The Use of Frequency Doubling Technology to Determine Magnocellular Pathway Deficiencies

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Abstract

The Matrix® is the latest generation Frequency-Doubling Technology (FDT) perimeter, introduced to the eye care professions in 2003. With seven tests available, visual field testing can proceed from the macula to an eccentricity of thirty degrees. Its ability to detect magnocellular pathway deficiencies has made FDT an excellent tool in the management of glaucoma.

The purpose of this article is to discuss FDT, review some of the literature regarding the magnocellular pathway, outline the technical aspects of the Matrix, and to present clinical examples and observations of the use of FDT technology in areas of visual function that are of particular interest to behavioral optometrists.

Key Words

amblyopia Frequency-Doubling Technology (FDT), glaucoma, Humphrey® Matrix, magnocellular, saccades, Streff syndrome, traumatic brain injury, visual fields

Introduction

The preferential damage of Magnocellular (M) cells in glaucoma is well documented.[1-8] Researchers used the basic properties of the M cell to create a simple, yet meaningful, test in assessing the visual fields of glaucoma patients. The most recent addition to the family of visual field instruments is the Matrix by Humphrey® utilizing Welch Allyn® frequency-doubling technology.[a]

Frequency Doubling Technology (FDT)

In 1966 Kelly reported the doubling appearance of a grating stimulus when it was counterphase-flickered.[9] That is, when a person views a grating of alternating black and white sinusoidal stripes of low spatial frequency that are rapidly reversed, or flickered, the grating appears to have twice the number of stripes; hence, frequency doubling. Rectification and compression of nonlinear responses in the visual system have been attributed to the frequency doubling effect perceived by the human visual system.[10-12] It was not until the 1990s that this phenomenon was linked to a subgroup of M cells that could be selectively lost in glaucoma, and since has received a lot of research emphasis.[1-9]

Retinal Ganglion Cells

Cells at the retinal ganglion cell layer differ in many ways. They can be categorized into various classes depending on anatomy, physiology, or response to stimuli. At the amacrine cell level, three categories of cells are identified: magnocellular (M), parvocellular (P), and koniocellular. This differentiation continues in pathways to various areas of the brain.[13,14] The P pathway is the only one that has visual resolution of detail capability. The kinocellular pathway has not gained the level of interest in the literature as has the M-P dichotomy. This dichotomy is also known as the transient-sustained system respectively, because of the transient and sustained nature of amacrine cells.[15]

The Magnocellular (M) System

Anatomically, the M pathway is considered to have a greater influence in the peripheral retina. This may explain some of the characteristics of the system. Although they are larger in size than the P cells, the M cells only represent 10% of the retinal ganglion cells in the primate eye. This may explain why only the two ventral layers of the six layers of the dorsal lateral geniculate nucleus (LGN) have M cell synapses, while the P cell synapses are found in the remaining four layers. After the LGN synapses, the M pathway takes a dorsal route that eventually reaches the middle temporal, superior temporal, and parietal cortices.[16,17]

The M and P systems differ in at least four functional ways: color sensitivity, contrast sensitivity, temporal resolution (motion) and visual spatial resolution (acuity). The M system has poor color sensitivity and poor acuity; however, it is very sensitive to movement and low spatial frequency stimuli. [18-22] Though the exact role of the M pathway is not fully understood, it is known that it carries information on movement, stereopsis, spatial localization, depth perception, hyperacuity, figural grouping, illusory border perception, and figure/ground segregation.[23]

Although there is some conflict in the literature, most agree that there is a disruption or imbalance of the M-P systems in many patients with visual functional problems. For example, an imbalance has been well documented in saccadic eye dysfunctions and dyslexia.[24-30]

The M system plays an important role in saccadic suppression as the visual system fixates from one point to another. Breitmeyer claims that an intact M system is essential for the brain to keep the packet of information taken in by the P system during each fixation separate from the next packet, during a saccade.[31] The M system is thought to suppress the P system without disrupting perception.[30]

Some studies have indicated that there is a dysfunction of the M pathway in dyslexia (specific reading disorder).[32-34] Flicker fusion thresholds, motion judgment tasks, evoked potential measures, coherent motion, and the spatial frequency doubling illusion all offer evidence that the M system is not functioning well in dyslexia.[35] A recent publication by Chase, et al. demonstrated the M pathway as being an important contributor to text perception.[36] Without the M pathway individuals would be able to see detail via the P pathway, but text perception provided by the M pathway would be lacking. Deficiencies in the visual attention system are also M related.[37] There are skeptics, however, who consider dyslexia solely a linguistic dysfunction.[38-39] A review of the literature would indicate dyslexia as being more than a simple condition; more like glaucoma, i.e., a variety of conditions grouped under one heading.[35,40-41]

