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Fixation Locus in Patients with Bilateral Central Scotomas for Targets that Perceptually Fill In

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Abstract

Purpose—In this experiment we investigated whether target type affects the retinal fixation location and stability in patients with bilateral central scotomas, and specifically whether targets expected to perceptually fill in are imaged at or near the vestigial fovea.

Methods—The retinal location and stability of fixation were measured using the Nidek MP-1 microperimeter in twelve patients with bilateral central scotomas for six types of fixation target, three expected to fill in and three that included letters. The approximate position of the vestigial fovea was delineated in 10 of the patients either by using residual retinal landmarks or by locating the residual foveal pit in a dense macular scan, obtained with a Spectralis Optical Coherence Tomographer. Fixation location and stability were compared for the different target types and referenced to the position of the vestigial fovea.

Results—All of the subjects except one fixated consistently on targets that included a letter using peripheral retinal locations outside of the central scotoma. Eleven of the twelve subjects used a retinal location closer to the vestigial fovea to fixate targets expected to fill in, compared to letters. Although four of the subjects imaged the fill-in targets at or within a half degree of the vestigial fovea, six other subjects imaged the fill-in targets at a retinal locus removed from the vestigial fovea. Target type produced no overall significant difference in fixation stability, specified in terms of bivariate contour ellipse area (BCEA). However, in some individual subjects, fixation tended to be more stable on letter targets than on fill-in targets.

Conclusions—In patients with central field loss, letter targets generate more consistent fixation behavior than fill-in targets and should be used for eccentric viewing training and perimetry.

Keywords

macular degeneration; scotoma; perceptual filling-in; fixation; eccentric viewing; low vision

Patients who develop central scotomas as a consequence of macular degeneration frequently lose their ability to read, drive, and recognize faces. To compensate for the loss of central vision, these patients must learn to use the peripheral retina to perform tasks normally performed with the fovea or parafovea.

Patients typically adopt one or more specific eccentric retinal loci to track and view objects and to read. These loci have been termed preferred retinal loci (PRLs) and their characteristics have been described.^{1,2} In most patients, the use of a PRL as a “pseudofovea” is incomplete, as their oculomotor behavior demonstrates a lack of complete re-referencing from the fovea. Some patients may continue to image objects of interest in the scotoma by making foveating saccades.³

One of the most frequently used techniques for teaching a patient to use his or her remaining functional vision is eccentric viewing training, in which the patient is taught to move his or her eyes or head so that objects are imaged on healthier peripheral retina.⁴ Despite its wide implementation as a regular part of low vision services, the benefit of current techniques to train eccentric viewing is debatable.⁵

Much of the current eccentric viewing training is done without the use of fundus imaging and focuses on helping the patient recognize where he or she has to look to perceive objects and perform visual tasks, such as reading. During such training the specific area on the retina the patient uses to perform tasks is uncertain and the examiner is left to estimate the magnitude of the patient's eye movements, and hence the retinal locus being used, by gross observation. Without dedicated instrumentation, it is not possible to tell if a patient has moved his or her eye sufficiently or too much to perform a specific visual task. In general it remains unclear where precisely the scotoma is in relation to the targets being viewed and whether the patient's scotoma overlaps the target of interest. Scotoma location relative to the PRL also is not clear when performing perimetry using a tangent screen, Humphrey field analyzer or other device that does not image the fundus because the retinal location of fixation is uncertain. A method to predict the retinal location of fixation without fundus imaging would be useful both in training eccentric viewing and in field analysis.

The use of a scanning laser ophthalmoscope (SLO) or Nidek MP-1 microperimeter allows the examiner to evaluate eccentric viewing with greater accuracy.⁶⁻⁹ With these instruments the examiner is able to observe an image of the patient's fundus while the patient is performing a task such as fixating a target or reading a sentence. The patient is still unable to perceive the location of his/her scotoma, but the examiner can coach the patient to move his/her eye to a more “optimal” location. These instruments have yet to become implemented widely in routine low vision evaluations, possibly because of limited accessibility, high cost, increased in-office time, and the need for substantial technical skill.

