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The Effect of Induced Intraocular Stray Light on Recognition Thresholds for Pseudo-High-Pass Filtered Letters

Nilpa Shah[1], Steven C. Dakin[1,2], Pádraig J. Mulholland[1,3], Kalina Racheva[4], Juliane Matlach[1,5], and Roger S. Anderson[1,3]

[1] NIHR Biomedical Research Centre at Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology, London, UK
[2] School of Optometry & Vision Science, University of Auckland, Auckland, New Zealand
[3] Centre for Optometry and Vision Science, School of Biomedical Sciences, University of Ulster at Coleraine, N Ireland, UK
[4] Institute of Neurobiology, Bulgarian Academy of Sciences, Sofia, Bulgaria
[5] Department of Ophthalmology, University Medical Centre, Johannes Gutenberg University Mainz, Germany

Correspondence: Nilpa Shah, Moorfields Eye Hospital NHS Foundation Trust, 162 City Road, London, EC1V 2PD, UK.
e-mail: nilpashah@nhs.net

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Purpose: The Moorfields Acuity Chart (MAC)—comprising pseudo-high-pass filtered "vanishing optotype" (VO) letters—is more sensitive to functional visual loss in age-related macular degeneration (AMD) compared to conventional letter charts. It is currently unknown the degree to which MAC acuity is affected by optical factors such as cataract. This is important to know when determining whether an individual's vision loss owes more to neural or optical factors. Here we estimate recognition acuity for VOs and conventional letters with simulated lens aging, achieved using different levels of induced intraocular light scatter.

Methods: Recognition thresholds were determined for two experienced and one naive participant with conventional and VO letters. Stimuli were presented either foveally or at 10 degrees in the horizontal temporal retina, under varying degrees of intraocular light scatter induced by white resin opacity-containing filters (WOFs grades 1 to 5).

Results: Foveal acuity only became significantly different from baseline (no filter) for WOF grade 5 with conventional letters and WOF grades 4 and 5 with VOs. In the periphery, no statistical difference was found for any stray-light level for both conventional and VOs.

Conclusions: Recognition acuity measured with conventional and VOs is robust to the effects of simulated lens opacification, and thus its higher sensitivity to neural damage should not simultaneously be confounded by such optical factors.

Translational Relevance: The MAC may be better able to differentiate between neural and optical deficits of visual performance, making it more suitable for the assessment of patients with AMD, who may display both types of functional visual loss.

Introduction

The ability of the visual system to resolve spatial detail is limited by a combination of optical and neural factors. Visual recognition acuity is conventionally assessed using high-contrast black-on-white letter targets. The complex spatial frequency (SF) spectra of such optotypes render them particularly vulnerable to the effects of phase reversals in the presence of optical defocus,[1,2] making them excellent targets for determining optimal refractive correction. However, testing with conventional optotypes is relatively poor at indicating early visual loss in neural conditions such as age-related macular degeneration (AMD).[3,4] By contrast, the Moorfields Acuity Chart (MAC) consists of pseudo-high-pass filtered letters or "vanishing optotypes" (VOs) first described by Howland et al.[5] Tests conducted with the MAC are more sensitive to functional loss arising from age-related macular degeneration than conventional optotype charts,[6,7] and in very recent investigations, VO recognition contrast thresholds have demonstrated a strong structure–function relationship with retinal–ganglion cell damage in glaucomatous eyes.[8] Previous work has also confirmed that, unlike conventional letters, visual acuity (VA) measured with these VO letters remains robust to optical defocus.[9] This is important as it potentially allows for the MAC to help distinguish the functional consequences of neural and optical loss (at least for defocus).

The intraocular stray light that results from the age-related development of lens-scattering particles results in image degradation that differs from that associated with uncorrected refractive error. Conventional VA measurement has been shown to be only weakly related to intraocular light scatter[10] and can underestimate the real-world visual disability caused by cataract.[11–15]

A commonly reported symptom of cataract is a reduction in visual contrast. Such contrast reduction results from an increase in retinal stray light,[12,16,17] as a consequence of forward scattering of light by the optics of the eye. This, in turn, greatly increases the width of the point-spread function, leading to a "veiling" luminance on the retina. Assessment of other components of visual function, such as spatial contrast sensitivity (CS)[15,18,19] and disability glare,[15,19,20] can provide important information about visual quality, accounting for complaints of poor vision in those whose VA remains normal. Indeed, quality-of-life questionnaires provide information on functional impairment from cataract that VA measures alone do not convey.[11,21,22] Certainly, measurements of binocular CS correlate better with a patient's perceived visual disability than binocular VA measurements.[13] Hess and Woo[23] report that wide angle scatter is associated with a reduction in contrast across all SFs and conclude that this is the source of complaints of significant visual problems in those patients with cataract who maintain a good VA.[24] However, the impact of optical degradation caused by lens aging on VO acuity thresholds is currently unknown.

