Properties of Visual Field Defects Around the Monocular Preferred Retinal Locus in Age-Related Macular Degeneration

Jonathan Denniss,[1] Helen C. Baggaley,[1,2] Graham M. Brown,[3–5] Gary S. Rubin,[3–5] and Andrew T. Astle[1]

[1]Visual Neuroscience Group, School of Psychology, University of Nottingham, Nottingham, United Kingdom
[2]Optometry Unit, Ophthalmology Department, Nottingham University Hospitals NHS Trust, Nottingham, United Kingdom
[3]Institute of Ophthalmology, University College London, London, United Kingdom
[4]Moorfields Eye Hospital NHS Foundation Trust, London, United Kingdom
[5]NIHR Moorfields Biomedical Research Centre, London, United Kingdom

Correspondence: Jonathan Denniss, School of Optometry & Vision Science, University of Bradford, Bradford BD7 1DP, United Kingdom; j.denniss@bradford.ac.uk.

Submitted: November 9, 2016
Accepted: March 27, 2017

Citation: Denniss J, Baggaley HC, Brown GM, Rubin GS, Astle AT. Properties of visual field defects around the monocular preferred retinal locus in age-related macular degeneration. *Invest Ophthalmol Vis Sci*. 2017;58:2652–2658. DOI: 10.1167/iovs.16-21086

Purpose. To compare microperimetric sensitivity around the monocular preferred retinal locus (mPRL) in age-related macular degeneration (AMD) to normative data, and to describe the characteristics of visual field defects around the mPRL in AMD.

Methods. Participants with AMD (total $n = 185$) were either prospectively recruited ($n = 135$) or retrospectively reviewed from an existing database ($n = 50$). Participants underwent microperimetry using a test pattern (37 point, 5° radius) centered on their mPRL. Sensitivities were compared to normative data by spatial interpolation, and conventional perimetric indices were calculated. The location of the mPRL relative to the fovea and to visual field defects was also investigated.

Results. Location of mPRL varied approximately 15° horizontally and vertically. Visual field loss within 5° of the mPRL was considerable in the majority of participants (median mean deviation −14.7 dB, interquartile range [IQR] −19.6 to −9.6 dB, median pattern standard deviation 7.1 dB [IQR 4.8–9.0 dB]). Over 95% of participants had mean total deviation worse than −2 dB across all tested locations and similarly within 1° of their mPRL. A common pattern of placing the mPRL just foveal to a region of normal pattern deviation was found in 78% of participants. Total deviation was outside normal limits in this region in 68%.

Conclusions. Despite altering fixation to improve vision, people with AMD exhibit considerable visual field loss at and around their mPRL. The location of the mPRL was typically just foveal to, but not within, a region of relatively normal sensitivity for the individual, suggesting that a combination of factors drives mPRL selection.

Keywords: age-related macular degeneration, perimetry, fixation, microperimetry, scotoma

Microperimetry, or fundus perimetry, is increasingly being used in the clinical assessment of central vision loss in a range of disorders including age-related macular degeneration (AMD).[1] Due to diminished central vision, patients with AMD and similar disorders commonly use extrafoveal retinal locations for fixation in everyday tasks such as reading and face recognition, as well as during clinical tests such as measurement of visual acuity and perimetry.[2–8] While visual function may be improved at these extrafoveal locations compared to the damaged fovea, fixation stability is typically reduced.[2,8,9] Microperimeters overcome this problem by inbuilt eye tracking enabling gaze-contingent stimulus presentation. Unlike many conventional perimeters, microperimeters also enable the clinician to manually shift the position of the test grid, for example, to test a retinal region of particular interest, and some feature biofeedback training paradigms that aim to improve fixation stability when fixating with a chosen extrafoveal location.[10–14]

The considerable advantages of microperimetry in terms of customizing tests to individual patients bring with them one significant disadvantage: Because patients are tested at disparate retinal locations, either due to noncentral gaze or due to manual selection of noncentral test locations by the clinician, comparison of measured sensitivities to conventional normative databases is not possible. Although microperimetric sensitivity in AMD has been previously studied,[15–19] because of this limitation it has not been possible to discern the properties of visual field defects caused by AMD at nonfoveal locations, relative to normative data. We have recently demonstrated a spatial interpolation method that enables comparison to normative data in microperimetry, as well as the calculation of local and global summary indices[20] that are familiar from conventional automated perimetry.[21] In this study, we used this method to explore the properties of microperimetric defects in patients with AMD, tested at their self-selected retinal fixation locations, which we term the monocular preferred retinal locus (mPRL). We also hypothesized that patients would use their visual sensitivity to guide their choice of mPRL location, and that this would be revealed

by comparison of microperimetric sensitivities to normative data.