M deficits have been noted in patients who have Alzheimer's disease. In these patients a degeneration of the optic nerves and the retinas has been found. Patients with Alzheimer's have difficulty perceiving low spatial frequencies and demonstrate atrophy of the associated cortex of the posterior parietal and occipital lobes.[42-45]

Glaucoma has been extensively studies and continues to be extensively researched. The M system damage has been shown to be significant in this disease, with FDT being sensitive to this type of damage at least at the same time or sooner than white on white fields.[46-52] The Humphreys® Matrix[a] (the Matrix) is specifically designed to target the M system that is thought to be damaged in the earlier stages of the disease. It is well documented that the M fibers are greatly affected in this devastating disease.

Table 1. The Matrix Testing Strategies[53]

FDT Test	Field of view tested (degrees)	Approximate target size (degrees)	Spatial frequency (cycles/degree)	Temporal frequency (Hz)
N-30-5 (-1) Screening	Central 30	10 x 10	0.25	25
24-2-5 (-1) Screening	Central 30	5 x 5	0.50	18
N-30-F Threshold	Central 30	10 x 10	0.25	25
24-2 Threshold	Central 30	5 x 5	0.50	18
30-2 Threshold	Central 30	5 x 5	0.50	18
10-2 Threshold	Central 10	2 x 2	0.50	12
Macula Threshold	Central 5	2 x 2	0.50	12

Table 2. The Matrix Tests[53]

FDT Test	Visual Field Locations	Probability Level Class-ifications	Fixation Catch Trials	False Positive Trials	False Negative Trials	Test Strategy
N-30-5 (-1) screening	19	4	3	3	0	Supra-threshold
24-2-5 (-1) screening	55	2	10	10	0	Supra-threshold
N-30-F Threshold	19	4	6	6	3	MOBS
24-2 Threshold	55	4	10	10	6	ZEST
30-2 Threshold	69	4	10	10	6	ZEST
10-2 Threshold	44	4	10	10	6	ZEST
Macula Threshold	16	4	6	3	0	ZEST

MOBS= Modified Binary Search, ZEST= Zippy Estimate of Sequential Testing

The Matrix

To fully understand the clinical use of any instrument, it is necessary to understand the tests the instrument provides. The Matrix uses FDT to specifically target the M pathway. One of the limitations in the original instrument was the large testing target (stimulus) size. The new generation instrument uses smaller targets; thus, it is able to test for smaller and more localized defects. Tables 1 and 2 present the specifics of the instrument's testing strategies and test specifics respectively.

With the classic Heijl-Krakau method of monitoring fixation, reliability of patient fixation can be measured, through fixation losses.[53] Other reliability measures include false positive and false negative catch trials. The sum of the reliability factors determine the field's overall reliability. Stimuli are presented in random order with a test duration of 300ms per stimulus. The mean test background illumination is set at 100 cd/m.[2] Contrast ranges vary from 56dB to 0dB (N-30 tests), and 38dB to 0dB (24-2, 30-2, 10-2 and macula test).[53] Most testing can be done in five to six minutes per eye.

Clinically the test appears reliable in detecting many M deficits. First and foremost is its ability to detect damage secondary to glaucoma. The instrument has become my first choice of glaucoma field tests. We have also increasingly used the instrument for baseline fields on most traumatic brain injury and vision therapy patients. In the following sections I present a discussion, some preliminary observations and illustrative FDT (Matrix) visual fields, of several conditions that are of interest to the behavioral optometrist.

The presented visual field figures are of one eye since, in all these patients, the other eye's visual field was essentially the same. All figures are presented on pages 34 and 35.

Streff Syndrome

Streff syndrome is said to exhibit a reduction of acuity in both eyes, with distance acuity worse than near acuity. Although these patients retinoscope or autorefract between -0.50 and +1.00, there is most usually no improvement in acuity with the indicated corrective lenses. The syndrome is mostly found in children around the age of puberty, often with significant, stressful, life and school situations. Usually a low plus prescription over their manifest helps these patients significantly,[54-60] perhaps by stimulating the M pathway.