"Objective" measures of cataract severity include slit-lamp examination, which is dependent on back scatter.[25] The amount of back scatter, however, is not always a good indicator of the amount of forward scatter,[24,26] and thus the appearance of the lens does not always correlate well with the quality of vision. Furthermore, this assessment, while not relying on patient input, is still reliant on the subjective judgment of an examiner. More recently, it has been suggested that stray-light measurement is a better, more objective method for quantifying cataract.[12,17,18,27,28] Valid and highly repeatable measurements of intraocular forward light scatter can be made using a computer-controlled stray-light meter, the C-Quant (Oculus GmbH, Wetzlar, Germany), that employs the compensation comparison method.[12,29]

The present study extends a methodology that has been validated previously[30,31] to investigate the effect of different levels of intraocular light scatter on foveal and peripheral acuity measured with both vanishing and conventional optotypes. Similar to many psychophysical studies, we chose to employ a small number of observers[9,32–37] and to interrogate those observers (both naive and nonnaive) intensively,[38,39] the assumption being that, even though there are subtle quantitative differences between participants, one normal visual system behaves qualitatively similarly to another. We are thus able to examine the effect of the intervention more carefully, with each participant acting as his or her own control. Stimuli were created using different densities of white opacity-containing filters (WOFs). These filters have flat transmission spectra and induce different levels of wide-angle light scatter that is similar to at least some forms of cataract.[40] Thus, the filters allow us to simulate age-dependent increases in light scatter and absorption in carefully controlled quantities and with known characteristics. Our use of induced stray light on a group of relatively young participants permits us to isolate the effect of increased stray light on acuity without the confounding effects of age-related, individually variable loss of neural function.

Methods

Ethical approval for this study was obtained from the UCL Research Ethics Committee, and all procedures adhered to the tenets of the Declaration of Helsinki. Two experienced psychophysical observers (observer A, aged 31 years; observer B, aged 41 years) and one naive observer (observer C, aged 29 years) undertook the acuity tasks. Participants had no significant ocular abnormalities and a VA of 6/5 or better. Refractive error was corrected prior to the start of each testing session using trial lenses for foveal (observer A, −0.25 diopters sphere (DS); observer B, −0.75 DS/−0.25 diopters cylinder (DC) × 100; and observer C, −3.75 DS/−0.50 DC × 180) and extrafoveal testing at 10° eccentricity in the nasal field of the right eye (observer A, plano; observer B, −0.50 DS/−0.25 DC × 100; and observer C, −3.50 DS/−0.50 DC × 180).

VO and conventional letters had a conventional 5:1 size/stroke ratio and were generated using MATLAB (version 7.6; MathWorks, Inc., Natick, MA, USA). Experiments were controlled by an Apple Macintosh computer (Apple, Inc., Cupertino, CA, USA) with stimuli displayed on a γ-corrected high-resolution

Figure 1. The 10 vanishing optotypes comprising the Moorfields Acuity Chart.

(1280 × 1024 pixels) Dell Trinitron P992 CRT monitor (Dell Corp. Ltd, Bracknell, Berkshire, UK). True 14-bit contrast resolution was achieved using a Bits++ video processor (Cambridge Research Systems, Ltd., Rochester, UK), and spatial scaling of the stimuli was done using the OpenGL capabilities of the computer's built-in graphics card (ATI Radeon X1600; AMD, Sunnyvale, CA, USA). Following previous work,[41] VO stimuli of a pseudo-high-pass design were constructed with an inner black core flanked by a white border (of 106.6 cd/m^2) half the width of the central section (Fig. 1), yielding a Michelson contrast of 98%. Vanishing stimuli were presented on a gray background whose luminance (53.3 cd/m^2) matched the mean luminance of the letter. For the conventional black-on-white letters, the white background had a luminance of 113.2 cd/m^2, again yielding a high contrast of 99%. Stimuli were presented for 500 ms. All testing was conducted under low room illumination to avoid screen reflections with a viewing distance of 8 m for all foveal testing and 1.6 m for all peripheral testing. The screen subtended 11.6° × 9.8° and one pixel subtended 0.55 arc min at the closer distance.