Methods

This study adhered to the tenets of the Declaration of Helsinki. Data were collected from the University of Nottingham and the University College London (UCL) Institute of Ophthalmology. Data collection at the University of Nottingham received approval from the National Health Service (NHS) National Research Ethics Service, and all participants gave written informed consent to take part. Data collected from UCL Institute of Ophthalmology were retrospectively collected from the anonymized database of the EFFECT Study (Brown GM, et al. *IOVS* 2016;57:ARVO E-Abstract 5171). Approval to retrospectively use the anonymized data for this study was granted by the NHS National Research Ethics Service.

Participants

Participants at the University of Nottingham ($n = 135$, 78 female) were prospectively recruited via advertisements in local clinics, media, and a patient newsletter. Data from participants at UCL Institute of Ophthalmology ($n = 50$) were retrospectively collected from suitable participants of the EFFECT Study (Brown GM, et al. *IOVS* 2016;57:ARVO E-Abstract 5171). All participants had clinically diagnosed AMD in one or both eyes. In order for the study population to be as representative as possible of the clinical use of microperimetry in AMD, any type of AMD at any manifest stage was eligible for inclusion, and current or past treatment or the lack thereof did not affect inclusion. Participants had no known coexisting or previous eye disease that could affect the visual field, except for mild cataract, and had not undergone intraocular surgery except uncomplicated cataract surgery. All participants were aged over 50 years, were able to perform the microperimetry test, and had refractive error within the range that can be compensated for by the microperimeter's inbuilt focusing (−15.00 to +10.00 diopter [D] spherical equivalent and maximum 4.00 D cylinder).

Prospectively recruited participants in Nottingham attended a single study visit during which they provided their ophthalmic history and undertook microperimetry (see later), visual acuity measurement using an Early Treatment Diabetic Retinopathy Study (ETDRS) letter chart, and slit-lamp binocular indirect ophthalmoscopy to verify the diagnosis of AMD and confirm the lack of coexisting eye disease. If both eyes met the inclusion criteria, both were tested, but only data from the worse eye were included in the main analysis.

For retrospective data from UCL, we included the most recent eligible test where more than one was present. Again, in cases where data from both eyes were present we included the worse eye in the main analysis.

Because binocular PRL location may be driven by the vision of the better eye if AMD is binocular but unequal between the two fellow eyes, a supplementary analysis of mPRL location was also performed to consider the better eyes of those participants who had AMD in both eyes. This analysis included 32 participants (24 from Nottingham, 8 from UCL).

Microperimetry

All tests were conducted using the 4-2 Expert test of the MAIA microperimeter (CenterVue, Padova, Italy). Data from UCL were collected using a MAIA-1, while participants in Nottingham were tested on a MAIA-2. However, there is no difference in the testing procedure, stimulus, or background between the two instruments; therefore the results are entirely interchangeable. The 4-2 Expert test uses Goldmann size III (0.43° diameter) stimuli, a 37-point concentric test pattern with 5° radius, and a staircase thresholding procedure that increments by 4 dB until the first reversal and then by 2 dB until terminating on the second reversal. It should be noted that due to differences in maximum stimulus luminance the dB scale used by the MAIA instruments differs from that of some other common perimeters.

The test pattern was centered on the mPRL, as determined by the instrument during an initial 10-second period of fixation during which gaze is monitored and the mean horizontal and vertical gaze position is taken as the mPRL. Once the mPRL is established, the stimuli are presented in a gaze-contingent fashion, with the eye being tracked at 25 Hz via the live scanning laser ophthalmoscope image. Participants who struggled to see the standard fixation marker (0.78° diameter circle) were guided toward it using the instrument's alternative markers (crosses in selectable positions closing in on the central annulus) as appropriate. The MAIA instruments require a 2.5-mm pupil for successful image capture; natural pupils were used if they were sufficiently large, otherwise pupils were dilated with one drop of 0.5% tropicamide prior to testing. All participants completed sufficient practice for the perimetrist to be convinced that the task was fully understood. Tests not deemed reliable due to excessive eye movement were discarded and repeated.

