USE YOUR PC TO QUICKLY MAP REMAINING VISION AFTER FOVEAL VISION LOSS

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Introduction

This research and development project addresses the needs of patients with foveal and/or parafoveal field loss due to, for instance, Age-Related Maculopathy (ARM). If this loss is foveal and binocular, the patient will have to learn to use eccentric retinal areas that are still intact. This requires adopting a new gaze strategy called "eccentric viewing". [1-8] This means that gaze will have to be intentionally diverted in such a way that the image of the object of interest falls onto intact parts of both retinae. Using appropriate magnification, most patients can learn this technique and can even learn how to read again. Some achieve this goal on their own, while others require goal-directed instruction and training. [9]

The learning process patients need to master can be broken down into the following steps:

A. Awareness of the existence, position and size of the scotoma. Usually this is spontaneously evident only to those who are motivated to experiment by themselves, which is often not the case.[10] Motivated patients can acquire this knowledge at home by keeping the eye directed at a conspicuous landmark while moving an object through the visual field in different directions. In a clinical setting, it can be demonstrated by flicker campimetry or careful tangent screen testing.

B. Awareness of the position in the visual field, where a stimulus has to appear to be seen most clearly. This position can later be adopted as a Preferred Retinal Locus (PRL) for eccentric viewing. Our Macular Mapping Test (see below) provides this information for the majority of patients who do not get to this point by themselves.

C. Practice to willfully direct gaze, so that the image of interest falls and stays on the PRL.

D. Practice to consciously keep sustained focal attention deployed at the PRL to optimize perception, i.e. to make the best of remaining vision. Research has shown that the ability to do this may depend on the location in the visual field[11], which would explain why many patients choose PRL locations that are not favorable for reading, the primary goal of low vision rehabilitation.[12-14]

E. Willful control of scanning eye movements with eccentric viewing of changing objects of interest, e.g. across a text for the purpose of reading.

The Macular Mapping Test ("MMTest") described here provides patients with sensory evidence that they have a scotoma. The primary target population consists of patients with a recently acquired maculopathy, i.e. those who have not yet established their eccentric viewing habits. It also teaches those who do not find out by themselves, where their best remaining vision is. The results also tell the eye care specialist which gaze strategy to recommend to the patient without having to perform a complete course of conventional perimetry.

A precursor of this test, developed on a now obsolete computer has been described elsewhere [15-16], as was an earlier version of the PC implementation[17].

Methods

2.1. Computer hardware and software

The current PC-compatible program follows the same strategy as the previous implementation (see Mackeben and Colenbrander, 1994). The development was guided by the following objectives:

A. Preserve topographic accuracy (help stabilize gaze with special test background)
B. Minimize discomfort and fatigue (no eye movement monitoring, short duration)
C. Use targets relevant to reading tasks (letters and words)
D. Keep costs low (allow use of ordinary PC without hardware modification)
E. Maximize ease of handling (make options obvious, follow Windows conventions).

The test procedure was programmed in Delphi 1 (Borland-Inprise, Inc.). It runs on all IBM PCs and compatibles that can run the Windows operating system (version 3.1 and up) and with any video card. It does not require any hardware modifications and requires very little memory (< 1 Mb).

2.2. Patients

The test (both implementations) was performed 186 times using 95 eyes of 71 patients. Ages ranged from 25 to 92 (mean: 69.2 +/- 19.4). The visual acuities of tested eyes ranged from 20/40 to 20/1000. A majority of patients (47/71 = 66%) suffered from Age-Related Maculopathy (ARM), but other pathologies causing central field loss were included (e.g. glaucoma [7], Stargardt's disease [5]). The number of tests reported is higher than the number of subjects, because either both eyes were tested (24 Ss), or the same eye was tested more than once to assess test-retest reliability. If foveal vision was severely impaired in both eyes, only the one with the better visual acuity was tested; otherwise, the one with remaining foveal vision was tested (OS: 23, OD: 24).

Most patients were tested after receiving an ophthalmological examination in the Low Vision Service directed by one of us (AC). All signed an informed consent form that was approved by the Institutional Review Board at California Pacific Medical Center.

2.3. Setup

Subjects were comfortably seated in front of a monitor. The viewing distance (here 70 cm) was adjusted according to screen size by a one-time calibration routine, so that a central field of 16 degrees diameter was tested. Viewing was monocular, while the subject's head was stabilized by a chin- and forehead-rest.