Recognition threshold VA was determined using an adaptive staircase procedure (QUEST) for the right eye of each participant, for both conventional and VOs, in the fovea and periphery. Our rationale for testing only one eye of participants was based upon two considerations: (1) the relative interocular difference (or lack thereof) in recognition acuity levels in the participants examined and (2) limiting participant fatigue. Participants performed a 10 alternative forced-choice (AFC) (Sloan letter set) task, reporting the identity of the optotype presented. The initial letter size displayed was 115.8 × 115.8 arc min. The slope (β) of the psychometric function used was set to 3.5 with *gamma* (*guess rate*) and *pThreshold* parameters set to 10% and 75% correct, respectively. Each test run involved 50 letter presentations in total with the final acuity estimate determined from QUEST's built-in maximum likelihood estimation procedure of threshold. Participants were made aware of the letter set available, and the participant's verbal report of the letter identity was entered by the examiner on the keyboard.

These measurements were repeated three times for six different levels of induced stray light (where order of presentation of levels was randomized). Differing levels of induced stray light were created using either one of five white resin opacity-containing filters (filters 1 to 5 in increasing density; LEE Fog Filters, Andover, UK) or with no filter (filter 0). This manipulation was intended to simulate known increases in light scatter and absorption with age (but without the associated and individually variable loss of vision attributable to reduced neural function). A computer-controlled stray-light meter (C-Quant; Oculus GmbH) was used to measure the baseline intraocular stray light (no fog filter), using the psychophysical compensation comparison method[42] and the individual increase in forward intraocular stray light when each of the filters was placed in front of the eye close to the cornea. Values are expressed as log [stray-light parameter] (log[s]), with higher values indicating greater levels of stray light.

Figure 2 demonstrates the increase in stray-light parameter with each increasing grade of filter for an experienced participant (observer A) and a participant naive to psychophysical tests of this nature (observer C). Baseline measures with no filter were within the normal expected range given the age of the participants, and it can be seen that the filters progressively increase the stray-light value as expected. A measure of the reliability of the stray-light value is provided by the C-Quant, and all measurements were found to be within acceptable reliability parameters with expected SD ≤0.08 log units and reliability coefficient (Q) ≥1. Using its normative database, the C-Quant software permits an estimation of the typical age increase that is simulated with each WOF. Filters 1, 2, and 3 increase the stray-light levels of an average 31-year-old (observer A) to that of a 62-, 72-, and 90-year-old, respectively. The last two filters (4 and 5) take the stray-light value into levels expected with significant cataract.[16]

Statistical Analysis

The final threshold letter size under each WOF condition was converted to a logMAR score for further analysis. For the VOs, "stroke width" was considered to include both the central dark bar and surrounding white flanks. The GraphPad Prism statistical analysis package (GraphPad Software, Inc., La Jolla, CA, USA) was used to compare VA thresholds using a one-way repeated-measures analysis of variance (ANOVA), and statistically significant results ($P < 0.05$) were investigated using Bonferroni's multiple-comparison post hoc analysis for selected pairwise comparisons.