Data Analysis

Data from left eyes were converted to right eye format for analysis. Since test locations are reported by the instrument relative to the optic disc, the location of the mPRL on the retina was determined assuming that the optic disc was in the average position from our previous normative study using the same instrument (in right eye retinal coordinates relative to the fovea; 15.54°, 2.12°).[21,22] This method is subject to error due to individual variation in the relative locations of the fovea and optic disc; however, this variation has been shown to minimally affect comparison to normative data in the central retina.[21] All sensitivity estimates were adjusted by 0.05576 dB per year to age 26 (the median age of participants in the normative database) to account for sensitivity decline with normal aging. This adjustment factor was taken from the central 17 points of Figure 2 of Heijl et al.[23]

Age-adjusted sensitivities at each location were then compared to the series of normative surfaces at corresponding locations as previously described in full.[21] Briefly, individual participants are tested at different retinal locations due to disparate mPRL locations on which the test grids are centered. It is therefore not possible to compare sensitivities to conventional pointwise normative data. For this reason, sensitivities are compared to the corresponding locations on high-resolution fitted surfaces to calculate indices that are ultimately analogous to those used in the common Humphrey Field Analyzer series of perimeters (Carl Zeiss Meditec, Jena, Germany).[20] Sensitivities are compared to the mean normative surface to determine total deviation (TD) values, and sensitivities adjusted for TD at the location with 85th percentile sensitivity are again compared to the mean normative surface to determine pattern deviation (PD) values. We also compare TD and PD values to a surface fitted to the empirical 5th percentile of the normative data in order to derive TD and PD probability maps. Global summary indices mean deviation (MD) and pattern standard deviation (PSD) are calculated using an additional surface fitted to the variance of the normative data.

Investigative Ophthalmology & Visual Science

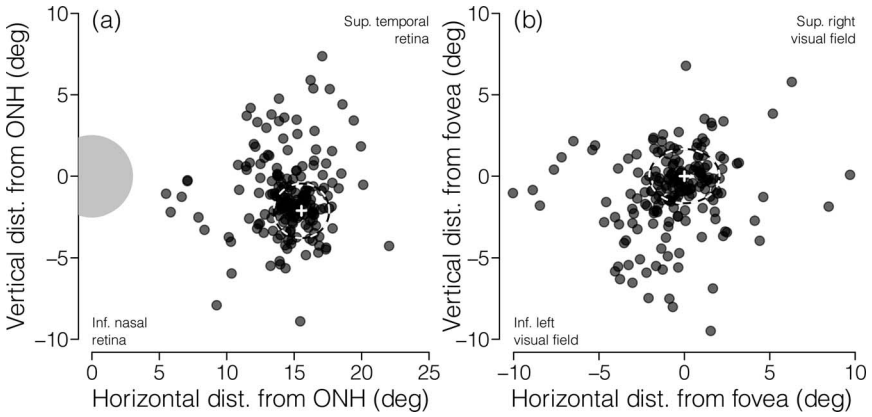

Figure 1. The distribution of monocular preferred retinal loci for all participants, shown in (**a**) retina space for a left eye and (**b**) visual field space. In both portions of the figure the *white cross* indicates the presumed location of the anatomic fovea, and the *dashed ellipse* represents the 95% normative population limits from our previous study.[21,22] The *large gray circle* in (**a**) indicates the optic disc location. The data (**a**) are shown for a left eye to allow for a positive abscissa.

For the present study, we also consider the choice of mPRL location made by the participants. We calculated mean TD and PD both across the whole tested region and within 1° of the mPRL to test the hypothesis that participants located their mPRL in an area of normal sensitivity. We also considered the spatial location of the mPRL in relation to apparent defects on TD and PD 5% probability maps.

All analyses were carried out in *R* (version 3.2.0).[24]

Results

Data from one eye each of 185 patients with AMD were included. Participants were aged 57 to 97 years (median 80 years). Participants chose varied mPRL locations with a range of approximately 15° horizontally and vertically. There was a tendency toward mPRLs to be superiorly (median 0.59°, interquartile range [IQR] –0.47° to 2.01°) and nasally (mean 0.8°, IQR –0.60° to 1.79°) displaced on the retina relative to the presumed location of the anatomic fovea. Considered in visual field space, mPRLs tended to be displaced to the left (median 0.55°, IQR 1.67° left to 0.92° right) and inferiorly (median 0.59°, IQR 2.01° inferior to 0.47° superior). Of the 185 participants, 100 had mPRL locations outside of the normative population limits for relative fovea–optic disc location. The direction of the displacement of the mPRL relative to the presumed location of the anatomic fovea remained the same for these participants. The distance between the mPRL and the presumed location of the anatomic fovea was only weakly related to fixation stability (95% bivariate contour ellipse area) during the initial 10-second period over which the mPRL was established (Spearman's ρ 0.3, $P < 0.001$, see Supplementary Fig. S1). The full distribution of mPRL locations in both retinal and visual field space is shown in Figure 1.