Perceptual filling-in, the perception that the color and texture of the surrounding visual field extend into the area of the scotoma, likely complicates training eccentric viewing and oculomotor control and may contribute to the lack of substantial improvement in some patients. Zur and Ullman demonstrated that gratings and regular dot patterns that span the scotomatous region of the visual field are nevertheless perceived by patients with AMD to be uniform and continuous.¹⁰ Investigators have also shown that the commonly used Amsler grid is perceived as complete by many patients with dense central scotomas.^{11,12} Because of perceptual filling-in, patients are generally unaware of their scotoma, which makes it difficult for them to understand how they must move and position their eyes to use their remaining peripheral vision.¹¹ Research to evaluate the effect of perceptual filling-in on

visual functioning and to develop techniques that allow patients to visualize their pathological scotomas is needed.

On the other hand, perceptual filling-in may allow us to elicit fixation using the vestigial fovea in patients who have not shifted their oculocentric visual direction to the PRL. Large targets that extend beyond the central scotoma are expected to perceptually fill in and patients with absolute scotomas should see these targets as complete and continuous. For example it is expected that when fixating a large cross patients will perceive each of the legs of the cross as complete and continuous without a gap in the middle despite the scotoma being positioned over part of the target. If a patient perceives a target as filled in, we predict that the patient should position the retinal locus that corresponds to the primary oculocentric visual direction near the center of the target. This would be at the vestigial fovea for patients who have not experienced a shift in their oculocentric visual direction. In contrast, the use of small targets that cannot fill in, such as letters, is expected to elicit the use of the patients' PRL.

A better understanding of the retinal locus patients use to fixate targets that are expected to perceptually fill in and those that are not may allow us to develop targets that give increased confidence about the retinal location of fixation. These targets may in turn be used when eccentric viewing training and perimetry are performed without imaging the fundus. In addition, it is desirable to determine whether fixation stability is better with any one target, as stability frequently limits what clinical tests can be performed.

If targets expected to fill in are imaged at or near the vestigial fovea, these target types could be used to better approximate the projected location of the vestigial fovea and scotoma during eccentric viewing training and visual field testing outside of fundus imaging devices. If on the other hand patients use an alternate retinal locus to view the center of the fill-in targets, it would imply that fill-in targets are unsuited for eliciting fixation at the vestigial fovea and shouldn't be used in eccentric viewing training or perimetry, during which it often is assumed that patients fixate with their vestigial fovea.

Methods

Subjects

Twelve subjects with bilateral central scotomas were recruited from the Center for Sight Enhancement at the University of Houston, College of Optometry. Subjects ranged in age from 21 to 88 years old and were diagnosed previously with age-related macular degeneration, Stargardt's macular dystrophy, cone-rod, or cone dystrophy (Table 1). All subjects had stable vision at the time of the study with no recent gross changes in the state of pathology. Monocular fixation location and stability for different target types was determined for the eye with better letter acuity, which also corresponded to the eye that the patient reported using to read. In subjects whose letter acuity was the same in both eyes and who reported no eye preference, an ocular dominance test similar to the Dolman hole-in-the-card method was used to determine the eye to be tested. The eye not being tested was patched during measurements. Both eyes were dilated with 2.5% phenylephrine to improve retinal image quality. The research followed the tenets of the Declaration of Helsinki and the

experimental protocol was approved by the University of Houston Committee for the Protection of Human Subjects. The subjects granted written informed consent before participating in the study.

Stimuli

Each subject was presented with 2 groups of custom targets created using Image J software and presented with the Nidek MP-1 microperimeter's native software. Targets expected to perceptually fill in consisted of a large filled disk, a large cross, and two superimposed crosses, one with legs along the 90 – 270 and 0 – 180 deg meridians, and the other with legs along the 45 – 225 and 135 – 315 deg meridians (Figure 1). We will call the last type of target a spoke target. The width of the spokes and the legs of the crosses was 1.5 degrees. All targets were black on an illuminated white background of approximately 130 cd/m².

The second group of targets consisted of a single letter and a similar cross and spoke as in the first group of targets, but with a letter in the center. Sloan-font letters R, S, N, H, K, or Z were used.¹³ All of the fixation targets were the same overall diameter of 30 degrees, except for the isolated letter target, which was 0.83 degrees (20/200) for patient's with 20/200 or better acuity, and 1.67 degrees (20/400) for patients with acuity worse than 20/200 but better than 20/400. None of the patients had letter acuity in the better-seeing eye worse than 20/400 (Table 1). The size of the letter stimuli for each patient was based on the visual acuity measured during an eye examination within the previous month.