Results

3.1. Program Description

3.1.1. Procedure

Each test begins with a background screen showing a circular display area and 8 radial spokes ("wagon wheel pattern", see Figure 1a). The center is usually empty, but a central fixation mark is available for patients with intact or residual foveal vision. This background pattern gives patients with a central scotoma peripheral feedback when the eye moves and allows correcting eye movements.
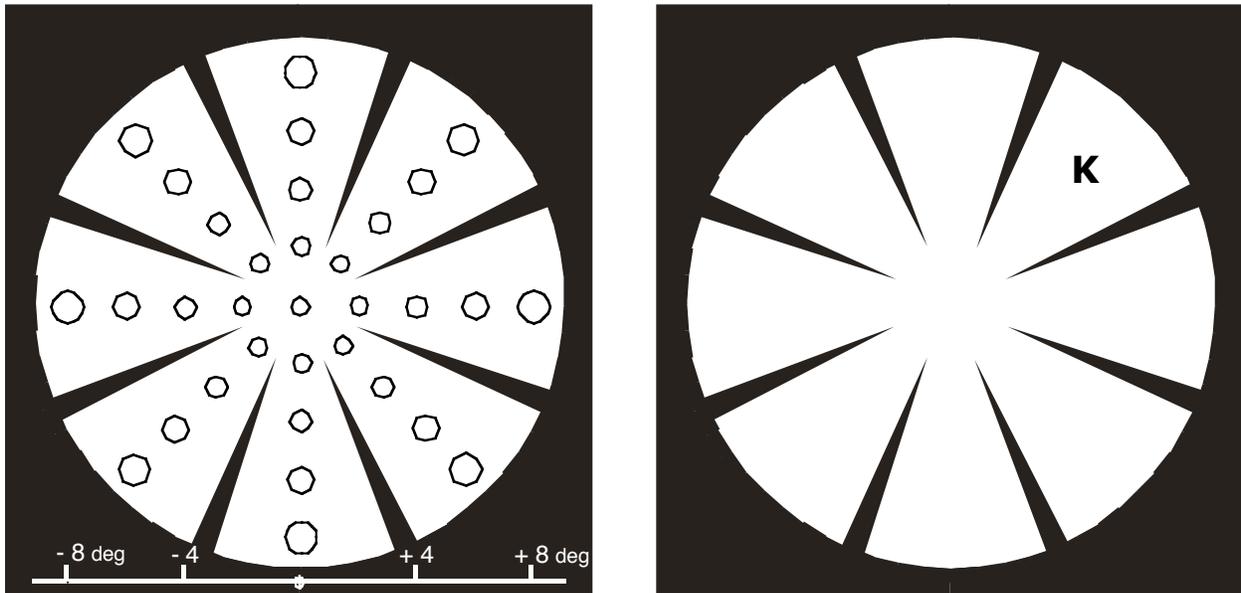
Figure 1: A. shows the "wagon wheel" background pattern designed to help gaze stabilization. The dots show all possible test locations and are not visible. They lie at 2, 4, 6, and 8 deg eccentricity. B. is the background and a letter target (duration = typically 250 ms) as seen during a trial by the patient.

3.1.2. Instructions

We avoid the words "look at" or "fixate" in the instructions to the patient. Instead, we asked "Do you have a sense where the center of the circular display area is?" Patients always said "yes". This was followed by the request "Please direct your gaze at that center and leave it there as still as possible throughout the test". In a previous study, we found that most patients with central scotomata can perform this task with acceptable accuracy [18].

3.1.3. The task

Each trial displays a single letter or a word in an unpredictable sequence in each of the 33 test locations (8 each on 4 rings, plus the fovea; see Fig. 1a). The center is tested 4 times and with increasing letter sizes to test for residual foveal vision. Thus, the standard "global" round of field exploration comprises 36 trials. Targets are the letters of the Sloan set [19] or 5-letter words. The presentation time is adjustable, the default is 250 ms (see Fig. 1b). The letter height depend on two factors: A variable universal size factor, based on the visual acuity rating, and a fixed eccentricity factor, based on eccentricity in the field [6]. The patient reports to the examiner whether a letter was seen, and if yes, which letter it was. Accordingly, responses fall into 3 categories: "Not detected", "detected, but not recognized", and "recognized". The examiner enters the response on the keyboard, and the program automatically stores these data in a data base.