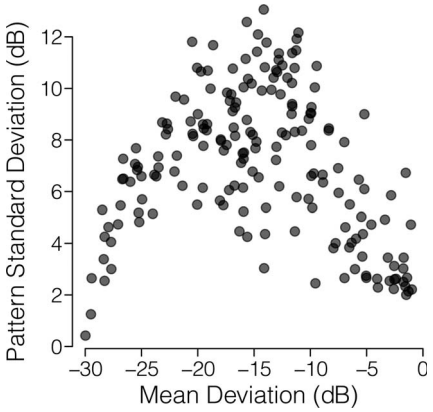

Figure 2. Mean deviation versus pattern standard deviation for all patients, centered on their monocular preferred retinal locus.

Across all tested locations (within 5° radius of the mPRL) most participants exhibited considerable visual loss, with median MD –14.7 dB (IQR –19.6 to –9.6 dB) and median PSD 7.1 dB (IQR 4.8–9.0 dB). Figure 2 shows the complete distribution of MD and PSD for all participants. The relative paucity of points in the lower portion of Figure 2 reflects that few participants exhibited low PSD (5% < 2.5 dB), indicating that sensitivity loss tended to be deep and localized rather than shallow, diffuse loss. The inverted "U" shape of the outer envelope of the data is likely due to floor effects in the combination of MD and PSD. For example, in the limiting case where all points are perimetrically blind, MD will be maximally negative, but PSD will necessarily be zero.

Figure 3 shows the distributions of mean TD and PD at all tested locations and at only those locations within 1° radius of the mPRL. Again, most patients exhibited considerable sensitivity loss; 95% of participants had mean TD worse than –2.0 dB across all locations, and this proportion increased to 97% when only locations within 1° of the mPRL were considered. At the central point of the test pattern, representing the closest approximation available to the center of the mPRL, TD was outside normal limits in 183 of 185 participants (99%). Median TD at this location was –13.8 dB (IQR –23.2 to –8.4dB). At the same central location, PD was outside normal limits in 154 participants (83%); median PD was –6.6 dB (IQR –10.7 to –4.0 dB). Similar to Figure 2, the "U" shape of the outer envelope of the data in Figure 3a is due to the interaction of the mean TD and mean PD in extreme cases. For example, if TD is maximally negative at all locations, then all locations are equivalent and PD at all locations is zero. Such a pattern is less evident in Figure 3b because the calculation of PD at locations within 1° of the mPRL is influenced by sensitivity at locations outside this region.

Across all tested participants and tested locations, TD fell below the 5th percentile of the normative surface at median 36 of 37 locations (IQR 29–37). The same proportion for PD was median 24 of 37 locations (IQR 20–27).

Eighty-one (44%) participants had noncentral regions within the tested area, that is, within 5° radius of the mPRL

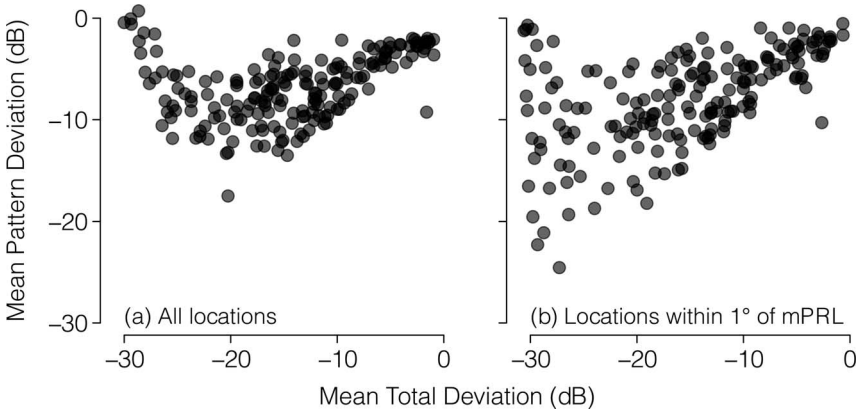

Figure 3. Distributions of mean total deviation and mean pattern deviation across (**a**) all locations and (**b**) locations within 1° radius of the monocular preferred retinal locus.

but not at the mPRL, that had sensitivity within normal limits. In 77% of occurrences this region of normal sensitivity was at a greater distance from the anatomic fovea than the chosen mPRL. One hundred forty-five participants (78%) exhibited a common pattern of fixating just foveal to a region with sensitivity within normal limits by PD, that is, a region of relatively normal sensitivity for that individual. Among those 78% of participants, this pattern was apparent only on the PD probability plot (not the TD probability plot) in 68% of cases. This proportion of participants selecting an mPRL just foveal to a region of normal PD was similar when we considered either dataset alone (Nottingham data 79%, UCL data 76%). We also considered only those participants whose mPRL location fell outside of the normative population 95% limits for relative fovea–optic disc locations (i.e., those whose mPRL was clearly separated from the anatomic fovea). In these participants, 85% exhibited the same pattern of fixation just foveal to a region of normal PD, and this was not apparent on the TD probability plot in 69% of those cases. Figure 4 shows examples from five participants who showed this pattern of fixation.