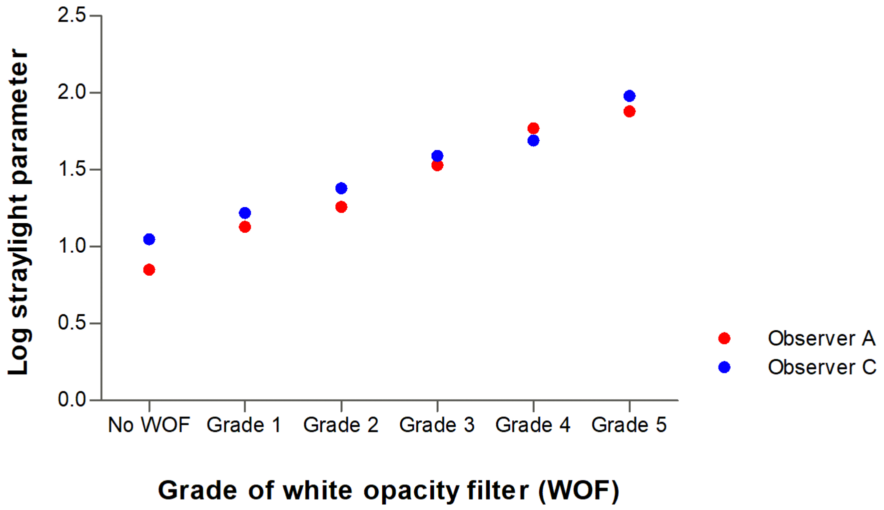

Figure 2. Stray-light values for each WOF measured using the C-Quant stray-light meter. Baseline stray-light value (no WOF) and stray-light values for each filter (filters 1 to 5) are shown for an experienced (observer A) and naive (observer C) participant.

Results

Figure 3 displays the average of the three measured VA thresholds plot against increasing grade of filter. Graphs show data from the experienced (Figs. 2a, 2b) and naive participants (Fig. 2c). Graphs on the left are for foveally presented optotypes, and graphs on the right show data collected using stimuli presented at 10° in the periphery. Error bars show the standard deviation of the three threshold measurements made within a condition.

In line with previous studies,[9,41,43] VA was poorer for VOs than for conventional optotypes across all test conditions and participants. The reason for this is that VOs do not contain significant low SF information, which forces the visual system to rely on higher SF information for letter identification. This ultimately results in a higher estimate of threshold optotype size (i.e., poorer acuity).

In the fovea, VA thresholds for all three participants for each WOF were very similar. The range in VA thresholds for the conventional letters for the different WOFs was −0.16 to −0.07 logMAR for observer A, −0.18 to −0.09 logMAR for observer B, and −0.14 to −0.04 logMAR for observer C. For the VOs, the range was 0.19 to 0.27 logMAR for observer A, 0.18 to 0.27 for observer B, and 0.23 to 0.30 logMAR for observer C. A one-way repeated measures ANOVA on acuity thresholds yielded significant differences with filters from baseline when measured with the conventional letters ($F_{5,2} = 4.90$, $P = 0.016$) and VOs ($F_{5,2} = 15.91$, $P = 0.001$). However, a post hoc Bonferroni's multiple-comparison test indicated that the mean acuity thresholds for the three participants only became significantly different ($P < 0.05$) from the baseline with the final WOF grade 5 for conventional letters and with WOF grades filters 4 and 5 for the VOs.

Acuity thresholds attained at 10° in the nasal field were again similar for all participants. The range for the conventional letters for the different WOFs was 0.52 to 0.57 logMAR for observer A, 0.54 to 0.59 for observer B, and 0.50 to 0.54 logMAR for observer C. The range in acuity for the VOs was 0.78 to 0.80 logMAR for observer A, 0.82 to 0.88 for observer B, and 0.77 to 0.81 logMAR for observer C. No significant difference from baseline was found for any of the WOFs with a one-way repeated ANOVA for both the conventional letters ($F_{5,2} = 3.45$, $P = 0.05$) and the VOs ($F_{5,2} = 0.65$, $P = 0.670$).

Discussion

When investigating the potential use of VOs to detect neural retinal damage specifically, it is important to investigate the robustness of their performance to the possible attenuating effects of the eye's optics. Our previous work has demonstrated VO recognition acuity thresholds to be more robust to the effects of optical defocus compared to conventional letters; this is particularly the case for the periphery compared to the fovea,[9] and we know that patients with AMD increasingly rely on extrafoveal acuity as the disease progresses. The rich spatial-frequency spectra of conventional letters make them particularly vulnerable to the effects of phase reversals caused by optical