3.1.4. Special features:

A. To explore a promising "candidate" spot further, the examiner can choose to get more data around this location by clicking on it and performing a "local" test with 8 more tightly spaced test points. For even greater accuracy, the tested location can also be

determined by a tiny mouse-driven cursor that the patient cannot see. After positioning the cursor, the examiner clicks the mouse to elicit the next trial.

B. To assess the lateral extent of promising areas, 5-letter words can be used instead of the letter targets. This provides a more realistic connection with reading performance. Letter spacing can be increased to compensate for the increased crowding effects in the retinal periphery [20-22].

C. Test data sets can be extracted from the data base and sent by email as ASCII files to any other MMTest installation.

D. The default eccentricity-dependence of the targets can be inactivated to allow the analysis of the capabilities a patient has with a given, constant letter size, as in a natural reading situation.

E. The foreground and background colors can be reversed to white-on-black to reduce glare.

F. The foreground and background colors can be set separately to any of 16 gray values. If there is need for quantitative work, the program supports an absolute luminance calibration of each gray value using an external photometer.

3.2. Test results

The 186 "global" tests reported here took on average about 3 minutes (184.4 +/- 43.0 seconds), and the test durations showed no significant correlation with age. If a patient experienced fatigue, he/she could ask for an interruption of the test (usually 1 min); sixteen patients used this chance, which also showed no correlation with age (mean = 71.8 ± 19.3 vs. 69.2 +/- 19.4 for all patients). The reported test durations represent "pure" test durations, i.e. they do not include rest intervals).
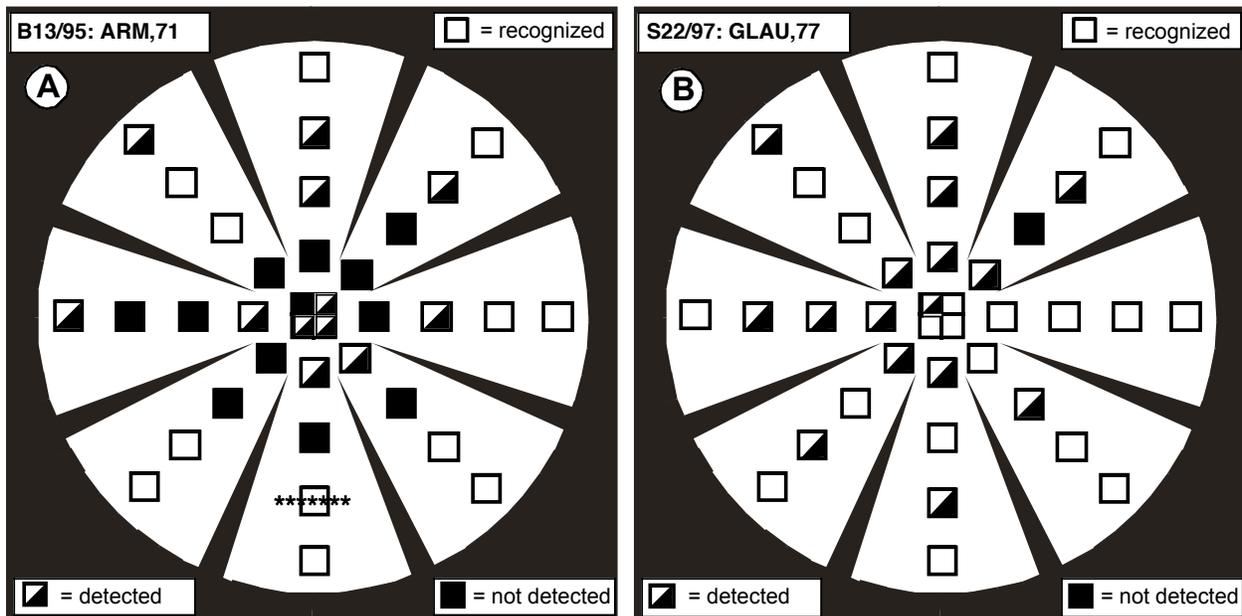

Figure 2: A. Results chart of a 71 year old ARM patient. Foveal vision is impaired by a relative scotoma that prohibits letter recognition even at the largest size. By observing the patient and by asking him to describe how he reads, it appears that he uses the area below the center (marked "*******") as Preferred Retinal Locus (PRL) for reading. B. This 77 year old glaucoma patient has intact foveal letter recognition at all sizes from 10 arcmin on. She reads with modest magnification, but complains that she often has problems finding things.