In the supplementary analysis of mPRL location in the better eyes of participants with binocular AMD ($n = 32$) we found broadly similar properties. Eighteen (56%) had regions with sensitivity within normal limits within the tested area. Of those 18 participants, the region with normal sensitivity was at the same or lower eccentricity than the mPRL in 6 cases. The common pattern of fixating just foveal to a region with sensitivity within normal limits by PD discussed above was observed in 20 cases (63%), and 13 of these (65%) were not apparent from TD probability plots.

Discussion

People with AMD exhibit significant visual field loss within 5° of fixation, even when they are allowed to fixate eccentrically using a nonfoveal retinal region of their choice. In this study, people with AMD were tested using gaze-contingent microperimetry centered on the mPRL, the region of retina they had chosen to fixate with. We observed a wide variation in mPRL location between participants (Fig. 1), with different participants fixating with disparate areas of retina. Given that people choose to fixate extrafoveally due to the localized damage to their central retina, it seems reasonable that they would use a functionally normal area of retina. However, in this study, we found significant visual loss in the majority of patients both within 5° and within 1° radius of the mPRL, and at the test location centered on the mPRL. This visual loss is age adjusted and relative to a healthy population at the same retinal eccentricity, so it exists even after accounting for sensitivity decline with age and eccentricity. People with AMD therefore move their chosen point of fixation, but not typically to a point where their vision is unaffected by the disease. This finding is consistent with previous studies showing that people with AMD tend not to locate their PRL at the retinal location with greatest microperimetric sensitivity,[25] and that visual acuity and letter contrast sensitivity at the PRL is typically worse than that of visually healthy participants at the same retinal eccentricity.[26]

Visual field loss close to fixation as exhibited by the majority of participants in this study is likely to impact upon the daily visual tasks most complained of by people with AMD such as face recognition, shopping, and reading.[27] Faces span approximately 2° of visual angle at approximately 5 m, and the same angular subtense at a typical reading distance represents around 1.4 cm on the page (one or two words of typical print). The scotomas evident within 1° radius of fixation in this study are therefore likely to have significant impact on daily tasks, which may be additional to that of reduced visual acuity.

In this study, we found a common pattern of mPRL location just foveal to a region of normal PD. This pattern occurred in nearly 80% of all participants in both independent datasets and in 85% of patients whose mPRL was distinctly separated from the fovea. The region of normal PD had sensitivity within normal limits (normal TD) in only approximately one-third of these cases, so the choice of mPRL seems to be made to be adjacent to a region of relatively high sensitivity compared to the nearby surrounding retina. Better sensitivity at the point of fixation could therefore be achieved in approximately 80% of study participants by encouraging them to fixate 1° or 2° more eccentrically; however, it is as yet untested whether this would compromise their vision in another way, for example, in terms of visual acuity. It may be that their choice of mPRL represents a trade-off between contrast sensitivity as measured by the microperimeter and other visual factors such as visual acuity and neural conditioning to fixate with the fovea. Further study is ongoing in our lab to investigate this, though it is worth noting that people with Stargardt's disease have been previously reported to fixate more eccentrically to their central scotoma than do those with AMD.[3]

Participants in this study demonstrated a tendency to place their mPRL in their left and/or inferior visual field, with those with greater displacement being more likely to use inferior than superior visual field (Fig. 1b). This finding is consistent with previous reports investigating PRL locations relative to manifest scotomas in central retinal disease.[3–6] One previous study investigated PRL location longitudinally following the