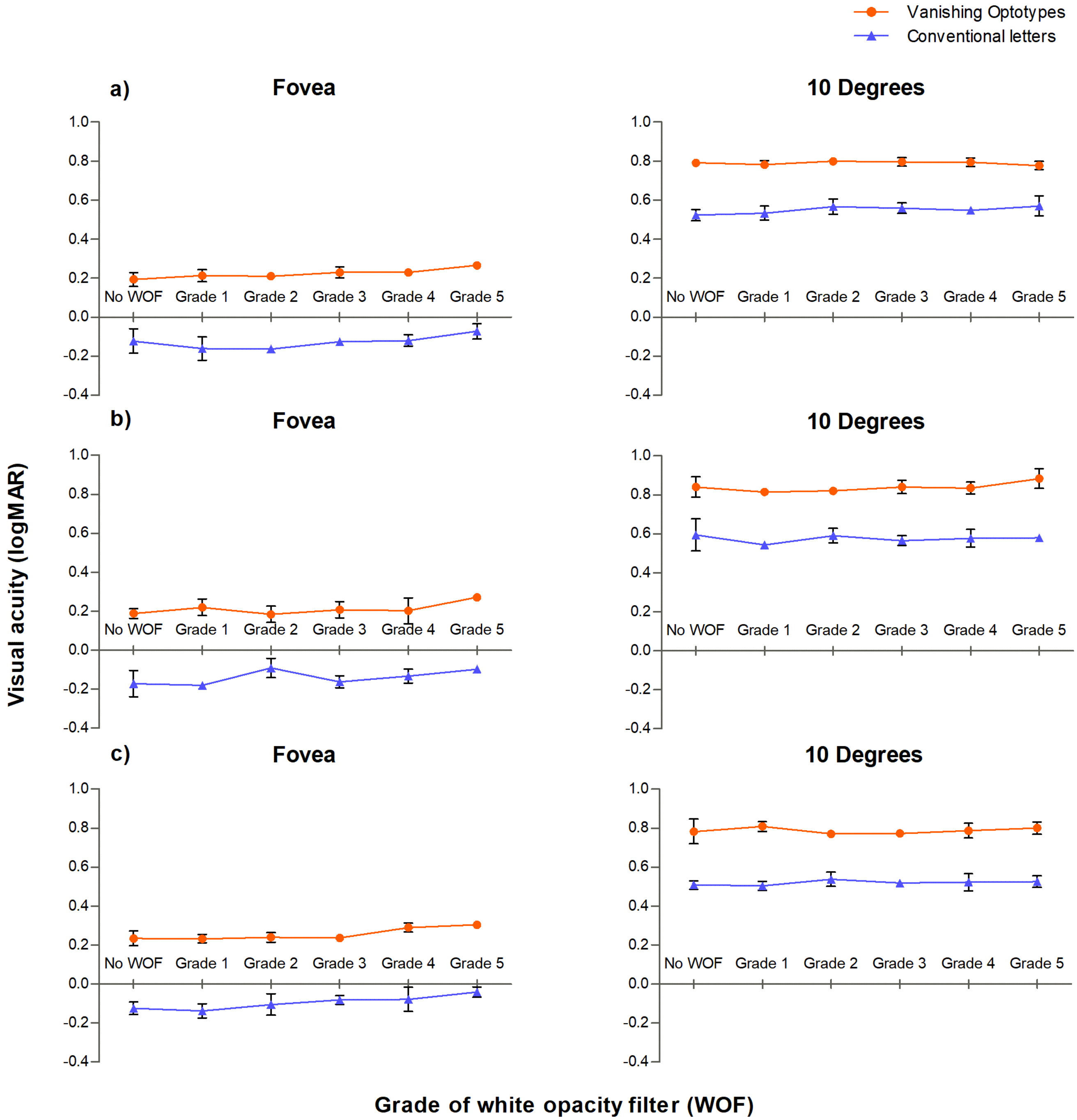

Figure 3. Acuity thresholds, with simple linear interpolation for each WOF, measured with stimuli presented (*left column*) in the fovea and (*right column*) at 10° in the periphery. Results are shown for (a) experienced observer A, (b) experienced observer B, and (c) naive observer C. *Error bars* represent the standard deviation of the three threshold measurements made with each WOF.

defocus,[1,2] and this makes them a very appropriate target in procedures such as refraction. Additionally, while recognition thresholds for VOs in the fovea are limited by the low-pass filtering of the eye's optics, under peripheral viewing conditions, recognition and detection thresholds were found to separate and remained so with even up to +7 D of optical defocus. For peripheral viewing of VOs, this suggests that recognition is limited more by neural sampling than by optics since the lower density sampling array of the peripheral retina means that higher SFs are neurally unresolvable even if well focused optically.[9,44–47]