The patients' instructions depended on target type. For the targets expected to fill in, the instructions were, “move your eye to the center of the object, and keep your eye as steady as you can while looking at the center of the object.” The instructions for the letter targets were, “move your eye to see the letter, and keep your eye as steady as you can while making sure you can see the letter.”

Each target was presented twice. Presentation order was randomized and then counterbalanced within each group of targets. The targets expected to perceptually fill in were presented first. Patients indicated with a button push when they were fixating the center of the target or the letter and fixational eye movements were recorded at a rate of 25 samples/s for a period of 30 s using the fixation examination native to the Nidek MP-1 microperimeter.

After each 30-s recording period with the targets expected to fill in, each subject was asked what the fixation target was and whether it was complete, if there were any broken or missing parts, or if there were any blurry or faint parts of the object. In the trials with letter targets, the patient was asked which letter he or she saw. After the conclusion of the fixation trials, the scotomas in the tested and non-tested eye were mapped with a custom perimetry program using the Nidek microperimeter software.

Perimetry

Two spoke-like perimetry patterns were used to measure whether the scotomas were absolute and bilateral and whether the fixation targets spanned the scotoma in the study eye. The perimetry programs were designed with the Nidek perimetry software and used

Goldman size III stimuli. Tested points were spaced 2 degrees apart over the central 28 degrees with twice the density of points for the study eye along the horizontal and vertical meridians. The automatic threshold strategy was '4-2' for the study eye and 'fast' for the non-study eye. Stimulus duration was 200 ms. Sample perimetric results are shown for subject 4 in figure 2. The center of the perimetric array was placed by the examiner at the approximate location used by the patient to fixate the center of the fill-in targets during the preceding trials. Patients whose perimetry results indicated that there was central sparing in either eye were excluded from the study. In all cases but one, subject 7, the 30 degree targets spanned the scotoma of the study eye. The spanning of the scotoma by the target is thought to be an important prerequisite for perceptual filling-in to occur.^{14,15}

Eye Position Measurements

Horizontal and vertical eye positions during fixation were recorded on each trial for a period of 30 seconds using the fixation examination native to the Nidek microperimeter (MP-1). In the fixation exam, a region of interest (ROI), such as a blood vessel crossing, is chosen from a stationary infrared image of the fundus. The MP-1 then uses a cross correlation of this ROI with images of the fundus sampled at 25 Hz to track the eye position. Because of the instrument's software design, a separate ROI had to be chosen on each trial but, in general, the same region of the fundus was used to track fixation for all of the trials for an individual subject. The tracking algorithm in the Nidek includes a threshold correlation value below which the instrument indicates that it has lost track. A real time image of the region of interest was monitored during each trial to confirm that the MP-1 was accurately tracking. In addition, the recorded eye positions for each trial were analyzed off-line for tracking losses (see below). Because fixation eye movements are not recorded when the tracking algorithm indicates it has lost track, some trials required longer than 30 s to obtain a total of 30 s of fixational eye movements. The length of each trial depended on retinal image quality and how reliably the MP-1 was able to track the fundus image. Although one patient had one trial that lasted 70 s, the typical duration for a trial including the non-tracked portion was between 30 and 40 seconds. Infrequently, a trial had to be restarted using an alternate region of interest because of poor instrument tracking.

Analyses

Vertical and horizontal eye positions were plotted against time for each trial and a custom MATLAB program was used to detect and remove portions of the data where the MP-1 had lost track but had still recorded fixation values. Tracking loss was evidenced by large upward and downward spikes in the fixation data. The periods of tracking loss demonstrated a high positive velocity coupled with a high negative velocity within two data points or 80 ms. Because two large consecutive saccades cannot occur within this brief time frame, a calculated velocity profile was used to detect these periods of tracking loss and differentiate them from real saccades.

After removing the periods of tracking loss the data were analyzed for multiple fixation positions. We classified shifts in the fixation locus as an absolute change in the mean fixation position that is greater than 1.5 degrees as well as greater than two standard deviations of the mean horizontal or vertical eye position before and after the potential shift.

We limited our analysis to shifts that were sustained for at least ten percent of the trial duration, or 3 s.

