

Effect of Optical Defocus on Detection and Recognition of Vanishing Optotype Letters in the Fovea and Periphery

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PURPOSE. Vanishing optotypes (VOs) are pseudo high-pass letters whose mean luminance matches the background so that they “vanish” when the recognition acuity threshold is reached in the fovea. We determined the effect of increasing blur on acuity for these optotypes and conventional letters, in both foveal and extrafoveal viewing.

METHODS. Detection and recognition thresholds were determined separately for each of the 26 letters of both a conventional and VO alphabet, both in the fovea and at 10° in the horizontal temporal retina, under varying degrees of positive dioptric blur.

RESULTS. In the fovea, detection and recognition thresholds were similar for individual VOs, increased steadily with blur, and separated somewhat at higher levels of defocus (3 diopters [D]). While the recognition thresholds for VOs changed on average by 0.28 logarithm of the minimum angle of resolution (logMAR)/D, those for conventional letters changed more rapidly by 0.35 logMAR/D. In the periphery, recognition thresholds were significantly higher than detection thresholds for the VOs at 0 D blur; both thresholds increased steadily thereafter, converging as blur increased. Peripheral recognition acuity displayed a loss of only 0.09 logMAR/D. In both the fovea and periphery, the interletter variation in recognition acuity was much lower for VOs than conventional letters (0.04 vs. 0.09 logMAR).

CONCLUSIONS. Outside the fovea, high-pass VOs display significant differences in their detection and resolution thresholds up to +7 D blur, with a logMAR/D loss of a quarter that of the fovea. The lower interletter legibility differences indicate that VO letters may be better stimuli from which to design clinical letter charts. (*Invest Ophthalmol Vis Sci.* 2012;53:7063–7070) DOI:10.1167/iovs.12-9864

Any test of visual acuity (VA) should deliver accurate, precise, and repeatable measurements in order to reliably identify significant change in performance resulting from either

abnormality or therapy. There is increasing evidence that conventional letters charts, including logarithm of the minimum angle of resolution (logMAR) charts, are failing to do so, displaying test–retest variability of between 0.06 and 0.19 log units even for normal, focused eyes,^{1–11} with this variability increasing significantly with the presence of optical defocus¹² or retinal disease.¹³

Vanishing optotype (VO) targets, first described by Howland et al.,¹⁴ have a pseudo-high-pass design and are typically constructed of a dark core surrounded by light edges, or vice versa, which results in the mean luminance of the letter matching that of the background. Their construction means that, like gratings, size thresholds for detection and recognition of VOs are closely matched in the fovea when the letters are well focused and, unlike conventional letters, the characters “vanish” almost as soon as the recognition limit is exceeded. However, the relative legibility of VO letters across the whole alphabet has not yet been examined.

Conventional letters make good stimuli to detect defocus in the fovea because their rich spatial frequency spectra make them especially vulnerable to the effects of phase reversals associated with defocus, something which has much less effect on grating acuity.¹⁵ However, the relative vulnerability of VOs to the effects of optical defocus remains unknown.

Many subjects for whom we require measures of letter acuity, such as patients with age-related macular degeneration (AMD), have lost foveal function and view extrafoveally. Although detection and recognition thresholds for VOs are similar in the fovea, numerous studies of peripheral acuity, employing gratings with the same mean luminance as their surround (as with VO letters), have found a significant difference between detection and resolution thresholds outside the fovea, indicating that peripheral grating resolution is limited, not by optics, but by retinal ganglion cell sampling density.¹⁶ Further evidence for the sampling limited nature of peripheral grating acuity comes from the observation that resolution acuity remains robust to optical blur up to 3 to 4 diopters (D).^{17,18} In this study, we also wished to determine the differences in detection and recognition performance for individual letters of VO design in peripheral vision under differing levels of defocus.

Our goals were thus to determine VO legibility on an individual letter basis under foveal and extrafoveal presentation, examine the effect of optical defocus on acuity for VO compared to conventional letters (both foveally and extrafoveally), and determine if differences in detection and recognition performance exist peripherally for individual VO letters under these differing levels of defocus.

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. Testing using both conventional and VO letters was predominantly conducted on two experienced psychophysical

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observers (NS and RSA), with no ocular abnormalities and corrected visual acuities of 6/5 or better. As a control, we also employed a naïve observer when testing under zero-blur conditions.

The VOs were constructed with an inner black “core” flanked by a white border of half the width of the central section. This resulted in a target with the same mean luminance as the background (53 cd/m^2) and an on-screen contrast of 98%. The appearance of several different VOs can be viewed down the left side of Figure 1.

For the conventional letter measurements, black letters were presented on a white background (B/W) of luminance 113 cd/m^2 , thus yielding the same on-screen contrast as the VOs (98%). Since this higher background luminance could potentially introduce an additional influence on acuity estimates relative to the VO test conditions, control measurements were also made with white letters on the same gray

background (W/G) as the VOs (53 cd/m^2) in the zero defocus condition. While this afforded the same individual retinal illuminance as for VO letters, it resulted in a lower on-screen contrast of 35%.