A 14 year-old- male presented with reduced acuity both at distance and at near in each eye. He exhibited the classic tubular fields on confrontation tangent screen testing. Humphrey® Matrix testing was performed, with considerable abnormalities noted. There was a general depression of the visual field that was repeatable, and not attributable to pathology. The mean deviation is greatly reduced, but there are no major defects on the pattern deviation. These findings indicate a dysfunction of the M pathway. See Figure 1.

Saccadic Dysfunction

Saccades involve conjugate eye movements allowing the visual system to refixate to another point of interest. The pathway that initiates the saccade is located in the brain stem with active input from the frontal lobe.[61,62] When reading it is necessary to dampen the visual signal between rapid eye movements. This is accomplished by saccadic suppressions.[63] However, if there are deficiencies in the M pathway, these saccadic suppressions can be adversely affected. In this instance it is not uncommon to experience visual smear or word overlap that can cause visual confusion. The dampening aids in preventing visual confusion while reading.[64-66]

We have done preliminary observations on the FDT visual fields of some patients with saccadic dysfunction. We have obtained repeatable visual field loss or reduction in the mean deviation that is not a function of pathology. There is usually a notable depression of the central fixation sensitivity noted on most patients. The average central depression ranges about two to five decibel of sensitivity. The mean deviation is often also depressed by at least two decibels. See Figures 2 and 3.

Amblyopia

Amblyopia is a myriad of conditions that may involve irregularities in the P or M systems, and at times is a combination of both systems.[67] Our overall impression is that some strabismic amblyopic patients' FDT fields are impaired, with reduced foveal sensitivity and reduced mean deviations, while those with refractive amblyopia have more intact FDT fields, unless their acuity is worse than 20/50. However, these are clinical impressions at this time, and are offered as such.

Glaucoma

The selective impairment of the M system in glaucoma, and the ability of FDT to illustrate these impairments have been well documented.[1-8] We have found that many of these patients present with asthenopic symptoms, particularly when engaging in near centered tasks. Often, they are diagnosed with oculo-motor dysfunction, convergence insufficiency, and reduced stereopsis. This is in agreement with at least several reports.[68,69] Visual fields obtained using FDT technology are similar to those obtained from the usual white on white field.[70] However, we have observed that in at least some glaucoma patients, good central sensitivity is retained till later in the disease when mean deviation is greatly reduced. It is at this time that most visual functional problems seem to occur; usually the worse the central deviation is from normal, the worse the patient's binocular problems. See Figures 4 and 5.

Traumatic Brain Injury (TBI)

Brain insults resulting in damage to the visual pathways from the retina to the occipital lobes often result in visual field defects characteristic of the part of the pathway that is damaged. When higher areas of the brain are damaged, as in the frontal eye fields, it is not uncommon to encounter problems with saccadic and pursuit eye movements.[61,62] When areas in the parietal and temporal lobes are affected, visual neglect can result.[71] We have found the Matrix to be effective in detecting changes in patients with M deficiencies, and visual field loss. We have found that the FDT visual fields of TBI patients usually demonstrate a reduced central sensitivity and an overall diffuse loss of sensitivity noted in the reduced mean deviation. A mean reduction of at least six to ten decibels is noted on the total and pattern deviation maps at central fixation. See Figures 6 and 7.

Some of these TBI patients with no complaints have an overall visual field defect, but no central reduction of sensitivity. This is evident in the patient who had diffuse brain injury, with scattered defects. See Figure 8. However, the patient was not symptomatic at the time of visit, and had demonstrated good central sensitivity.

Conclusion

I have illustrated several cases where FDT has been useful in obtaining information that show promise in adding to the diagnosis, treatment and management of several visual conditions that optometrists frequently treat. There is the potential for its use for other conditions since the M pathway is involved in many visual tasks.

We intend to institute further investigations of the efficacy and use of FDT technology. For example: a comparison of the efficacies of FDT visual fields versus various conventional static and kinetic perimetry; the effect of vision therapy on FDT visual fields; studies of FDT visual fields in the various aspects of binocular function such as accommodation and vergences. Such research may provide a valuable tool to document and better understand a wide range of functional visual problems.

The author has no financial or other interest in the Humphrey® Matrix Visual Field Instrument with WelchAllyn Frequency Doubling Technology.