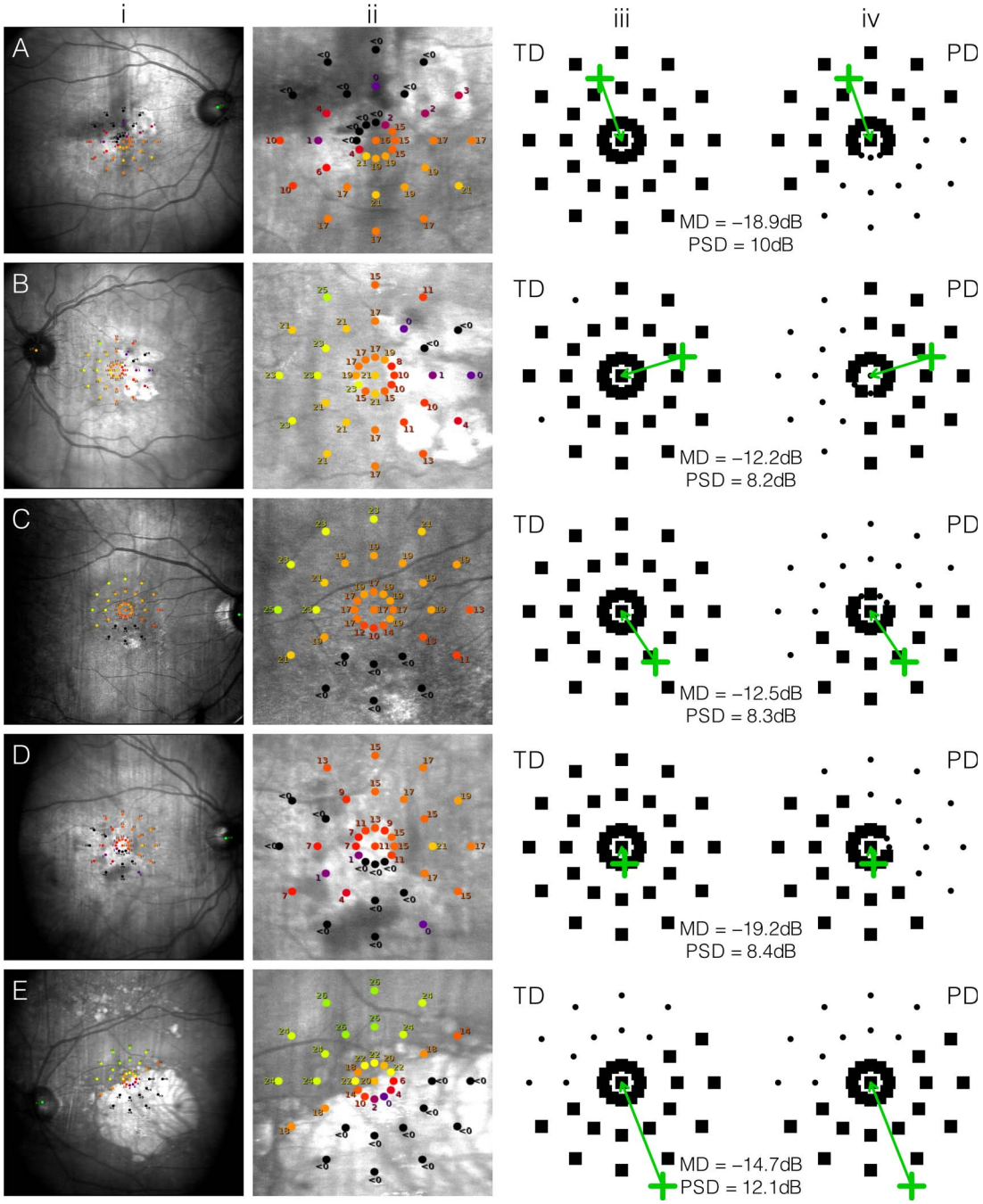

Figure 4. Examples from five participants (rows **A–E**) who demonstrated the pattern of fixating just foveal to a region of pattern deviation within normal limits. *Columns*: **(i)** the scanning laser ophthalmoscope image with superimposed test pattern, **(ii)** measured sensitivity at each tested location, points color coded according to the instrument's own scale, **(iii)** total deviation probability plots, **(iv)** pattern deviation probability plots. In columns **(iii)** and **(iv)**, *black squares* indicate points below the 5th percentile of the normal population, *dots* indicate points within normal limits. Test patterns in columns **(iii)** and **(iv)** are centered on the monocular preferred retinal locus, which is deviated from the presumed location of the anatomic fovea (*green crosses*) by the distance and direction indicated by the *green arrows*. Mean deviation (MD) and pattern standard deviation are also shown. Note that visual field sensitivities are represented in retinal orientation to match the image in column **(i)**; this is inverted relative to visual field space and conventional clinical representations of the visual field.

onset of disease in the second affected eye, finding that PRLs were initially distributed evenly among the cardinal meridians, but commonly became established in left and/or inferior visual field by the study endpoint.[7] In the context of these previous studies, the wide distribution of mPRL locations found in the present study indicates that many are unlikely to be well-established, stable functional adaptations. This is unsurprising given that many of the participants had monocular disease; however, it is likely that our data represent initial mPRL selections in most patients, and this is reflected in the consistent patterns of fixation observed between participants. Further, the results of the subanalysis of the better eyes of participants with binocular AMD also conformed to a similar pattern. It is possible that the monocular environment of the

microperimetry test may force a similar compensation process as would occur at the onset of new binocular vision loss prior to the longer-term development of more stable eccentric fixation strategies.