All letters had the same outline form. For both stimulus types, the letter height and width were five times the “stroke width,” which in the case of the VOs incorporated both the dark middle bar and its two white flanks. All optotype stimuli were generated using MATLAB v7.6 (MathWorks, Inc., Cambridge, UK) and were presented on a high-resolution (1280×1024 pixels) Dell Trinitron P992 CRT monitor (Dell Corp., Ltd., Bracknell, Berkshire, UK) driven by an Apple Macintosh computer (Apple, Inc., Cupertino, CA). True 14-bit contrast resolution was achieved using a Bits++ video processor (Cambridge Research Systems, Ltd., Rochester, UK).

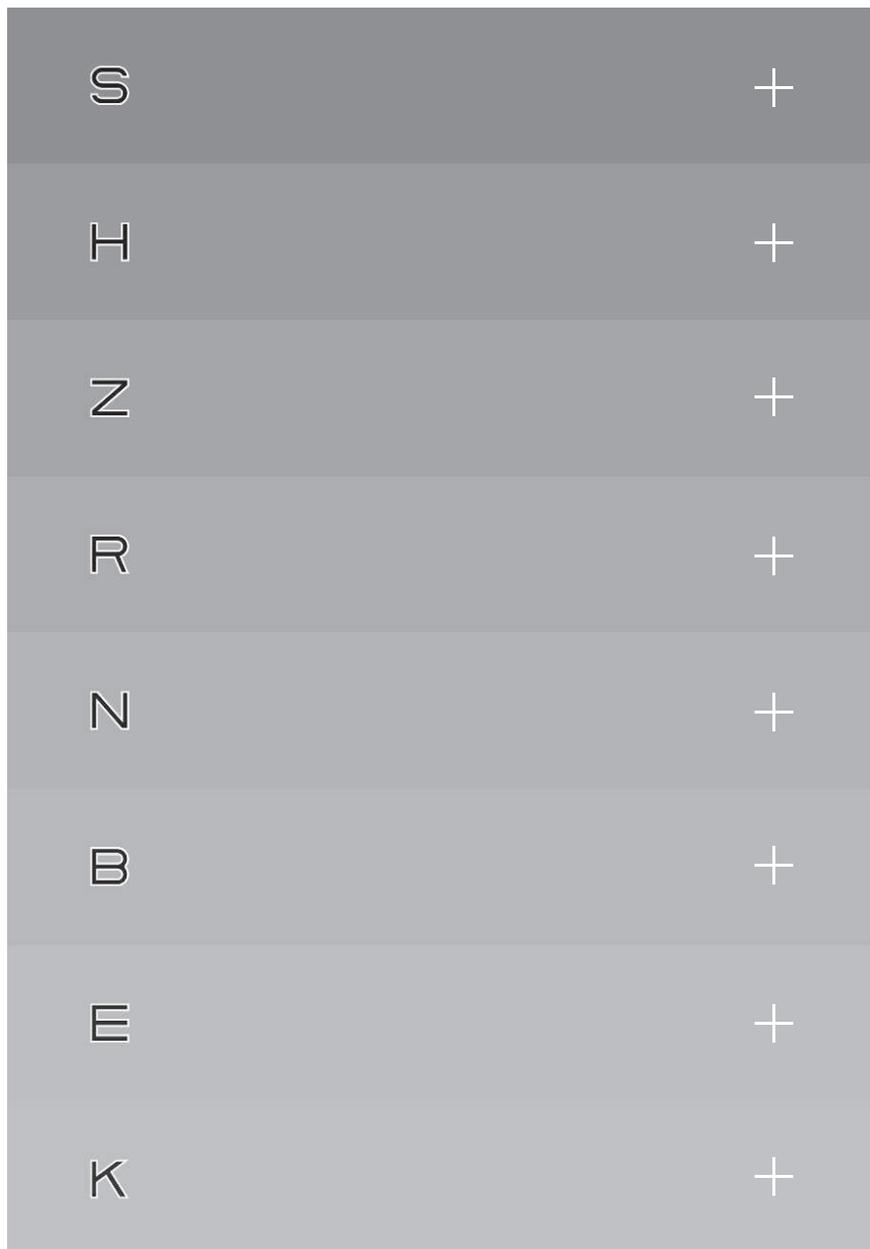


FIGURE 1. The left side displays different VO letters under different gammas. While covering one eye, the reader should observe the figure at a distance of around 4 m (or less if not fully corrected optically) and choose the letter with the appropriate gamma so that it disappears into the background. Next, at a distance of 50 cm, the reader should observe this same letter extrafoveally while fixating the cross to its right (to achieve a viewing angle of 10°). It should be observed that, while difficult to resolve, the letter is clearly detectable.

Scaling of stimuli was achieved using the OpenGL capabilities of the computer's built-in graphics card (ATI Radeon X1600). This (bilinear interpolation) procedure allowed us to display stimuli of arbitrary size with subpixel resolution while retaining accurate representation of their (balanced) luminance structure.

