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A computerized perimeter for assessing modality-specific visual field loss

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Abstract

The characterization of visual field loss provides a valuable diagnostic metric for studying the effects of damage to the retina, optic nerve or visual cortex. We describe a tool, the Quadrant Vision Perimeter (QVp), to rapidly and accurately measure visual fields. In addition to measuring the location of visual deficits, the tool can assess modality-specific field loss (e.g., impaired detection of luminance, motion, depth and color) and severity of the deficit. We present validation and normalization for parameters of visual attributes, as well as exemplar comparisons of visual fields obtained automatically using QVp to standardized perimeters for three stroke patients. Patient visual fields are compared among visual features to assess modality-specific deficits, and over time, to measure fine changes in visual fields, due either to spontaneous recovery or visual degradation.

I. Inroduction

Insults to the brain, such as tumors, stroke, or traumatic brain injuries often leave the patient with severe visual field (VF) defects which interfere significantly with the patient's ability to carry out a large number of activities of daily living. Among these deficits, the most devastating, is the homonymous hemianopsia, the loss of half of the visual field on the same side of both eyes. Damage to the left side of the posterior brain often causes blindness in the right visual field of view in both eyes (and vice versa). Homonymous hemianopsia results from a lesion in the visual pathway posterior to the optic chiasm. Complete hemianopsia leaves the patient blind to an entire half of the visual field. A more subtle deficit is the homonymous quadranopsia which involves one quarter of the visual field [1, 2]. Quadranopsia occurs most often with lesions in the occipital lobe, but it may also occur with lesions involving the posterior temporal or parietal lobes. Lesions causing quadranopsia will affect the opposite visual field; e.g., left dorsal lesions cause visual field loss in the lower (below fixation) right field, while left ventral lesions affect the top (above fixation) right field [1]. Many other visual field losses of different shapes and locations can occur following infarcts affecting portions of the visual pathway between the retina and cortex (Figure 1).

In a seminal paper, Riddoch [3], examined patients with gunshot head wounds sustained during WWI and found that patients with hemianopsias were able to see motion in an otherwise totally blind visual field, citing the need to create separate visual field charts for static and moving visual features. Additional modality-specific deficits have been reported

due to lesions high-level areas in the visual hierarchy, where visual processing has become more specific (e.g., [4]).

Accurate assessment of visual field loss is therefore critical to characterization of the extent of functional damage following cortical damage. Two common tools are used to measure impaired visual fields, Goldmann [6] and Humphrey [7] perimetries. Goldmann perimetry measures visual field loss for both static and kinetic stimuli, but is time consuming and variations exist due to differences in speed and exposure duration among clinical settings. The Humphrey automated perimeter provides an automated assessment with slightly reduced sensitivity and specificity [8, 9]. However, both perimeters are limited in their ability to characterize how visual field loss depends on the type of visual information.

Can visual field deficits recover?

A group in Germany [10] has developed personal computer software for visual restitution training (VRT) in patients with visual field defects due to optic nerve disease and post-chiasmal brain lesions. Initial clinical trials in patients with optic nerve disease or postchiasmal lesions reported a significant enlargement of the visual field after training [10]. The training was performed on a computer monitor, using binocular visual stimulation in a transition zone between the field defect and the intact visual area [11–13]. However, when tested with standard visual perimeters, no change in VF was observed [14, 15]. Although the ability to actively facilitate VF recovery remains an open question, the VRT has demonstrated the ability of computerized tests to accurately localize VF deficits.

The Quadrant Vision Perimeter

We will describe a perimetry test, the Quadrant Vision Perimeter (QVp), which we have developed to provide a means for rapidly screening subjects' central visual field (10 or 20°) along different visual dimensions. QVp requires no specialized hardware beyond a computer, and is designed to be used in rehabilitation settings, bed-side, in a doctor's office, etc, where formal perimetry is not readily available. QVp has been validated on subjects with normal vision as well as compared to established perimeters in a group of stroke patients, and has been tested longitudinally for the evaluation of spontaneous recovery or degradation of VFs.

II. Methods

A. Visual presentation

The base stimulus consists of a random dot kinematogram (RDK) display covering the central 20° (diameter) in which subjects must detect the appearance of a small (default 3°) circular patch (the "target") that may be distinguished from the background on the basis of a specific visual parameter. The target can be defined based on luminance, motion, binocular disparity, and others (see Figure 1A for all parameters). The use of random dots with an equal density of dots in the background and stimulus (Figure 1C) prevents any edges between the target and background, thus ensuring that detection is based solely on the parameters of interest.