Possible shifts in the fixation locus using the above criteria were detected with a custom MATLAB program and confirmed visually during off-line analysis (Figure 3). Some patients demonstrated rapid back and forth movement between two retinal loci. We did not register these as different fixation positions as we were concerned primarily with the effect that two or more relatively stable fixation loci would have on the variability of fixation, as described by the bivariate contour ellipse area.^{16,17} This back and forth behavior was interpreted to indicate that fixation was unstable and thus the bivariate contour ellipse area would be descriptive of these data without adjusting for the use of multiple PRLs.

Fixation Stability as Bivariate Contour Ellipse Area

The formula: $\text{Area} = \pi \chi^2 \sigma_x \sigma_y \sqrt{1 - \rho^2}$ was used to calculate the 68% bivariate contour ellipse area (BCEA) for each trial. In the formula, χ^2 is the value that includes 68% of the area of a chi-square distribution with 2 df. The use of the BCEA to describe fixation stability has been described in detail elsewhere.^{16,17} Simply put, the BCEA is the area of an ellipse that contains a specific percentage of the horizontal and vertical fixation positions. Although this gives us an understanding of overall stability during a trial, care must be taken in its interpretation, as some subjects may shift fixation location during a trial, resulting in an inflated value for the calculated BCEA. A large BCEA may give the impression that the eye moved around substantially during the trial when, in fact, the subject maintained relatively stable periods of fixation at two or more different retinal loci. In our study, six subjects demonstrated shifts between two fixation loci during 1 to 3 of the 12 trials. This resulted in larger BCEAs for those trials. We analyzed the data with and without accounting for these changes in the fixation locus. To calculate an adjusted BCEA for the trials in which a change in fixation locus was detected, the median of the horizontal and vertical positions before the fixation change were subtracted, respectively, from the horizontal and vertical eye-position data after the fixation change and the adjusted BCEA was calculated from these normalized data.

An alternate method for analyzing fixation stability that accounts for multiple fixation loci based on density plots has been described previously.^{18,19} We decided to analyze our data as described above because we were looking to identify clear sustained changes in the fixation locus during a trial, such that the overall BCEA was not really descriptive of the subject's fixation stability. The unadjusted BCEAs were preferred to an analysis using density plots, which potentially could have identified multiple PRLs when unstable fixation consisting of quick back-and-forth movements shifted the image between separate retinal loci within a single extended PRL. The analysis of fixation positions across time gave a clearer delineation of whether multiple fixation loci were used. During most of the trials, patients used a single area to view targets; however there were subjects whose fixation position drifted or shifted frequently between two or more points. In these examples, the unadjusted BCEA is likely to provide an accurate description of fixation stability.

For each subject, the fixation data from each trial were registered to a single retinal image to allow for the comparison of fixation positions between trials. This was necessary as the coordinates of the fixation data for each trial were specified relative to the retinal image that was captured when the ROI was defined for that trial. For each of the subjects, the fundus image captured on trial 1 was used as the reference to which all subsequent images were aligned. Alignment was done visually using Image J software and the Align3 TP plugin. Alignment was checked and fine-tuned by alternating between pairs of images at a frequency of approximately 4 Hz. Images were translated and then rotated until no image motion was apparent during alternation. The amounts of translation and rotation were then used to calculate the offset of each image relative to the image of trial 1, and this offset was applied to the data for that trial. The median horizontal and vertical fixation positions for each trial were then calculated and compared between trials.

For 9 of the 12 subjects, the residual foveal pit was visualized on a dense macular scan with the Spectralis Optical Coherence Tomographer and used to delineate the approximate retinal location of the vestigial fovea. This location is marked with an F on the fundus images for those 9 subjects. Unfortunately OCT was not a part of the original protocol and was not performed on the first three subjects (2, 5, and 6). Nevertheless, the approximate location of the vestigial fovea for subject 2 is apparent from retinal landmarks in the fundus image.

Results

ANOVAs were performed on the median horizontal and vertical fixation positions that were adopted for each of the six types of fixation target, separately for each subject. ANOVAs were not performed across subjects because the horizontal and vertical fixation positions are idiosyncratic and there is no way to relate the position used by one subject to the position used by a different subject. Planned post-hoc comparisons were made between the following combinations of targets: cross and spoke vs. cross-letter and spoke-letter, disk vs. the other 5 target types, disk vs. letter, cross and spoke vs. letter, and cross-letter and spoke-letter vs. letter. To keep the overall probability of a Type 1 error equal to 0.05, an alpha value of 0.01 was utilized for these analyses.