Foveal and peripheral VA measurements were made monocularly in the right eye of both subjects, using both conventional and VOs. All peripheral measurements were made at 10° eccentricity in the nasal field. This eccentricity was chosen, on the one hand, because the peripheral refractive error of both subjects differed little from that of the fovea at that location and, on the other hand, to prevent larger, defocused letters from encroaching on the fovea. In addition, it is not uncommon to find patients with AMD displaying a preferred retinal locus around this eccentricity.¹⁹

The refractive error was determined and corrected prior to the start of each testing session using trial lenses which were employed for both on- and off-axis testing. Little difference was found between the two locations (subject NS -0.25 diopters sphere [DS] fovea, 0 DS periphery; subject RSA +0.50 DS for both fovea and periphery). All foveal testing was conducted under low room illumination at a viewing distance of 8 m, at which the letters could vanish without pixilation effects. All peripheral testing was conducted under the same conditions at 1.6 m; at this near distance the screen subtended 11.6° × 9.8° and one pixel subtended 0.55 minutes of arc.

Each subject underwent the following tests: detection and recognition of conventional optotypes (both B/W and W/G) and detection and recognition of VOs, under foveal and peripheral viewing conditions (i.e., 12 test conditions in total). Detection and recognition tasks were conducted in separate runs.

All 26 different alphabet letters were used for each test condition. In the detection tasks using the method of limits, a letter was initially displayed at subthreshold size and the observer moved the computer mouse to progressively increase the letter size until the optotype was just visible, which they indicated by clicking the mouse button. In the recognition task, the observer was again requested to increase the size of the optotype, but this time was required to indicate the letter size when the letter identity was just discernable. The observer then verbally reported the letter identity to the experimenter; if the letter identity was incorrectly reported, the observer was required to continue increasing the size until able to correctly identify it. Viewing time was not restricted and five presentations were made, in a randomly interleaved order, for each letter of the alphabet under each condition.

We chose to employ an ascending method of limits (MOL) rather than forced choice procedures for nearly all of the testing. The reasons for this were several. First, employing forced-choice procedures in an individual-letter comparison experiment requires 26 different interleaved staircases resulting in more than 800 presentations for each run. When this is undertaken for both detection (two intervals per presentation) and recognition, and for each of eight blur conditions in both the fovea and periphery, this procedure inevitably introduces enormous variability as a consequence of observer fatigue. Second, it becomes more difficult to quantitatively compare detection and recognition thresholds because the thresholds would be measured under different forced choice conditions (two interval forced choice for detection, 26 alternative forced choice for resolution) yielding a different guess rate and potentially boosting performance for the smaller number of alternatives (detection). Third, in previous experiments²⁰ we observed that circular letters, such as O and Q, are most commonly confused with each other and can behave as something of a subset within a 26 alternative test. If, under forced choice conditions, an observer is able to determine that a letter is round, but unable to precisely identify which one, he or she will often bias towards a particular letter (e.g., O) thus artificially boosting "performance" for that letter. Under MOL procedures, rather than forcing a decision, the letter must be increased in size until the observer can more confidently report its identity, yielding a truer threshold for that individual letter. Finally, lacking previous similar

high-pass letter studies, we had no prior expectations of which of the 26 letters, if any, might display differences between detection and recognition acuity, thereby affecting our criterion. However, in order to assess the possibility that criterion-based methods may permit bias of the results in nonnaive observers, for comparison and control purposes, we employed forced-choice reversal staircase procedures (QUEST) in the zero-blur condition for one of the trained observers.

In the second stage of the study, both observers repeated the task with levels of defocus increasing, from their initial refraction, in +1 D steps to a maximum of +3 D under foveal viewing conditions and +7 D under peripheral viewing conditions (beyond +3 D of foveal blur the letters became too large to be generated on the screen at the test distance employed). Detection and recognition thresholds were measured in the same way as described above for the VOs, but only recognition thresholds were measured for B/W conventional letters.

The average detection and recognition size was recorded and converted to logMAR where, for the VOs, the stroke width was taken to include both the central dark bar and its white flanks.

RESULTS

Figure 2 displays both the detection and recognition values for the VOs, and the recognition values for conventional letters, presented under different levels of blur in both the fovea (Fig. 2a) and at 10° (Fig. 2b). Each point is the average across the 26 letters and both subjects. Error bars represent the SD of the 26 letter thresholds under each blur condition, averaged for both subjects.

Performance for recognition of conventional letters was significantly "better" than either detection or recognition performance for the VOs at zero blur (-0.01 logMAR vs. 0.11 and 0.14 logMAR; $P < 0.0001$, one-way ANOVA). Under foveal viewing conditions, detection and recognition thresholds for VOs were similar, increasing steadily with blur and separating somewhat at higher levels of defocus. However, while the recognition thresholds for VOs changed by 0.28 logMAR/D on average, those for conventional letters changed more rapidly by 0.35 logMAR/D so that, after +1 D blur, performance was "worse" for conventional letters than VOs ($P < 0.01$, paired t -test). The same pattern was observed for both subjects.