With regard to light scatter, Van den Berg[10] reported that the point-spread function of the normal aging and cataractous human eye is built upon two quite independent components, with aberrations (including defocus) controlling the central peak and light scattering controlling the periphery from about 1° onward. While the effect of defocus on conventional acuity is quite substantial, Van den Berg[10] confirmed only a small, although significant, effect on visual acuity from light scatter responsible for stray light, even for extreme levels of scattering. This is because the central portion of the point-spread function, which dominates visual acuity, is unaffected by the light-scattering process. Van den Berg[10] demonstrated that aberrations yield light spreading that remains confined to the minutes of arc range, whereas light scatter from the particles extends over degrees. Given the higher spatial frequency content of the VO characters and their typically larger size at resolution threshold, the aim of this study was to investigate if the effect of increasing stray light, in the form of wide-angle light scatter, on VO thresholds might be different from that for conventional letters.

de Wit et al.[16] have demonstrated the validity of simulating cataract-induced stray light by placing a scattering filter in front of the eye. A mean baseline measure of intraocular stray light of 0.95 log[s] was found for our two observers A and C, which agrees with other studies with similar-aged participants.[48]

Figure 3 demonstrates that while statistically significant differences in threshold acuity were found with the densest WOF grade 5 compared to baseline in the fovea for the high-contrast conventional letters, the actual reduction in VA thresholds was only 0.07 logMAR (averaged for all participants). Similarly, for the VOs, a statistical difference was found with WOF grades 4 and 5 compared to baseline in the fovea, and this was an actual reduction of only 0.04 and 0.07 logMAR, respectively (i.e., less than one line on a logMAR chart). The stray-light levels generated with WOF grades 4 and 5 as seen in Figure 2 are those expected only with significant cataract. In the periphery, thresholds with the VOs and conventional letters were found to be unaffected by even the densest WOFs. This is not surprising since resolution acuity for other stimuli with the same mean luminance as their background (gratings) has been shown to be sampling rather than contrast limited outside the fovea, evidenced by the subjective observation of aliasing and, as here, the fact that resolution performance remains flat as stimulus contrast reduces to levels as low as 10%.[45] Thus, it appears that acuity thresholds obtained with either the conventional letters or VOs, both in the fovea and in the periphery, are robust to the effects of simulated lens opacification inducing wide-angle light scatter. This is in line with Van den Berg[10] and other reports suggesting that high-contrast conventional black-on-white letter recognition acuity is a poor indicator of the functional impairment, which may be caused by light scatter.[11–15] It also indicates that—following our previous findings of a higher sensitivity to VA loss in AMD with the MAC[6]—this greater sensitivity to neural loss in AMD should not be confounded by any significant sensitivity to age-related light scatter.

This study simulated wide-angle scatter only and is not intended to predict the performance for all cataracts, which vary in color, location, shape, and density within the lens.[26,49] One of the reasons for using younger participants and employing simulated lens opacification was to avoid the other confounding factors associated with the aging eye and thus limiting the conclusions we can draw about lens opacity in isolation. Although 60-year-old participants may appear to have "no cataractous changes," stray light increases from the 20s onward and would need to be carefully quantified upfront before the addition of any additional opacity. The results suggest that, at least for the conditions explored in this study, only substantial levels of wide-angle light scatter associated with significant cataract reduce the contrast and/or retinal illuminance enough to affect conventional letter and VO recognition performance. This suggests that the MAC could potentially be used to better differentiate between optical and neural causes of visual loss than conventional acuity charts. This study could be extended in future work to compare visual function measured with the MAC, in patients with neural retinal losses both pre- and postcataract surgery to further investigate this.