Eleven out of twelve subjects (all but subject 10) showed a significant interaction between fixation location and target type in the horizontal or vertical fixation position, or both. Nine of these eleven subjects also demonstrated a significant difference in fixation locus for the cross and spoke vs. the cross-letter and spoke-letter, disk vs. the other 5 target types, and disk vs. letter. Seven of the eleven subjects demonstrated a significant difference in the fixation locus for the cross and spoke vs. letter and none of the subjects demonstrated a significant difference between the spoke-letter and cross-letter vs. the letter (Figure 4).

Fundus images on which the median horizontal and vertical fixation locations are marked illustrate the differences between the fixation targets that include a letter and the targets that were expected to perceptually fill in (Figures 5 and 6). Eleven of the subjects imaged the center of one or more of the fill-in targets within the scotoma while only one subject (subject 8, Figure 4C) frequently imaged the letter targets within the scotoma. Five of the subjects fixated the fill-in targets and the letter targets using retinal areas in close proximity to one

another at the edge of the scotoma. However, the fill-in targets were imaged closer to the vestigial fovea for all of the subjects but one (subject 12, Figure 5E). Six subjects (1, 3, 7, 9, 10, and 12) imaged the fill-in targets at a retinal locus other than the vestigial fovea and four of the subjects (2, 4, 8, and 11) imaged the fill-in targets within a half degree of the vestigial fovea. It was not possible to tell without OCT analysis whether the fill-in targets were imaged at the fovea in two of the subjects.

Nine out of the twelve subjects described the large fill-in targets as complete. Seven of these subjects reported no broken or missing parts despite much of the target being covered by the scotoma and the center of the target frequently being placed within the scotoma. Many of the subjects perceived some areas of the fill-in targets to be faint, blurry, or non-uniform.

ANOVAs also were performed on the fixation stability for the six types of targets, expressed as log BCEA for each individual subject, as well as a repeated measures ANOVA for the group as a whole. The log BCEA was used for analysis to better approximate a normal distribution of values. No significant difference in log BCEA between the target types was found for the entire group $F(11,55) = 2.511, p = 0.0646$. Two of the subjects (6 and 10) showed a significant difference in the log BCEA for the different target types ($F(5, 6) = 4.926, p = 0.0389$; $F(5, 6) = 8.583, p = 0.0105$, respectively). Post-hoc analyses indicated that the disk resulted in a significantly larger BCEA for these two subjects (Table 2). In addition, the cross-letter and spoke-letter targets had a significantly smaller log BCEA than the cross and spoke targets for subject 10; $F(1, 6) = 22.796, p = 0.0031$, and approached significance for subject 6; $F(1, 6) = 5.002, p = 0.0667$. There was no significant difference between the cross-letter and spoke-letter targets vs. the letter target for either subject.

Statistical significance did not change when the log BCEA values were adjusted for the use of multiple fixation loci within a trial, either in the group or individual comparisons. A change in fixation locus was found for subjects 1, 2, 3, 4, 8, and 12 on between one and three of the individual fixation trials. Multiple fixation loci did not occur more frequently for any particular target type.

Although most of the subjects demonstrated no significant difference in log BCEA values for the different target types, subjects 4, 5, 8, and 9 showed a trend for fixation to be more stable for targets containing a letter. This outcome agrees with the results for the two subjects who exhibited a significant difference in BCEA between target types.

Discussion

The difference in fixation location for large targets that span the scotoma and are expected to fill in compared to targets that contain a letter suggests that the occulocentric visual direction has not completely shifted to the PRL in most of the subjects of this study. Many of the patients imaged the center of the fill-in targets within the scotomatous region and four of the patients imaged the center of these targets at or very near the vestigial fovea, further demonstrating the lack of complete oculomotor re-referencing and providing evidence for perceptual filling-in of large targets. On the other hand, six patients used a retinal locus that was shifted from the vestigial fovea toward the location of the PRL to view the large fill-in

targets, which suggests a partial re-referencing of occulocentric visual direction from the fovea toward the PRL.