At 10° in the periphery (Fig. 2b), recognition thresholds for the conventional letters is again lower than for the VOs at 0 D blur and increases roughly in parallel with it as blur increases, converging somewhat at +7 D. Recognition thresholds were significantly higher than detection thresholds for the VOs at 0 D blur (0.85 vs. 0.56 logMAR; $P < 0.0001$, one-way ANOVA test). Thresholds for recognition appear to be little affected until around +1 D blur but increases steadily thereafter, resulting in a change of approximately 0.09 logMAR/D over the full 7 D blur range.

The lower part of Figure 3a displays the detection and recognition values for the individual B/W conventional-form letters in the fovea for 0 D blur (average of both subjects). Unsurprisingly, and owing to the large difference between the mean luminance of the letters and the background, both subjects displayed significantly lower detection thresholds than recognition thresholds (mean -0.59 logMAR for detection and -0.01 logMAR for recognition; error bars represent the SE of the five threshold measurements for each letter). It can also be seen that there are significant between-letter threshold differences for both detection and recognition, with detection displaying significantly less variation than recognition (SD 0.04 vs. 0.09 logMAR, mean of both subjects). For recognition, the highest thresholds were observed for the circular letters (CGOQ), which seemed to behave as a separate subset. For the W/G conventional letters (not plotted), performance was qualitatively and quantitatively very similar to that for the

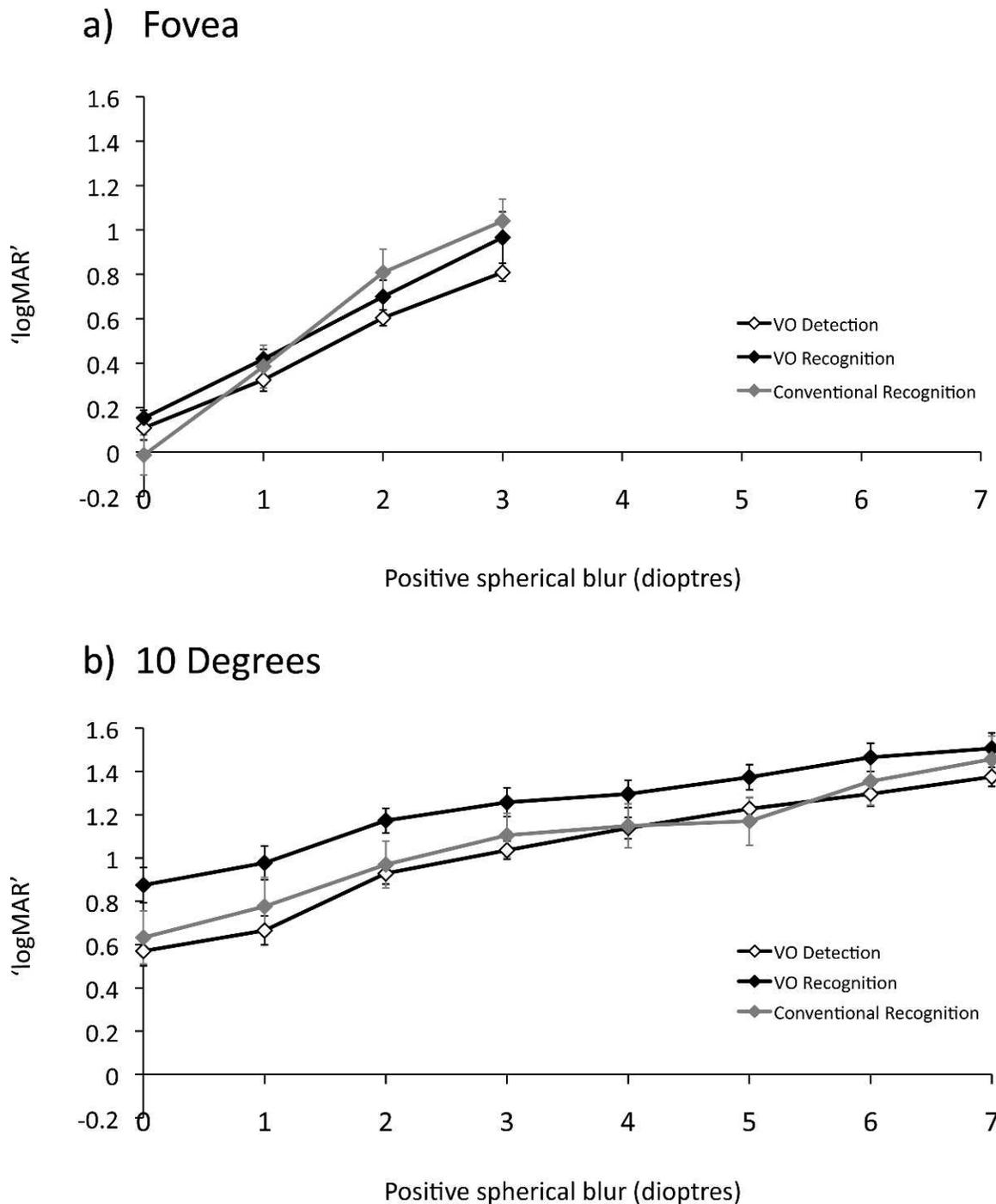


FIGURE 2. The detection and recognition thresholds for the VOs, and recognition values for the B/W conventional letters under different levels of blur in (a) the fovea and (b) 10° (average across the 26 letters and both subjects). *Error bars* represent the SD of the 26 letter thresholds (mean of both subjects).

higher contrast B/W letters, the only observable difference being slightly increased thresholds for letter detection than in the B/W case (-0.47 rather than -0.59 logMAR).