The test is run in blocks of 60 trials, lasting 3–5 minutes. Each block contains 40 target-present trials (10 per quadrant) and 20 "catch" trials in which no target was presented. In each trial, subjects indicate whether or not they saw the target (they do not need to indicate the location of the target). In each block, a parameter is chosen to specify how the target is defined (e.g., motion, luminance, depth, color, etc; see Figure 2). A "disc" mode (Figure 1B) is included in which the target is a bright, solid, circular patch, on a background of dots, similar to existing perimeters, which provides a rapid assessment of locations of total field

loss. All test modes include the same instructions to patients. This allows both fast, broad analyses of visual field loss in a matter of minutes, and detailed appraisal of task-dependent deficits in about 30 minutes, while minimizing task difficulty and confusion.

B. Data analysis and visualization

QVp automatically produces a summary chart with performance broken down by hemifield and quadrant and a visual representation of the integrity of the VF. The inclusion of catch trials allows for a quantitative analysis of the data. Performance (A') is calculated as the mean of the hit rate (h) and one minus the false alarm rate (fa):

$$A' = [h + (1 - fa)]/2 \quad (1)$$

This calculation is independent of the observer's criteria—that is, it is accurate and robust despite an observer's tendency to report "present" or "not present" in a large number of trials. A' is particularly useful as a metric because it provides a performance score on a 0–1 scale equivalent to percent correct (hence 0.5 corresponds to the chance, "guessing" rate).

Data has been collected for 13 healthy controls and 20 stroke patients with visual field loss. Data from representative patients is shown graphically by a "sensitivity map". This shows performance at each location in the visual field in a manner similar to other perimetrers. Stimulus (target present or not) and subject response for each trial is recorded along with the target location (when presented). For those trials in which the target was presented, hits and misses are determined based on the subjects response, and are shown in Figure 3A.

Based on the spatial pattern of hits and misses, a Gaussian kernel is applied to the data to measure the hit rate (hits per trial) at every location in visual space. Since there is a finite limit to the resolution for which target locations can be presented, applying this kernel (essentially a smoothing algorithm) allows us to interpolate performance for locations between target presentations. The algorithm works by analyzing each point of the visual field (in 0.2° increments) and calculates the distance to each target location. This distance is converted to a weight based on a Gaussian distribution with $\sigma = 3°$. A weighted average is then calculated based on all hits and misses and their distances. This method ensures that target presentations very near to visual space location contribute far more to the estimate of hit rate than points far away. The result is an interpolated map of hit rate over all of visual space. False alarm rate is then calculated and incorporated into this map. A' is for each location in the visual field based on the map of hit rate and the global value for false alarm rate. An example of the set of hits and misses (Figure 3A) and the resulting sensitivity map (Figure 3B) are shown for a patient with a lower-right field deficit.

III. Results

A. QVp validation on healthy controls

Each visual attribute (e.g., luminance, motion, depth and color) was first tested on healthy subjects with normal or corrected to normal vision, with no visual field cuts. Performance did not vary among quadrants, so data was combined across the visual field to estimate performance (A') as a function of the visual parameter of interest (e.g., luminance contrast in the 'Luminance' test, and coherence [16] in the 'Motion' test). These curves were then used to map the visual parameter to a standardized difficulty scale, spanning 0 to 1. This allows a calibration of each test to a standardized scale for comparison across visual tests and parameters. An example of validation data is shown in Figure 4.

B. Measuring VF loss in stroke patients with QVp

We have evaluated QVp by comparing visual fields obtained by QVp in stroke patients to their visual fields assessed clinically by Humphrey or Goldmann perimetry. Figure 5 and Figure 6 show two patients, CS and WR, with dorsal occipital lobe lesions leading to lower visual field quadranopsia. The overlay of their QVp-assessed visual field shows a high degree of similarity to fields acquired by Goldmann perimetry.

Patient MP had a ventral occipital-temporal lobe lesion, resulting in an upper-right field quadranopsia (Figure 7). Humphrey perimetry overlaid on the VF assessment obtained using QVp shows substantial agreement between the two measurements.

C. Modality specific visual field loss

One limitation of existing visual perimeters is the inability to characterize how visual field deficits depend on properties of the visual stimulus. QVp provides a quantitative tool for comparing the integrity of the VF's for different visual attributes by using targets defined by different features. Since stimuli are dot-based, no edges or object information is present, allowing the visual parameter of interest to provide the only means to identify the target. Here, we show examples of patients with differences in sensitivity to different visual features (Figure 8), and a patient whose visual deficit is modality specific (Figure 9).