Examples of result charts based on "global" rounds of testing are shown in Figure 2 a +b. We found the following general visual field features:

Foveal scotomata

Eighteen of the 47 ARM patients had an absolute foveal scotoma in the tested eye.

Ring scotomata

Eleven patients had a ring scotoma in one eye, 6 of whom had ARM. Seven others had a ring scotoma in both eyes, 5 of whom had ARM.

Locations with intact letter recognition

The tested eyes showed between 0 and 32 locations with intact letter recognition that lay between 0 deg (fovea) and 8 deg eccentricity. Their practical value is determined by their absolute position and distance from the fovea: As long as any foveal letter recognition was left or was achievable by magnification, patients reported that they used it in everyday life, albeit with high magnification requirement for some. For these patients, this test could only have a prognostic value with respect to eccentric viewing. Of the 22 patients with binocular absolute foveal scotomata, 10 had already discovered eccentric viewing and used it habitually. The other 12 did not; they received further demonstrations and instructions.

Comparison between eyes

Both eyes were tested in 24 patients. Of these, 15 had ARM, and the difference of disease progression between eyes varied widely. The number of locations with intact letter recognition was counted for both eyes and the results were compared (Better/Worse Ratio = BWR). The BWR values varied between 1 and 9 (mean = 3.0 ± 2.7).

Possibility of binocular eccentric viewing

Seven patients with advanced ARM showed only a low to moderate difference between the eyes (BWR ≤ 2.0), so that binocular eccentric viewing might be possible. The practicality of this finding depends on the question whether the "good" spots lay in corresponding retinal locations. In the eyes of these 7 patients we found 0, 2, 2, 4, 5, 6 and 8 corresponding "good spots" (mean = 3.86 ± 2.73). Hence, 6 of the 7 patients would have a chance to practice binocular eccentric viewing. In reality, only 2 used it regularly, 2 did not know about it, and 3 had no reason to use it, because foveal vision was still sufficient.

Practical usefulness

More extensive data were obtained in some patients by using the "manual" mode with letter and word targets, the results of which can be seen in Figure 3 a + b. These tests always confirmed the presence of a "good spot", but sometimes found it to be too small in horizontal extent to be of practical value for reading.

Exceptions

Two patient demonstrated visual acuity ratings and reading performance that could not be explained by our test results: Both had small "islands" of intact vision next to the fovea that allowed good letter acuity as well as reading of 14 point text, albeit with reduced speed. These islands were not captured by our limited number of test locations

in the "global" mode, but were later confirmed by testing in the "manual" mode. As can be expected, both could not identify 5-letter words without moving their eyes.
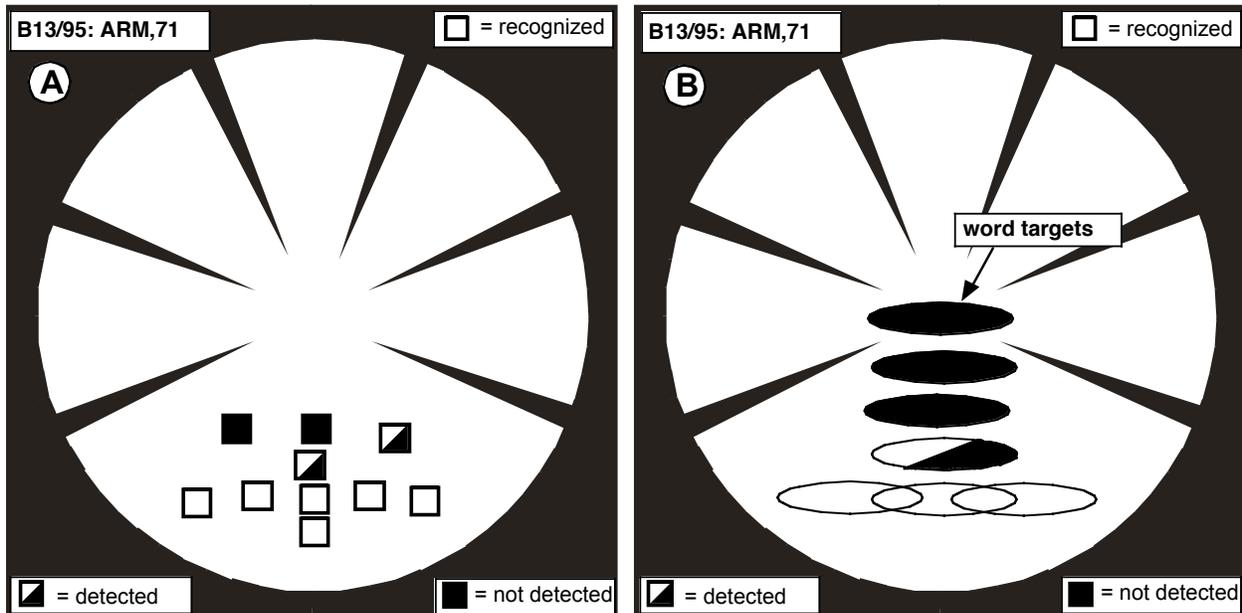