A study by Schuchard and Raasch examined whether the retinal locus used by patients with central field loss to fixate pericentral targets differs according to the instructions provided.²⁰ Schuchard and Raasch expected that patients would fixate with the vestigial fovea if asked to move their eye to aim directly at the center of the target, but would use an eccentric PRL if asked to move the eye to best see the target. The rationale for our experiment was similar, except that we expected subjects to use different retinal loci based on the target type, rather than solely in response to the instructions. Our results are in agreement with those of Schuchard and Raasch, who found a difference in the fixation location used for large pericentral targets compared to a smaller cross. Schuchard and Raasch reported that their one young patient with Stargardt's disease imaged pericentral targets at the fovea during fixation, but none of their six patients with central scotomas as a result of AMD did so. In contrast, at least a third of the patients in our study imaged the center of large fill-in targets inside the scotoma and close to the vestigial fovea. Indeed, all but one of our subjects imaged the center of the large fill-in targets significantly closer to the vestigial fovea than letter targets. Both the study by Schuchard and Raasch and our own results indicate that large pericentral or fill-in targets are unsuited for predicting the projected location of the vestigial fovea and scotoma in visual space, as different subjects do not consistently use the vestigial fovea to image the larger targets. This variability also suggests that fill-in targets are not optimal for fixation during vision testing, including visual field tests.

The observation that subjects imaged one or more of the fill-in targets within the scotoma indicates that these target types cannot be used for eccentric viewing training if the examiner wants to ensure that the patient fixates using the PRL. We could not always make a precise determination of whether subjects were using the vestigial fovea to fixate the center of the fill-in targets because of pathological changes in retinal morphology. However, it appeared from OCT scans or from landmarks in the fundus image that patients 2, 4, 8 and 11 were using an area relatively close to the vestigial fovea to view the fill-in targets, whereas subjects 1, 3, 7, 9, 10, and 12 clearly were using an alternate, non-central locus. Based on these results, it should not be assumed either in clinical practice or in research studies that a patient will place the vestigial fovea or macular scotoma over the center of a large pattern, such as the radial pattern that is sometimes used in tangent-screen perimetry.

Letter targets appear to be best suited for eccentric viewing training and for mapping the scotoma location relative to the PRL, as they elicit fixation at the location of the PRL and only rarely do patients image them within the scotoma.⁶ A letter target also gives the examiner and the patient feedback as to whether the patient is maintaining fixation outside the scotoma, as the letter will disappear if it is imaged within the scotoma. Based on the tendency that we found for fixation stability to be better for letter than fill-in targets, the use of a letter target for fixation would be expected to promote better reliability of vision-test results.

The majority of the patients reported the large targets to be perceptually complete, despite much of the target being covered by the scotoma and the center of the target frequently

being imaged near the center of the scotoma. This result agrees with prior research that demonstrated perceptual filling-in at pathologically blind areas and provides evidence for filling-in of additional target types. Zur and Ullman demonstrated filling-in of gratings and uniform dot patterns.¹⁰ One of the three subjects in their study also reported filling-in of a single 0.73 deg wide line, whereas the two other subjects reported the line to contain a gap, demonstrating a lack of complete filling-in for single-line targets.

Why subjects may perceive a uniform pattern as complete but not a line is unclear but may be related to the amount of visual information in the stimulus. In our study, the target that was most similar to a line was the cross, which was perceived to be complete by most subjects. The perceptual filling-in of the cross target may have been secondary to the increased information provided by two lines or from the greater thickness of the lines that comprised the cross, compared to the line in the Zur and Ullman study (1.5 deg vs. 0.73 deg). In addition, Zur and Ullman limited the duration of their stimuli to 400 ms, whereas we asked subjects about the completeness of the fixation targets after they had been fixating for at least 30 s. The additional viewing time in our study allowed patients to extract more visual information, as a consequence of the target being imaged at multiple retinal locations. Nevertheless, several of our patients reported areas of the fill-in targets that appeared faint or blurry, indicating that the filling-in process was not always complete and that there may be varying levels of perceptual filling-in.