D. Longitudinal assessment of spontaneous recovery and field loss

QVp also provides a means for longitudinal assessments of changes in VF loss over time. Once mapped, comparisons can be made between any two VF evaluations. Figure 10 shows an example of a patient who was only slightly impaired during an initial visit, but whose deficit became more pronounced over the following 6 months. Since QVp measures not only the location of VF loss but also the severity, this change is apparent (Figure 10C) even though the boundaries of the field loss have not changed significantly. Interesting, the patient had complained of worsening VF coverage, although there was no change seen in his VF by Goldmann perimetry over this time period.

IV. Conclusion

QVp is a tool for rapid, automatic assessment of visual field loss for patients with damage to their visual pathway. We have presented representative data from patients with cortical lesions demonstrating its effectiveness for determining the location, severity, modality-dependence, and longitudinal changes of VF loss. In addition to cortical lesions, visual field loss may arise due to many ocular and visual pathway diseases, including macular degeneration, glaucoma and optic nerve lesions. The ability to measure severity of the deficit, for arbitrary shapes of VF loss, suggests QVp may be a valuable tool for assessing VF loss from a variety of deficits. QVp development is ongoing to include more visual cues including high level function such as spatial attention. QVp can be used bed-side, rehabilitation settings, schools, or doctors' office. Since it does not require specialized equipment beyond a computer, is economic and easy to administer, we believe that QVp may have direct relevance for global health.

Acknowledgments

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V. References

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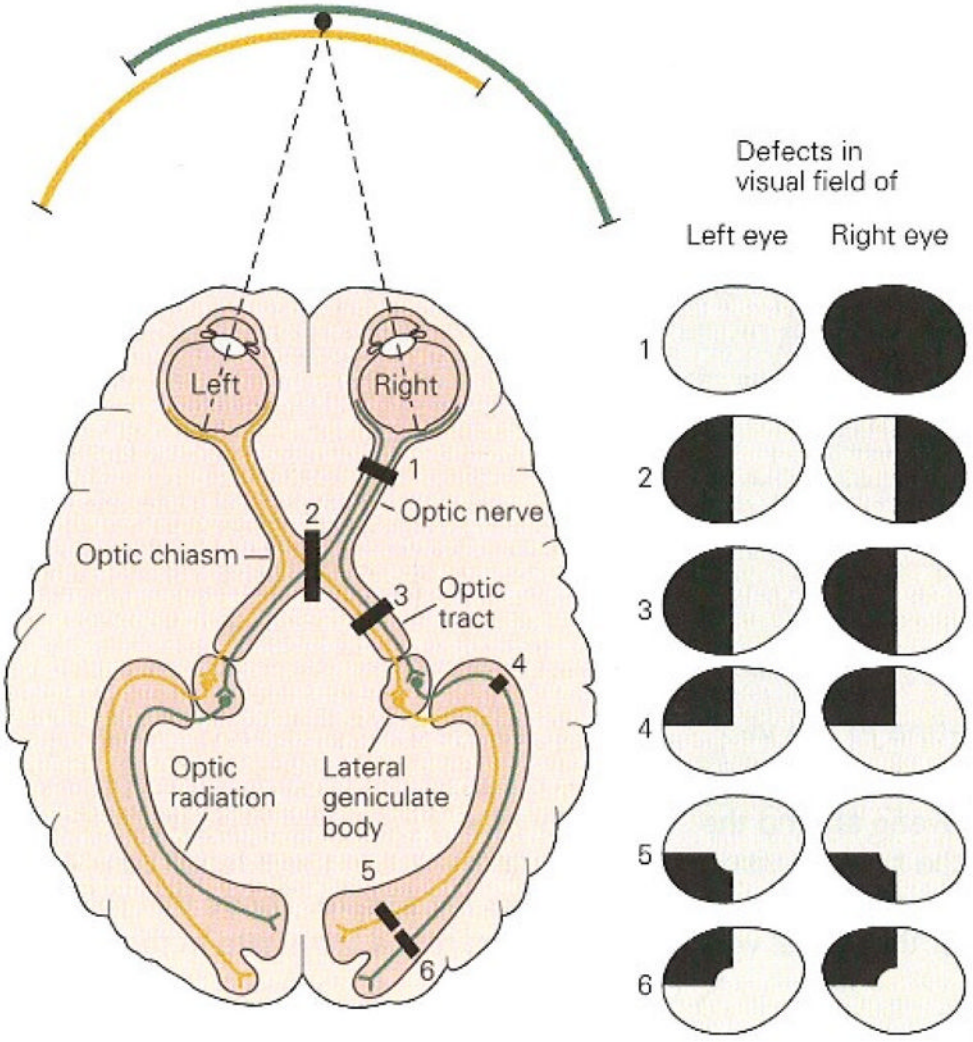

Figure 1.
Visual field deficits produced by lesions at various points along the visual pathway. Reproduced from Figure 27–20 of [5].