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References

1. Thorn F, Schwartz F. Effects of dioptric blur on Snellen and grating acuity. *Optom Vis Sci.* 1990;67:3–7.
2. Ravikumar S, Bradley A, Thibos L. Phase changes induced by optical aberrations degrade letter and face acuity. *J Vis.* 2010;10:18.
3. Neelam K, Nolan J, Chakravarthy U, Beatty S. Psychophysical function in age-related maculopathy. *Surv Ophthalmol.* 2009;54:167–210.
4. Qiu F, Leat SJ. Functional deficits in early stage age-related maculopathy. *Clin Exp Optom.* 2009;92:90–98.
5. Howland B, Ginsburg A, Campbell F. High-pass spatial frequency letters as clinical optotypes. *Vis Res.* 1978;18:1063–1066.
6. Shah N, Dakin SC, Dobinson S, Tufail A, Egan CA, Anderson RS. Visual acuity loss in patients with age-related macular degeneration measured using a novel high-pass letter chart. *Br J Ophthalmol.* 2016;100(10):1346–1352.
7. Pondorfer SG, Heinemann M, Wintergerst MWM, et al. Detecting vision loss in intermediate age-related macular degeneration: a comparison of visual function tests. *PLoS One.* 2020;15:e0231748.
8. Wen Y, Chen Z, Chen S, et al. Higher contrast thresholds for vanishing optotype recognition in macular visual fields among glaucoma patients: a structure-function analysis [published online May 24, 2021]. *Br J Ophthalmol.*
9. Shah N, Dakin SC, Anderson RS. Effect of optical defocus on detection and recognition of vanishing optotype letters in the fovea and periphery. *Invest Ophthalmol Vis Sci.* 2012;53:7063–7070.
10. Van den Berg T. The (lack of) relation between straylight and visual acuity: two domains of the point-spread-function. *Ophthalmic Physiol Opt.* 2017;37:333–341.
11. Amesbury EC, Grossberg AL, Hong DM, Miller KM. Functional visual outcomes of cataract surgery in patients with 20/20 or better preoperative visual acuity. *J Cataract Refract Surg.* 2009;35:1505–1508.
12. Van Den Berg TJ, Van Rijn LJ, Michael R, et al. Straylight effects with aging and lens extraction. *Am J Ophthalmol.* 2007;144:358–363.
13. Elliott DB, Hurst MA, Weatherill J. Comparing clinical tests of visual function in cataract with the patient's perceived visual disability. *Eye (Lond).* 1990;4(pt 5):712–717.
14. Zhu X, Ye H, He W, Yang J, Dai J, Lu Y. Objective functional visual outcomes of cataract surgery in patients with good preoperative visual acuity. *Eye (Lond).* 2017;31:452–459.
15. Elliott DB, Bullimore MA, Patla AE, Whitaker D. Effect of a cataract simulation on clinical and real world vision. *Br J Ophthalmol.* 1996;80:799–804.
16. de Wit GC, Franssen L, Coppens JE, van den Berg TJ. Simulating the straylight effects of cataracts. *J Cataract Refract Surg.* 2006;32:294–300.
17. Van der Meulen IJ, Gjertsen J, Kruijt B, et al. Straylight measurements as an indication for cataract surgery. *J Cataract Refract Surg.* 2012;38:840–848.
18. Bal T, Coeckelbergh T, Van Looveren J, Rozema JJ, Tassignon MJ. Influence of cataract morphology on straylight and contrast sensitivity and its relevance to fitness to drive. *Ophthalmologica.* 2011;225:105–111.
19. Superstein R, Boyaner D, Overbury O, Collin C. Glare disability and contrast sensitivity before and after cataract surgery. *J Cataract Refract Surg.* 1997;23:248–253.
20. Rubin GS, Adamsons IA, Stark WJ. Comparison of acuity, contrast sensitivity, and disability glare before and after cataract surgery. *Arch Ophthalmol.* 1993;111:56–61.
21. Steinberg EP, Tielsch JM, Schein OD, et al. The VF-14: an index of functional impairment in patients with cataract. *Arch Ophthalmol.* 1994;112:630–638.
22. Javed U, McVeigh K, Scott NW, Azuara-Blanco A. Cataract extraction and patient vision-related quality of life: a cohort study. *Eye (Lond).* 2015;29:921–925.
23. Hess R, Woo G. Vision through cataracts. *Invest Ophthalmol Vis Sci.* 1978;17:428–435.
24. de Waard PW, IJ JK, van den Berg TJ, de Jong PT. Intraocular light scattering in age-related cataracts. *Invest Ophthalmol Vis Sci.* 1992;33:618–625.
25. Elliott DB, Bullimore MA. Assessing the reliability, discriminative ability, and validity of disability glare tests. *Invest Ophthalmol Vis Sci.* 1993;34:108–119.
26. Gholami S, Reus NJ, van den Berg T. Changes in intraocular straylight and visual acuity with age in cataracts of different morphologies. *J Ophthalmol.* 2017;2017:5649532.
27. Galliot F, Patel SR, Cochener B. Objective scatter index: working toward a new quantification of cataract? *J Refract Surg.* 2016;32:96–102.