Figure 3: A. Results of field exploration in the "Manual" mode with the same patient as in Figure 2A. A The examiner directs a tiny cursor (invisible to the patient!) using the mouse to the desired locations and clicks to elicit the next trial with single letter targets. The finding confirms intact letter recognition to the right and left of the "good spot" found in the "global" mode (see Figure 2 A). B. The same area in the same patient as in A. is explored in "manual" mode using 5-letter word targets. The results confirm that this location enables the patient to recognize words and, thus, can be considered as a candidate for reading with eccentric viewing. A test with regular reading material in this patient showed that this is indeed the case (magnification requirement: 3X).

Discussion

The procedure of administering the test is easy for the examiner and requires little knowledge of computers or the software. As long as the patients responses are entered accurately on the keyboard, data integrity is preserved. This is augmented by the fact that typing mistakes can be corrected as long as it is done immediately. The data from every completed round of "global" test are saved automatically, which prevents data loss due to forgetfulness.

For the patient, however, the test is demanding due to the high level of concentration required for maintaining a stable gaze. This is partially compensated for by the short duration, which is only a fraction of what is required for conventional perimetry. No patient reported pain, eye strain, excessive fatigue or other signs of discomfort.

Topographic accuracy depends only on the patients ability to stabilize their gaze. This turned out to be sufficient for the resolution of the pattern of test locations, which lie 2 degrees apart. We attribute this favorable result to the use of the "wagon wheel" background. We found only three patients, to whom the test could not be administered,

as they showed insufficient gaze control. This could be explained by the presence of additional neurological disorders.

The adequacy of the topographic accuracy is also reflected in the > 90% test retest reliability. It cannot be expected to be perfect, especially in light of the fact that there is one trial per location. This is acceptable, because the results have to be viewed in the context of the overall test strategy that aims to detect "candidates", which can immediately be verified by other tests. This was confirmed by fact that additional testing of candidate locations in the "local" and "manual" modes always found one or more "good spots". The next higher order of testing provided by this test is the use of word targets, the highest validation short of actual reading. We found that adding these additional tests (local, manual with letters and manual with words) added about another 3 minutes to the procedure. This is an excellent performance, considering that the results have the potential to be actually helpful to the patient's rehabilitation.

We found that of the 47 ARM patients, only 7 (15%) showed a low to moderate Better-Worse-Ratio (≤ 2); in 85% we found a high BWR or we did not test both eyes because of the large differences in visual acuities between eyes. This confirms the clinical finding that there may be large differences in ARM onset or progression between the eyes.

Organizational aspects of our access to the patients prevented repeated measurements over a longer period of time in most cases. For the moment, we can only say that those patients with a real need for eccentric viewing, i.e. with an absolute foveal scotoma in both eyes, and with low "scotoma awareness" responded positively. They typically responded by calling the results "interesting", "helpful" and "teaching".

The small number of patients (6), whose eyes had comparable vision left (BWR ≤ 2) and who shared a few corresponding "good" locations, indicates that binocular eccentric viewing may be possible for only a few. The others will have to either neglect the input from the worse eye or cover it while using the better eye for eccentric viewing.

It is no surprise that the 2 deg spacing of our test locations should allow to miss small island of intact vision. Hence, the examiner should always look for discrepancies with the letter acuity and reading performance and, if indicated, follow up by testing in the "manual" mode.

Summary

We have demonstrated that this test provides a simple and inexpensive way to evaluate the functional topography of remaining vision in patients with various maculopathies. The findings can help in guiding the ever growing population of patients with age-related maculopathy towards earlier and more effective use of eccentric viewing and, hence, to preservation of a better quality of life.

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