Sources

a. Humphrey® Matrix Visual Field Instrument with WelchAllyn Frequency Doubling Technology. Zeiss Carl Zeiss Meditec. Carl Zeiss Meditec, Inc. 5160 Hacienda Drive, Dublin, California, USA 94568. 877-486-7473

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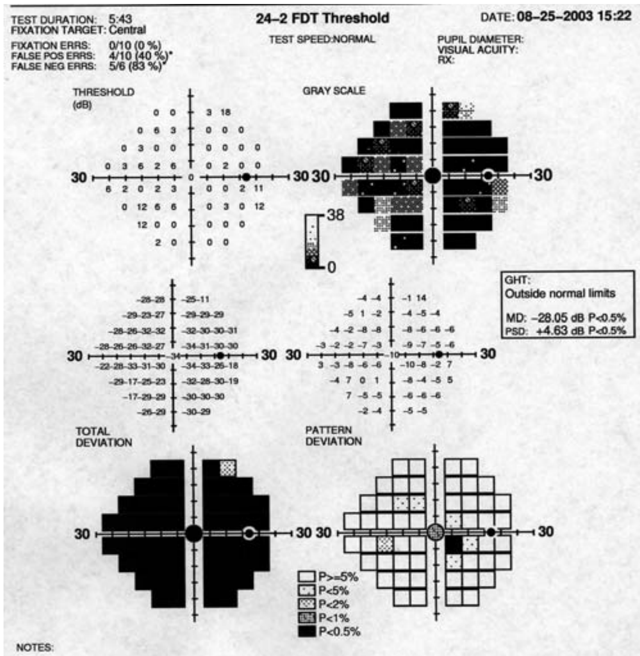

Figure 1. Right eye visual field. General reduction in sensitivity in patient with Streff Syndrome. Note the reduction in mean deviation (-28.05dB), and the close to normal pattern deviation. Note reduction in central foveal sensitivity even on pattern deviation (-10dB).

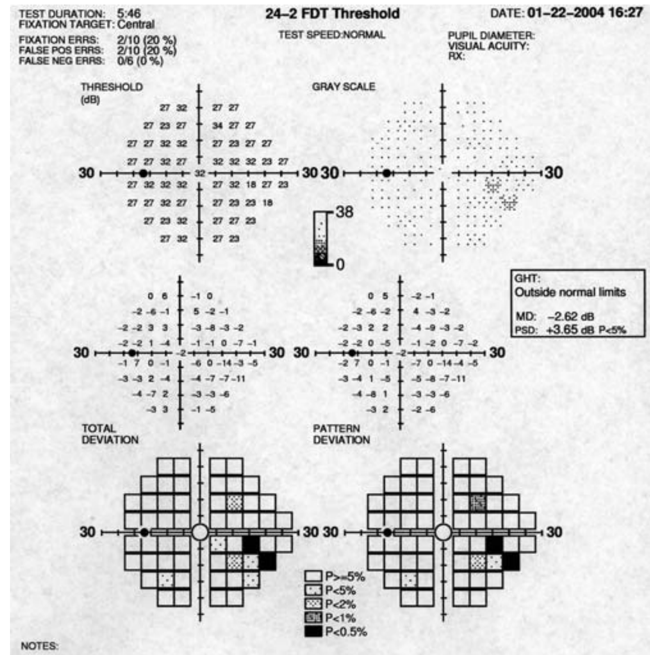

Figure 2. This left eye visual field of a patient with saccadic dysfunction illustrates a reduced mean deviation that is repeatable. Central depression usually measures around -1 to -5 dB on average.

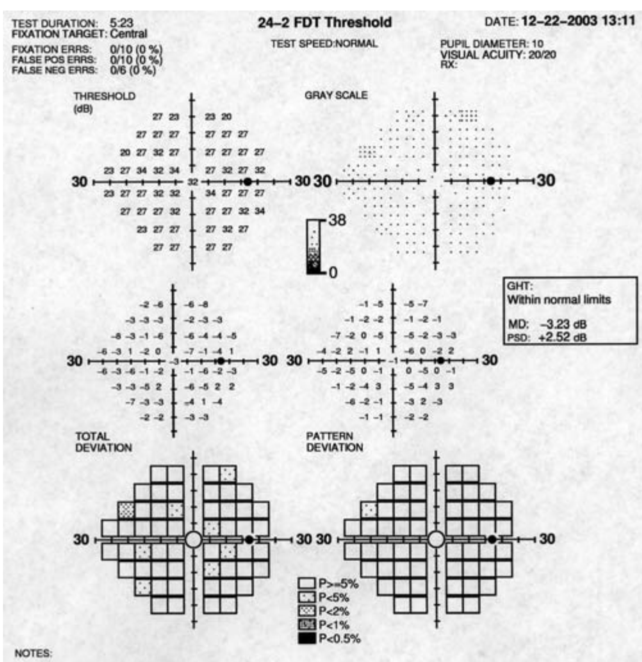

Figure 3. This figure represents left eye repeatable visual field of a 10-year-old male with mild saccadic dysfunction as determined with DEM and NSUCO tests. Notice the mild reduction in central sensitivity and mean deviation.