We already noted that the VOs display very similar average detection and recognition performance in the fovea, but the lower part of Figure 3b indicates that this also applies on an individual letter basis. As a consequence, while the SD of the between-letter differences for detection is similar to conventional letters (0.05 vs. 0.04 logMAR), the variation for recognition is much lower with VOs (0.04 vs. 0.09 logMAR,

mean of all letters and both subjects). Results under forced-choice staircase conditions, and for the naïve observer, were qualitatively similar but are not shown.

Looking at the results under peripheral viewing, the conventional B/W letters (Fig. 4a) display even larger differences between detection (mean -0.08 logMAR) and recognition (mean 0.63 logMAR) than in the fovea. Between-letter threshold differences display the same degree of variation as in the fovea for detection (SD 0.03 logMAR) and slightly greater variation for recognition (SD 0.12 logMAR),

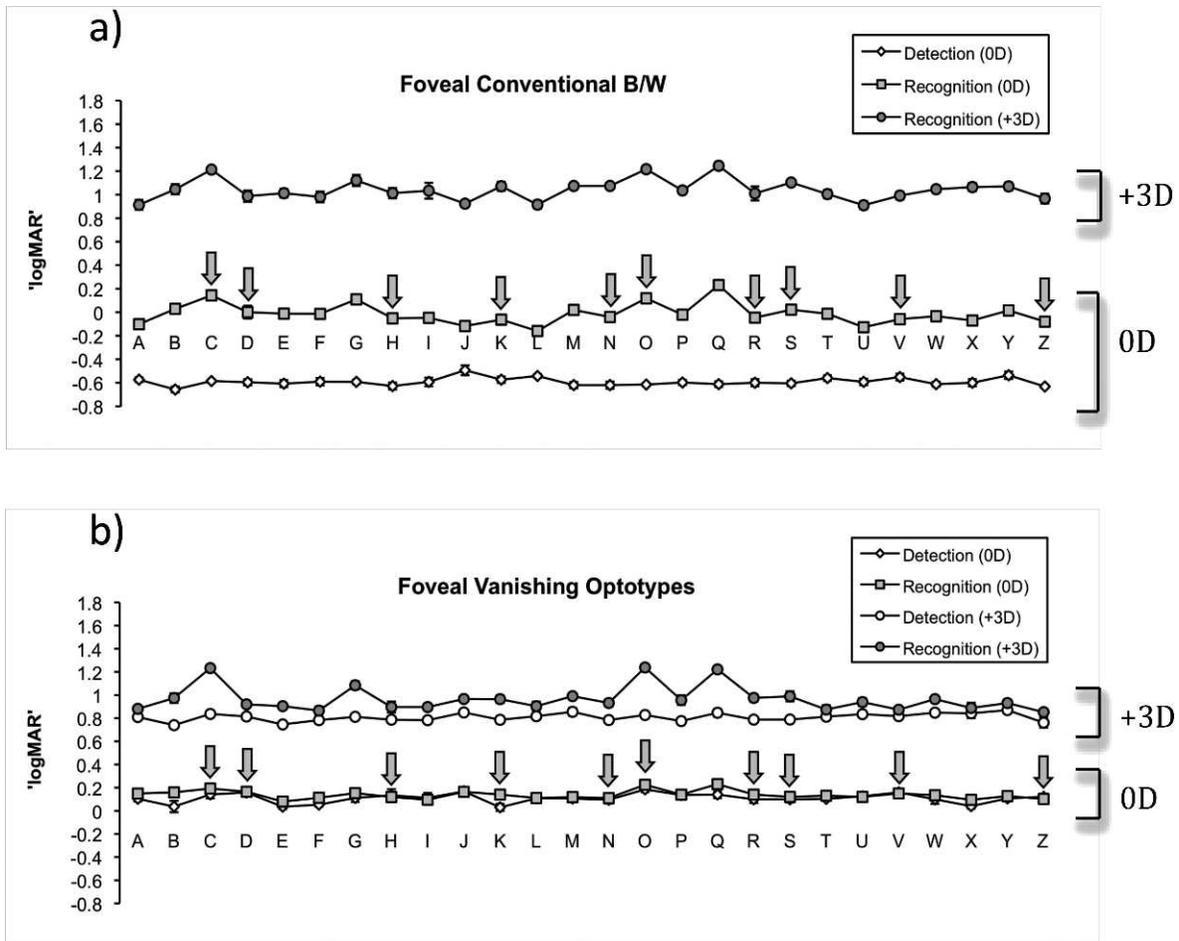


FIGURE 3. The lower part of (a) and (b) displays the detection and recognition values under 0 D blur in the fovea for the individual (a) B/W conventional letters and (b) VOs (average of both subjects). The upper part displays the (a) recognition values for the B/W conventional letters and (b) detection and recognition values for VOs under +3 D blur. Error bars represent the standard error of the five threshold measurements of each letter (average of both subjects). The arrows indicate thresholds for the set of 10 Sloan letters.

with the circular letters again displaying the highest recognition thresholds. The W/G letters again displayed very similar qualitative and quantitative performance to B/W and are not plotted.