Although the choice of mPRL location followed a strikingly common pattern among the study participants, there are further caveats to the interpretation of this finding. The visual environment of the microperimetry test (monocular, uniform background with fixation marker, aiming to detect small white lights) is unlike our usual complex visual environment. Therefore, it is not known whether the choice of mPRL made for undergoing microperimetry is representative of that used in patients' daily tasks, or for specific tasks with different visual demands such as reading. Their choice of mPRL therefore is probably representative of people's initial selection when first confronted with central vision loss, rather than necessarily that used in long-established disease. This, however, represents an opportunity for principled training in eccentric fixation strategies for those who lose central vision bilaterally, using retinal locations carefully chosen to provide optimum vision in natural conditions.

The methods used in this study and our previous study[21] allow sensitivities measured by microperimetry at any central retinal location to be compared to equivalent normative data. Microperimeters typically allow the clinician to manually position the test pattern in a location of interest. Recent studies have hinted at the possibility of sensitivity loss, measurable by microperimetry, preceding damage visible by current imaging techniques in progressing cases of AMD (Krishnan A, et al. *IOVS* 2016;57:ARVO E-Abstract 6100).[19,28] These methods, therefore, may be useful in enabling microperimetry to be used as a tool for detecting early signs of disease spread across wider areas of retina, enabling timely treatment to prevent further vision loss. To improve the methods, a larger multicenter normative database would be advantageous, and an improved method of determining the precise location of the mPRL relative to the anatomic fovea would allow for yet further improvements in the accuracy of the normative data comparison.[21]

In conclusion, people with AMD typically have significant visual field loss at, and in the area around, their chosen extrafoveal fixation point (mPRL). This visual field loss is likely to contribute to difficulties in daily tasks. The location of the mPRL in this study likely represents initial selections made by people when first confronted with central vision loss, and around four in five people located their mPRL just foveal to an area of PD within normal limits, though usually still with TD outside normal limits. This suggests that mPRL selection, at least initially, is multifactorial, with areas of relatively normal sensitivity playing a significant role. Microperimetric contrast sensitivity at the mPRL, at least, might be improved by directing fixation to a slightly more eccentric location than initially selected by patients, similar to the fixation patterns observed in Stargardt's disease.[3]

Acknowledgments

The authors thank Michael D. Crossland, PhD, for assistance with the UCL dataset.

Supported by a College of Optometrists Postdoctoral Award (JD, ATA), a National Institute for Health Research (NIHR) Postdoctoral Fellowship (ATA), and a Fight for Sight Programme Grant (GSR). This report presents independent research funded by the NIHR. The views expressed are those of the authors and not necessarily those of the National Health Service (NHS), the NIHR, or the Department of Health.

Disclosure: **J. Denniss**, None; **H.C. Baggaley**, None; **G.M. Brown**, None; **G.S. Rubin**, None; **A.T. Astle**, None

