharpness and/or clarity of the Sloan letters. However, practice protocol and most professional medical college education for eye physicians and surgeons does not as yet train the clinician with respect to blur detection retinal sensation thresholds. Neither is the training directed toward emphasis on larger targets as opposed to targets near the acuity spatial detail threshold.

From clinical experience, most practitioners might agree that It is no mystery that a hyperfocal refracted eye having spatial detail discrimination at 20/20 should washout three lines of acuity when +1.00 D is added [5 mm pupil]. In comparison, for a smaller pupil: two lines of acuity might washout instead. From second column of Tables below: it appears evident that added plus lens focusing blur [up to perhaps 1.20 D] does not washout text until around 4-degree peripheral viewing eccentricity from macula center. Tables 1 and 2 below has modulation transfer optics to the nearest 0.2 dioptre for letter targets 20/20 to 20/640.

Table 1: Contrast Modulation Dioptre Optics [~ 67% Decrement]

Acuity	Subtense	4 to 6 mm	2 to 4 mm	1 to 2 mm
20/20	5 arc-min	0.40 D	0.60 D	0.80 D
20/40	10 arc-min	0.80 D	1.00 D	1.20 D
20/80	20 arc-min	1.60 D	2.00 D	2.40 D
20/160	40 arc-min	2.40 D	3.00 D	3.60 D
20/320	80 arc-min	3.20 D	4.00 D	4.80 D
20/640	160 arc-min	4.00 D	5.00 D	6.00 D
Column 1 and 2: Spatial Scale; Column 3 to 5: Washout Dioptre [67%]				

Table 2: Column one [position] tabulates eccentric degree of upper field visual space along retinal anatomy below foveal attention to fixational target [along inferior retina].

Position	Acuity [Blur]	Optimal Size	Avoid Target
Fovea	20/20 [0.40]	5 arc-min	Blue on Black
2 deg	20/40 [0.80]	10 arc-min	Black on White
4 deg	20/80 [1.20]	20 arc-min	Black on Blue
8 deg	20/160 [1.60]	40 arc-min	White on Black
16 deg	20/240 [2.00]	60 arc-min	Yellow-Black
32 deg	20/360 [2.40]	90 arc-min	Orange-Black
Retinal Acuity for Upper Field Eccentric PositionS			

CONCLUDING REMARKS

Most clinical refraction protocols employed today in eye clinics run by optometrists, ophthalmologists, retina specialists, and by dispensing opticians: do NOT adequately comply with established optical effects known to engineers and advanced graduates studying white light focusing optics.

It might be difficult and ambitious to expect precise convolution of the aperture function with retinal sensation threshold: even for a geometric target. But standard alphanumeric optotypes do not accurately lend themselves for such 2-D image descriptors; being made from curvy, undefined orientation segments. Instead, finite thickness linear oriented targets arranged in a pattern can be subjected to Fourier and fractal geometric constituent analytic process. Such patterns can be moved in telescopic optics to enhance customer experience and help obtain reliable eyeglass prescribing for centrally impaired retina.

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