Unlike in the fovea, the VOs exhibit quite large differences between detection and recognition thresholds in the periphery, for all letters and for both subjects (Fig. 4b, lower part). The magnitude of this difference again varied with the letter in question. While the performance variation between letters was higher than in the fovea for these optotypes (SD 0.07 logMAR for both detection and recognition), performance variation for recognition was notably lower than for conventional letters at the same location. Acuities and SDs for all tasks at 0 D blur are summarized in the table. Again, results under forced-choice staircase conditions and for the naïve observer were qualitatively similar but are not shown.

The upper half of Figure 3a displays the letter recognition thresholds for individual B/W conventional letters under the maximum +3 D blur conditions in the fovea. While performance fell by an average of 1.05 logMAR under +3 D blur, the between-letter variability displays a very similar pattern to zero blur.

The upper half of Figure 3b displays both detection and recognition thresholds for the individual VOs in the fovea. Interestingly, it can be seen that the detection and recognition

thresholds increasingly separate with increased blur, most noticeably for the circular letters (CGOQ), which again begin to behave as a separate subset.

The upper parts of Figure 4a and 4b display the corresponding results for the periphery with the maximum +7 D of blur. For conventional letters (Fig. 4a), recognition performance on average decreased by 0.83 logMAR over this range, with a between-letter standard deviation very similar to 0 D blur (0.11 logMAR). The circular letters (CGOQ) again appear to behave as a separate subset.

For the VOs (Fig. 4b), both detection and resolution performance declined with blur, but detection more so. The 0.29 logMAR average difference observed between the two thresholds at 0 D blur narrowed to 0.13 logMAR at +7 D blur.

DISCUSSION

In a previous study,²⁰ we found that acuity thresholds measured with VO letters were less variable than corresponding measures made with conventional letters. Furthermore, we found that acuity estimates with VOs varied less with the number of available alternatives. In explaining this finding we proposed that attenuating the low spatial frequency components renders the letters more equally resolvable, and this in