A common test employed by many occupational therapists is the use of a clock dial to approximate the direction that patients should eccentrically view during visual tasks. Patients are asked to look at the center of a clock dial and to report which numbers appear the clearest. This information is then used to coach the patient to eccentrically view. A macular mapping test using a similar but more elaborate paradigm was developed with the aim of more accurately plotting a patient's residual functional vision.²¹ This test uses a large spoke-like target that is assumed to stimulate foveal fixation; the sizes of the surrounding letter targets are scaled with eccentricity based on this assumption. The results of this test and the clock-dial test become less interpretable when the retinal location of fixation is unknown. As the results of the current experiment indicate that a large fixation target does not necessarily ensure foveal fixation, these and similar tests may be improved if a letter target is used for fixation, which would allow the location of reduced vision relative to the PRL to be mapped. By incorporating letter targets for fixation, examiners will achieve more consistent and accurate results when they test the visual function of patients with macular scotomas.

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Figure 1.
Fixation targets. Targets, except for the single letter, were 30 degrees in size.

Figure 2. Results of Nidek MP-1 perimetry for the tested (A) and non-tested eye (B) for subject 4. The insert shows the 0-12 decibel scale.

Figure 3. Subject 1 Trial 9, (A) Horizontal and vertical eye position trace during fixation on the spoke-letter target. Leftward and upward eye movements are positive on the y-axis. (B) Retinal position of target center plotted on the fundus image. The use of two distinct PRLs is manifest.

Figure 4.

Results of the five planned post-hoc comparisons. The spoke and cross with the dot in the center represent the spoke-letter and cross-letter fixation targets, and the 'N' represents the letter fixation target.

Figure 5.

Subjects' median fixation location for 6 target types. Each target was presented twice. The width of the image is approximately 38 deg and the height is approximately 32 deg. An effort was made to position the center of the optic nerve on either the right or left edge of the image as a reference. When possible, the approximate position of the fovea as determined from OCT images or fundus landmarks is labeled with an F. (A) Subject 6, (B) Subject 2, (C) Subject 8, (D) Subject 9, (E) Subject 10, (F) Subject 3.

Figure 6.

Subjects' median fixation location for 6 target types. Each target was presented twice. The width of the image is approximately 38 deg and the height is approximately 32 deg. An effort was made to position the center of the optic nerve on either the right or left edge of the image as a reference. When possible, the approximate position of the fovea as determined from OCT images is labeled with an F. (A) Subject 7, (B) Subject 1, (C) Subject 5, (D) Subject 11, (E) Subject 12, (F) Subject 4.

Subject characteristics. Scotoma Size is given for the retinal area in which subjects were unable to detect the brightest target displayed by the Nidek MP-1. For subjects for whom information was available, the duration since diagnosis with macular disease is included.

Table 1

Subject Number	Age(yrs)	Gender	Diagnosis and Duration	Study Eye	Scotoma Size (diameter in deg)				Visual Acuity (calculated Snellen)	
					V	H	OD	OS	OD	OS
1	21	M	Stargardt's	OD	4	6	20/280	20/400		
2	46	F	Cone-Rod 1+ year	OD	10	10	20/60	20/70		
3	87	M	AMD 10+ years	OD	6	6	20/80	20/120		
4	80	M	AMD	OD	8	8	20/200	20/400		
5	75	F	AMD 4+ years	OS	14	14	20/240	20/160		
6	85	M	AMD 1+ year	OD	8	6	20/80	20/160		
7	54	F	Cone 17 years	OS	10	14	20/125	20/100		
8	84	F	AMD 16 years	OS	6	8	20/200	20/80		
9	26	M	Stargardt's 15 years	OD	10	10	20/320	20/360		
10	45	F	Stargardt's 12+ years	OD	6	10	20/120	20/120		
11	88	M	AMD	OS	20	16	NLP	20/100		
12	81	F	AMD 13 years	OD	10	10	20/160	20/120		

Table 2
Comparison of BCEA between target types for subjects 6 and 10. The significant values are **bold**.

Overall		c/s vs. c/sl		d vs. all		c/sl vs. l	
Subject	<i>F</i> (5, 6)	<i>p</i>	<i>F</i> (1,6)	<i>p</i>	<i>F</i> (1,6)	<i>p</i>	<i>p</i>
6	4.926	0.0389	5.002	0.0667	18.906	0.0048	0.7536
10	8.583	0.0105	22.796	0.0031	14.278	0.0092	0.9107

c = cross; s = spoke; cl = cross-letter; sl = spoke-letter; d = disk; l = letter.