References

1. Rohrschneider K, Bültmann S, Springer C. Use of fundus perimetry (microperimetry) to quantify macular sensitivity. *Prog Retin Eye Res*. 2008;27:536–548.
2. Whittaker SG, Budd J, Cummings RW. Eccentric fixation with macular scotoma. *Invest Ophthalmol Vis Sci*. 1988;29:268–278.
3. Sunness JS, Applegate CA, Haslewood D, Rubin GS. Fixation patterns and reading rates in eyes with central scotomas from advanced atrophic age-related macular degeneration and stargardt disease. *Ophthalmology*. 1996;103:1458–1466.
4. Fletcher DC, Schuchard RA. Preferred retinal loci relationship to macular scotomas in a low-vision population. *Ophthalmology*. 1997;104:632–638.
5. Guez J-E, Le Gargasson J-F, Rigaudierre F, O'Regan JK. Is there a systematic location for the pseudo-fovea in patients with central scotoma? *Vision Res*. 1993;33:1271–1279.
6. Greenstein VC, Santos RAV, Tsang SH, Smith RT, Barile GR, Seiple W. Preferred retinal locus in macular disease. *Retina*. 2008;28:1234–1240.
7. Crossland MD, Culham LE, Kabanarou SA, Rubin GS. Preferred retinal locus development in patients with macular disease. *Ophthalmology*. 2005;112:1579–1585.
8. Timberlake GT, Mainster MM, Peli E, Augliere RA, Essock EA, Arend L. Reading with a macular scotoma. *Invest Ophthalmol Vis Sci*. 1986;27:1137–1147.
9. Crossland MD, Culham LE, Rubin GS. Fixation stability and reading speed in patients with newly developed macular disease. *Ophthal Physiol Opt*. 2004;24:327–333.
10. Tarita-Nistor L, González EG, Markowitz SN, Steinbach MJ. Plasticity of fixation in patients with central vision loss. *Vis Neurosci*. 2009;26:487–494.
11. Amore FM, Paliotta S, Silvestri V, Piscopo P, Turco S, Reibaldi A. Biofeedback stimulation in patients with age-related macular degeneration: comparison between 2 different methods. *Can J Ophthalmol*. 2013;48:431–437.
12. Vingolo EM, Cavarretta S, Domanico D, Parisi F, Malagola R. Microperimetric biofeedback in AMD patients. *Appl Psychophysiol Biofeedback*. 2007;32:185–189.
13. Vingolo EM, Salvatore S, Cavarretta S. Low-vision rehabilitation by means of MP-1 biofeedback examination in patients with different macular diseases: a pilot study. *Appl Psychophysiol Biofeedback*. 2009;34:127–133.
14. Morales MU, Saker S, Amoaku WM. Bilateral eccentric vision training on pseudovitelliform dystrophy with microperimetry biofeedback. *BMJ Case Rep*. 2015:bcr2014207969.
15. Midena E, Vujosevic S, Convento E, Manfré A, Cavarzeran F, Pilotto E. Microperimetry and fundus autofluorescence in patients with early age-related macular degeneration. *Br J Ophthalmol*. 2007;91:1499–1503.
16. Iwama D, Tsujikawa A, Ojima Y, et al. Relationship between retinal sensitivity and morphologic changes in eyes with confluent soft drusen. *Clin Exp Ophthalmol*. 2010;38:483–488.
17. Parisi V, Perillo L, Tedeschi M, et al. Macular function in eyes with early age-related macular degeneration with or without contralateral late age-related macular degeneration. *Retina*. 2007;27:879–890.
18. Leonova A, Pokorny J, Smith VC. Spatial frequency processing in inferred PC- and MC-pathways. *Vision Res*. 2003;43:2133–2139.
19. Meleth AD, Mettu P, Agrón E, et al. Changes in retinal sensitivity in geographic atrophy progression as measured by microperimetry. *Invest Ophthalmol Vis Sci*. 2011;52:1119–1126.

20. Heijl A, Lindgren G, Olsson J. A package for statistical analysis of visual fields. In: Greve EA, Heijl A, eds. *Documenta Ophthalmologica Proceedings Series: Proceedings of the 7th International Perimetric Society Meeting 1986*. Dordrecht: Junk Publishers; 1987:154–168.
21. Denniss J, Astle AT. Spatial interpolation enables normative data comparison in gaze-contingent microperimetry. *Invest Ophthalmol Vis Sci*. 2016;57:5449–5456.
22. Astle AT, Ali I, Denniss J. Central visual field sensitivity data from microperimetry with spatially dense sampling. *Data in Brief*. 2016;9:673–675.
23. Heijl A, Lindgren G, Olsson J. Normal variability of static perimetric threshold values across the central visual field. *Arch Ophthalmol*. 1987;105:1544–1549.
24. R Development Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2015. Available at: http://www.R-project.org/. Accessed April 2, 2017.
25. Shima N, Markowitz SN, Reyes SV. Concept of a functional retinal locus in age-related macular degeneration. *Can J Ophthalmol*. 2010;45:62–66.
26. Rees AL, Kabanarou SA, Culham LE, Rubin GS. Can retinal eccentricity predict visual acuity and contrast sensitivity at the PRL in AMD patients? *International Congress Series*. 2005;1282:694–698.
27. Crossland MD, Gould ES, Helman CG, Feely MP, Rubin GS. Expectations and perceived benefits of a hospital-based low vision clinic: results of an exploratory, qualitative research study. *Vis Impair Res*. 2007;9:59–66.
28. Schmitz-Valckenberg S, Bültmann S, Dreyhaupt J, Bindewald A, Holz FG, Rohrschneider K. Fundus autofluorescence and fundus perimetry in the junctional zone of geographic atrophy in patients with age-related macular degeneration. *Invest Ophthalmol Vis Sci*. 2004;45:4470–4476.

Investigative Ophthalmology & Visual Science