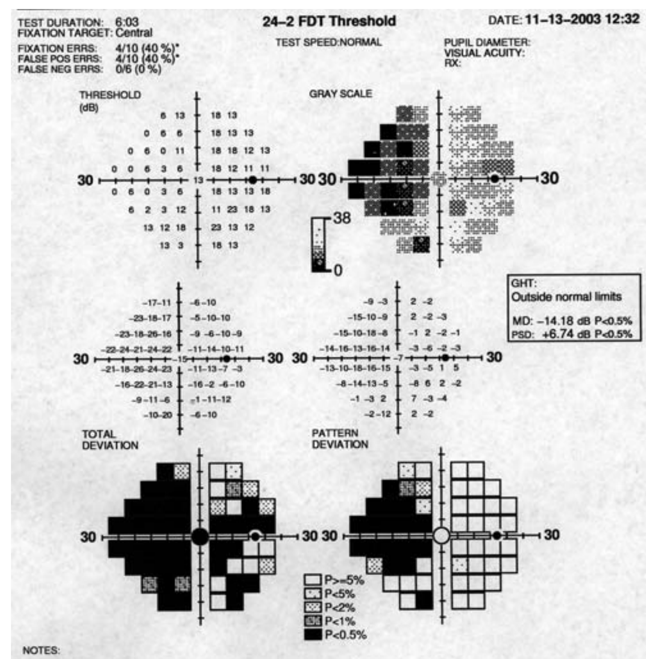

Figure 4. Right eye visual field of a glaucoma patient with complaints of fatigue and eye strain when reading, with occasional double vision. Notice that this patient has reduced foveal sensitivity (-7 dB), with reduced mean deviation.

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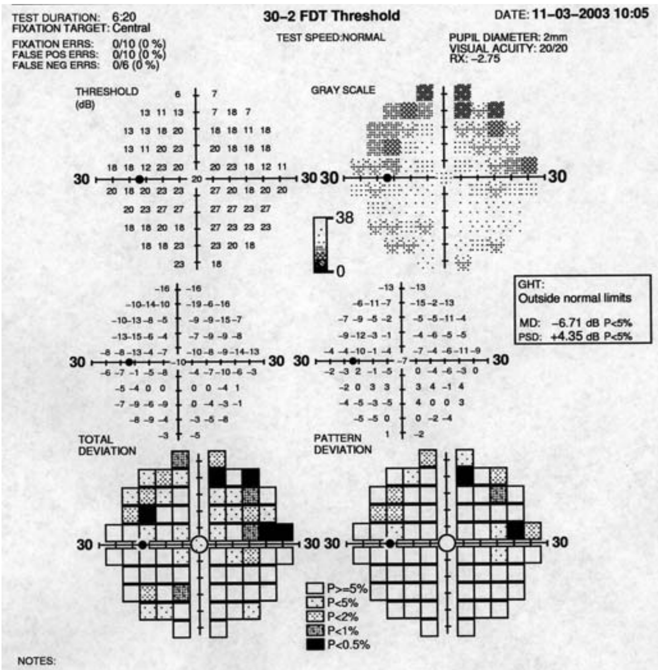

Figure 5. Left eye visual field of a 46-year-old female who presented with complaints of headaches and skipping lines while reading. The patient was diagnosed with glaucoma one year prior. Notice the reduction in foveal sensitivity and mean deviation.