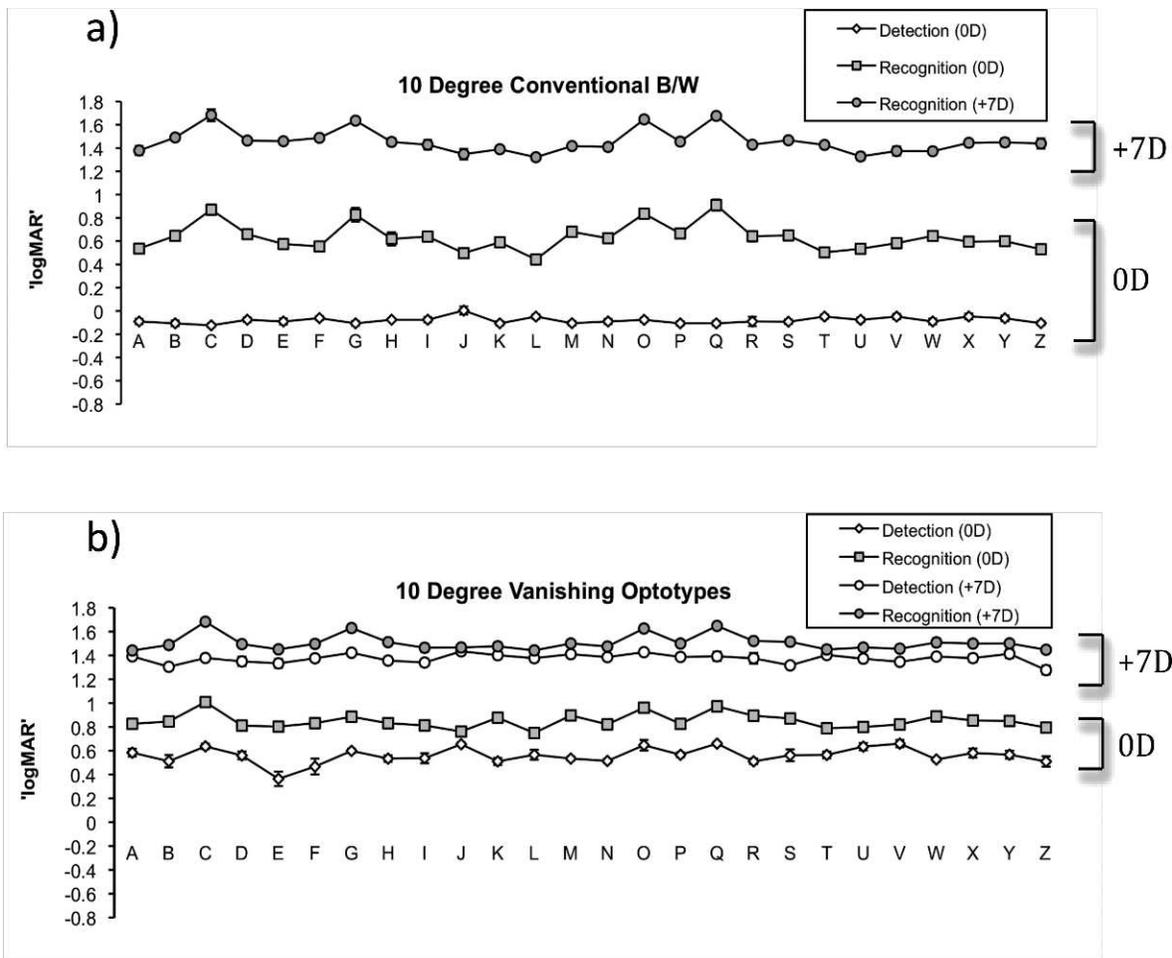


FIGURE 4. The lower part displays the detection and recognition values under 0 D blur in the periphery for the individual (a) B/W conventional letters and (b) VOs (average of both subjects). The upper part displays the (a) recognition values for the B/W conventional letters and (b) detection and recognition values for VOs under +7 D blur. Error bars represent the standard error of the five threshold measurements for each letter (average of both subjects).

turn results in lower variability in acuity thresholds based on letter discrimination.

In the current study we sought to separately measure the detection and recognition acuity thresholds for these optotypes on an individual basis, under both foveal and extrafoveal viewing. This allowed us to, first, determine if between-letter performance was in fact less variable than for conventional letters and, second, to determine if detection and recognition thresholds continued to be closely similar outside the fovea for these letters, and at different levels of blur.

It is apparent from Figure 2 that, in agreement with our previous study, foveal acuity thresholds for VOs were significantly larger than for conventional letters in the focused condition. This was not surprising given that most of the low frequency information was removed from the stimuli, requiring the letter to increase in size in order for the visual system to

utilize the higher frequency content. Surprising, however, is the observation that, while threshold letter size for VO recognition was larger in the focused condition, it became slightly, but significantly, smaller than for conventional letters as defocus increased above 1 D. Why might this happen? Since the high-pass VO letters contain less information at low frequencies, in the focused state they must necessarily become initially larger so that these higher object frequencies become lower in terms of retinal frequency in order for the visual system to resolve them and recognize the letter. When letters become progressively defocused, it is the higher retinal frequencies that first start to phase-reverse, which some previous studies have claimed results in masking of the lower frequencies, making the letters increasingly difficult to resolve.²¹ However, other computational studies have found that this is not necessarily the case. Akutsu et al.²² reported

TABLE. Summary of the Detection and Recognition Thresholds and Standard Deviations (Average of Both Subjects) for All Tasks under 0 D Blur Conditions

Acuity logMAR	B/W Detection	B/W Recognition	W/G Detection	W/G Recognition	High-Pass Detection	High-Pass Recognition
Fovea	-0.59 ± 0.04	-0.01 ± 0.09	-0.47 ± 0.05	0.01 ± 0.09	0.11 ± 0.05	0.14 ± 0.04
Periphery	-0.08 ± 0.03	0.63 ± 0.12	0.02 ± 0.06	0.73 ± 0.11	0.56 ± 0.07	0.85 ± 0.07

that removing the spectrum above the first cut-off of the optical transfer function had little effect on defocused letter VA. Ravikumar et al.²³ found that, in the presence of positive spherical aberration, the impact of phase correction on letter acuity depended on the sign of the defocus. For positive defocus (as in the present study), the impact on VA was not significantly different for standard, phase-rectified or low-pass filtered defocus, leading them to conclude that the primary cause of acuity loss for positive blur was contrast reduction; however, that was for conventional letters. For VO letters it may be that phase reversal of the higher frequencies, which make up the lighter edges of the stimuli, causes the edges to become darker and results in the letter strokes effectively becoming thicker and the letter more discriminable. However, it is beyond the scope of the present study to fully determine why performance for heavily defocused VO letters is actually "better" than for conventional letters.

The results found in the periphery provide interesting additions to our knowledge from previous studies. Unlike in the fovea, there is a significant difference between detection and recognition performance for VO letters, indicating that these letters do not, in fact, vanish extrafoveally. This is in agreement with our previous studies using high-pass targets with lower numbers of alternatives.^{24,25} The "vanishing" adjective may, therefore, be somewhat of a misnomer under these conditions. These letters behave in a partially similar manner to that found in previous studies that employed peripheral gratings with the same mean luminance as their surround. A superiority of detection acuity over recognition or resolution acuity for targets with the same mean luminance as their background, is strong evidence that the resolution task is, for the majority of letters, limited by retinal sampling rather than the eye's optics.