28. Sahin O, Pennos A, Ginis H, et al. Optical measurement of straylight in eyes with cataract. *J Refract Surg.* 2016;32:846–850.
29. Cerviño A, Montes-Mico R, Hosking SL. Performance of the compensation comparison method for retinal straylight measurement: effect of patient's age on repeatability. *Br J Ophthalmol.* 2008;92:788–791.
30. Anderson RS, Redmond T, McDowell DR, Breslin KM, Zlatkova MB. The robustness of various forms of perimetry to different levels of induced intraocular stray light. *Invest Ophthalmol Vis Sci.* 2009;50:4022–4028.
31. Bergin C, Redmond T, Nathwani N, et al. The effect of induced intraocular straylight on perimetric tests. *Invest Ophthalmol Vis Sci.* 2011;52:3676–3682.
32. Wang YZ, Thibos LN, Bradley A. Effects of refractive error on detection acuity and resolution acuity in peripheral vision. *Invest Ophthalmol Vis Sci.* 1997;38:2134–2143.
33. Wilkinson MO, Anderson RS, Bradley A, Thibos LN. Resolution acuity across the visual field for mesopic and scotopic illumination. *J Vis.* 2020;20:7.
34. Bex PJ, Mareschal I, Dakin SC. Contrast gain control in natural scenes. *J Vis.* 2007;7:12.1–12.
35. Wallis TS, Bex PJ. Image correlates of crowding in natural scenes. *J Vis.* 2012;12:6.
36. Wardle SG, Bex PJ, Cass J, Alais D. Stereoacuity in the periphery is limited by internal noise. *J Vis.* 2012;12:12.
37. Kartha A, Sadeghi R, Barry MP, et al. Prosthetic visual performance using a disparity-based distance-filtering system. *Transl Vis Sci Technol.* 2020;9:27.
38. Chen G, Pine DS, Brotman MA, et al. Hyperbolic trade-off: the importance of balancing trial and subject sample sizes in neuroimaging. *NeuroImage* 2021;247:118786.
39. Baker DH, Vilidaite G, Lygo FA, et al. Power contours: optimising sample size and precision in experimental psychology and human neuroscience. *Psychol Methods.* 2021;26:295–314.
40. Zlatkova MB, Coulter EE, Anderson RS. The effect of simulated lens yellowing and opacification on blue-on-yellow acuity and contrast sensitivity. *Vis Res.* 2006;46:2432–2442.
41. Shah N, Dakin SC, Redmond T, Anderson RS. Vanishing optotype acuity: repeatability and effect of the number of alternatives. *Ophthalmic Physiol Opt.* 2011;31:17–22.
42. Franssen L, Coppens JE, van den Berg TJ. Compensation comparison method for assessment of retinal straylight. *Invest Ophthalmol Vis Sci.* 2006;47:768–776.
43. Shah N, Dakin SC, Whitaker HL, Anderson RS. Effect of scoring and termination rules on test-retest variability of a novel high-pass letter acuity chart. *Invest Ophthalmol Vis Sci.* 2014;55:1386–1392.
44. Thibos LN, Cheney FE, Walsh DJ. Retinal limits to the detection and resolution of gratings. *J Opt Soc Am A.* 1987;4:1524–1529.
45. Thibos LN, Still DL, Bradley A. Characterization of spatial aliasing and contrast sensitivity in peripheral vision. *Vis Res.* 1996;36:249–258.
46. Anderson RS. Aliasing in peripheral vision for counterphase gratings. *J Opt Soc Am A.* 1996;13:2288–2293.
47. Anderson RS, Ennis FA. Foveal and peripheral thresholds for detection and resolution of vanishing optotype tumbling E's. *Vis Res.* 1999;39:4141–4144.
48. Michael R, van Rijn LJ, van den Berg TJ, et al. Association of lens opacities, intraocular straylight, contrast sensitivity and visual acuity in European drivers. *Acta Ophthalmol.* 2009;87:666–671.
49. Chua BE, Mitchell P, Cumming RG. Effects of cataract type and location on visual function: the Blue Mountains Eye Study. *Eye (Lond).* 2004;18:765–772.