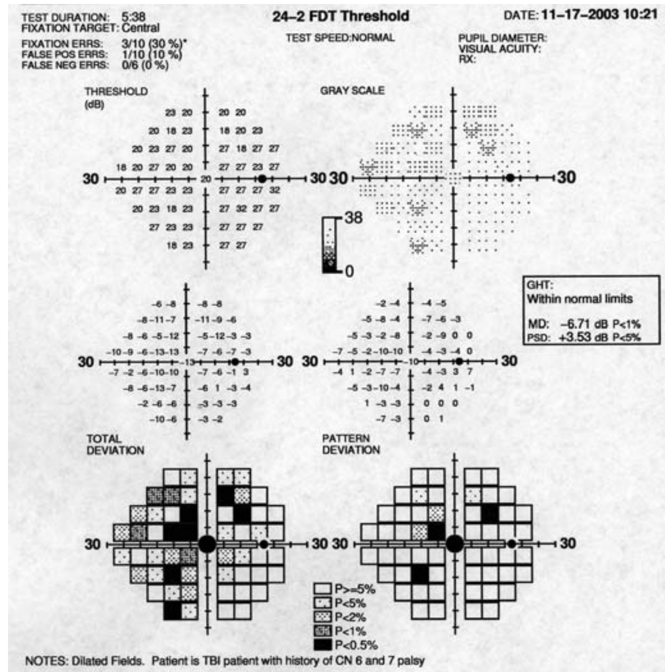

Figure 6. Right eye visual field of a 18-year-old female who presented 2 years post head trauma with poor saccades, pursuits and stereopsis. A 10-14 dB reduction of central sensitivity was noted on repeated fields.

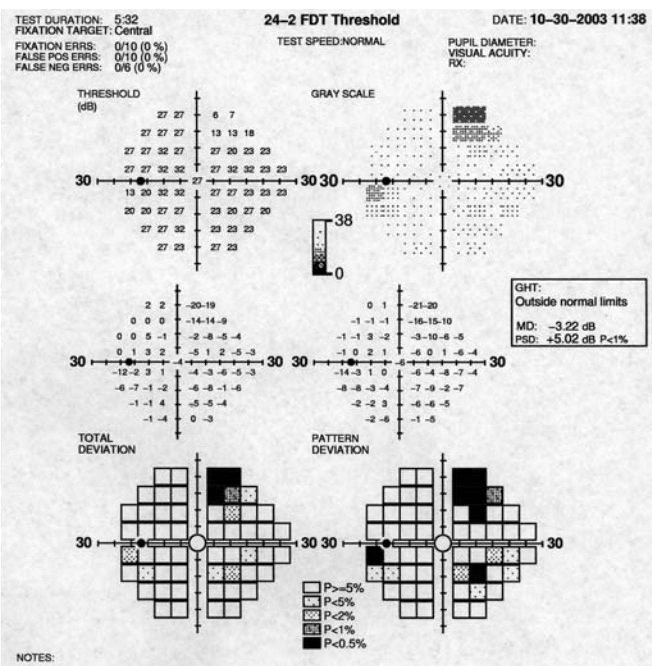

Figure 7. Left eye visual field of a 33-year-old male who presented post brain tumor removal. Note the reduction in central sensitivity. This patient has significant saccade and pursuit dysfunctions.

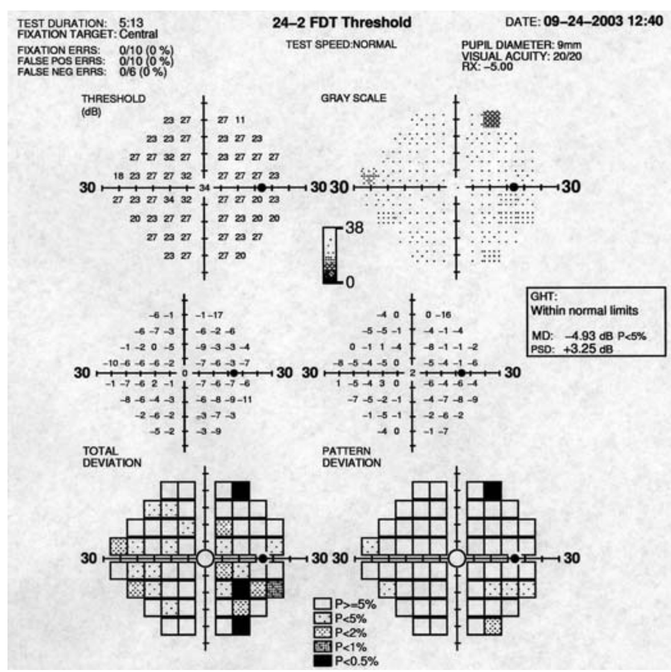

Figure 8. Right eye visual field of patient who suffered head trauma 10 years previously with minimal complaints at yearly follow up. Notice the close to normal foveal sensitivity.

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Date accepted for publication:
March 10, 2004