However, we found the effect of optical defocus on these letters to display both similarities and differences to the effects found with gratings.^{17,18} While the effect of optical defocus was substantially less outside the fovea for both the conventional and VO letters, displaying a logMAR/D loss of only approximately a quarter of that observed in the fovea, the recognition acuity was not quite so robust to blur with VOs as observed in previous studies using gratings. This may be because, unlike for gratings, retinal sampling is not the only significant limiting factor involved in peripheral viewing. While grating appearance remains largely veridical under optical phase reversal, the increasingly spurious appearance of the letters with increasing defocus renders the letter more ambiguous to the underlying retinal ganglion cell mosaic. Also, while the previous studies found that grating detection and resolution performance are identical by around 3 to 4 D defocus, there remains a difference between the two thresholds for high-pass letters all the way up to 7 D (Fig. 2b); again, this is likely because the spuriously defocused letter permits the eye to detect the presence of contrast that may not be sufficiently veridical to resolve. This would seem to also occur somewhat in the fovea where, as defocus increases, the detection and recognition thresholds of the VO begin to separate somewhat (Fig. 2a).

Looking at the individual letters more closely, we found that, under zero defocus (lower half of Fig. 3a), there were considerable differences in the recognition thresholds (gray squares) for different conventional letters, with an interletter range of 0.40 logMAR. The result was the same for W/G as for B/W letters. This variation was even greater under forced choice conditions (0.99 logMAR). When considering only the Sloan letters (vertical arrows) the legibility range reduces to 0.22 logMAR (SD 0.08 logMAR, mean of subjects), but this is still much greater than the desired 0.1 logMAR difference between lines on a conventional logMAR chart. These legibility

differences were similar to those found in previous studies²⁶ and further called into question the widespread acceptance that the Sloan letters are closely equal in legibility. As expected, the circular letters (CGOQ) displayed the lowest acuities and appeared to behave as a separate subset, or even as a pair of subsets (e.g., OQ and CG), likely owing to the close similarity to each other and strong dissimilarity to the other letters. The current findings support the notion that, when the within-line recognition differences become greater than the between-line differences, acuity measurement variability results. This was discussed by McMonnies and Ho²⁷ who found that chance combinations of easy or difficult letters can lead to significant line-difficulty variation. By reducing the within-line differences, we could reasonably expect test-retest variability to improve. For this reason, it may be possible to choose a different set of letters from the Sloan ones, with more closely similar legibility. Grimm et al.²⁸ have summarized some previous studies that have attempted to do this.

The VOs (Fig. 3b), however, in addition to displaying closely similar detection and recognition thresholds for all letters, displayed much lower between-letter variation in recognition under zero defocus (lower section); range 0.15 logMAR across all 26 letters, which reduced slightly further to 0.13 logMAR for the Sloan set. Our previous study²⁰ also found lower letter acuity measurement variability for VO letters, suggesting the reason to be the smaller interletter legibility differences. If a test chart's within-line legibility difference is greater than its between-line legibility difference, this will limit the reliability of acuity measurement and consequently its ability to register subtle alterations in VA that can signify changes in the disease state. While the purpose of this study was not to assess test-retest variability, which is a property of a specifically constructed instrument, it is possible from the error bars in Figure 2a to observe the lower variability of acuity measurements with VOs compared to conventional letters. VO letters may thus be more appropriate targets from which to construct acuity charts. Interestingly, the circular VO letters (CGOQ) did not so much behave as a separate subset under zero defocus, but increasingly did so as defocus increased (upper part of Fig. 3b). Why should this happen? These four letters are most commonly confused with each other and the information required to distinguish them most likely lies within the higher frequencies; as these higher frequencies are progressively attenuated by the low-pass filtering effects of the blur lenses, they will become increasingly difficult to tell apart. The inclusion of these VO letters on a clinical test chart could thus increase acuity measurement variability under higher levels of defocus.

In peripheral viewing, the interletter recognition differences were again substantial for the conventional letters, the circular letters again behaving as a separate subset (Fig. 4a), but these differences were again much smaller for VOs (Fig. 4b). However, unlike in the fovea, we found significant and often substantial differences between detection and recognition thresholds for all of the VO characters (Fig. 4b). This difference between detection and recognition thresholds, and the relative robustness to the effects of optical defocus, points towards a sampling limit for recognition, but not detection, of VO letters in peripheral vision.

This has implications for tests such as high-pass resolution perimetry (HRP),²⁹ which assumes that the detection and resolution limits remain the same for VOs in the periphery. While only one optotype is employed by HRP (a ring) it can be seen by observing our results for the O in Figure 4b that its detection and recognition thresholds are significantly different. However, our finding of blur-resistant, potentially sampling-limited recognition performance for VOs outside the fovea

points towards a patient friendly in vivo measure of localized ganglion cell density; in effect a true letter resolution perimetry test.

Finally, in conditions like AMD, in which there is loss of foveal photoreceptors or even a central scotoma necessitating extrafoveal viewing, these optotypes may no longer vanish when recognition fails and the targets remain visible for some time after. This situation, resulting in a discrepancy between detection and recognition, may even be a useful sign of early AMD. Further work on clinical patients is required to better determine the clinical usefulness of high-pass letters in the detection and diagnosis of diseases such as AMD and glaucoma. In addition, other possibly confounding age-related optical factors such as straylight and lens yellowing may also affect the detection or recognition or both of VOs and these should be investigated in future studies.

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