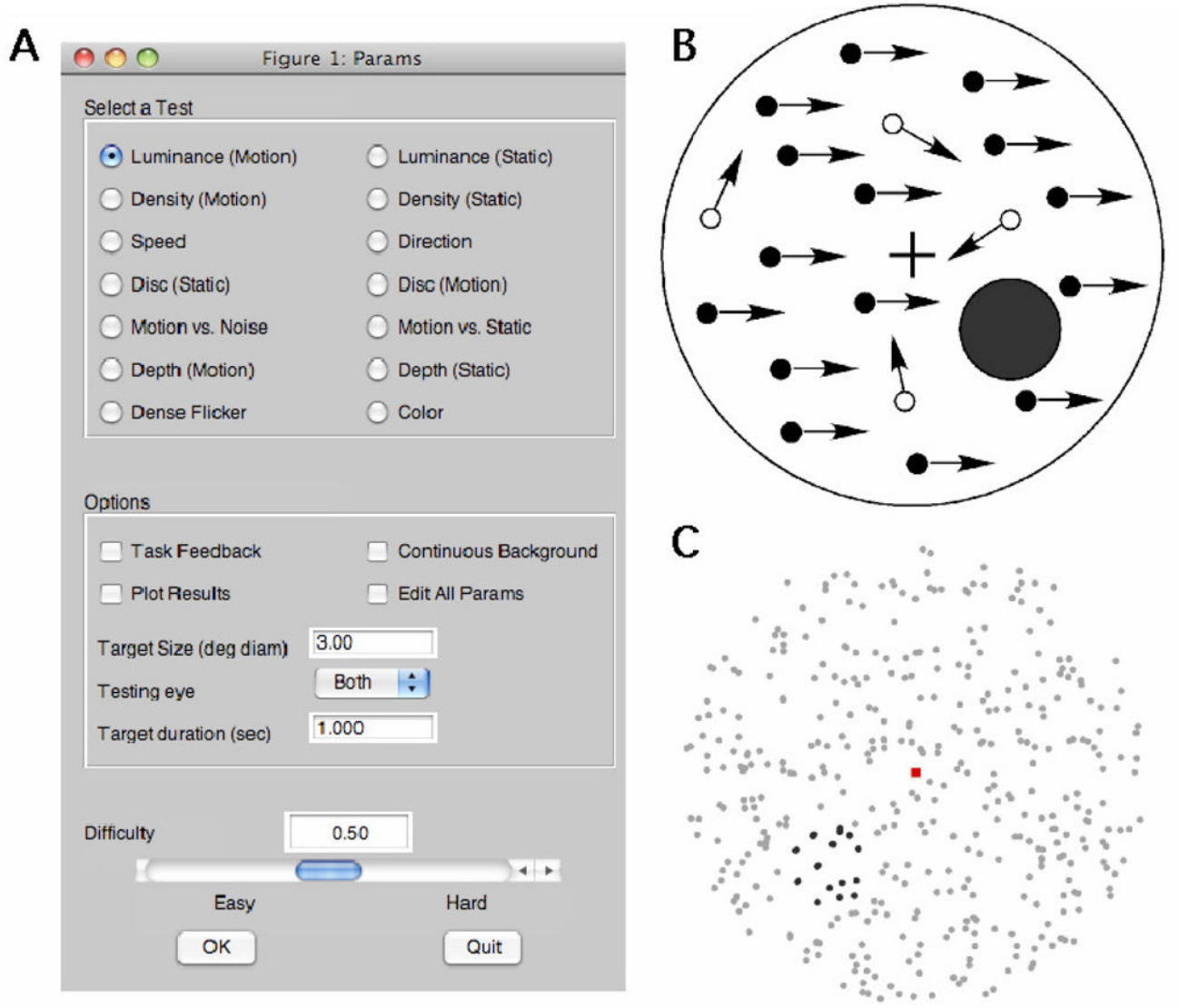

Figure 2.

(A) Settings for the QVp visual field assessment tool. Test options select the visual attribute to measure. Options include setting the size of the visual target, a notational setting for the eye tested, duration of the target, and a difficulty setting for the visual property being tested. (B) Schematic of the “disc” mode QVp test for coarse deficits. (C) Example of the luminance-defined target.

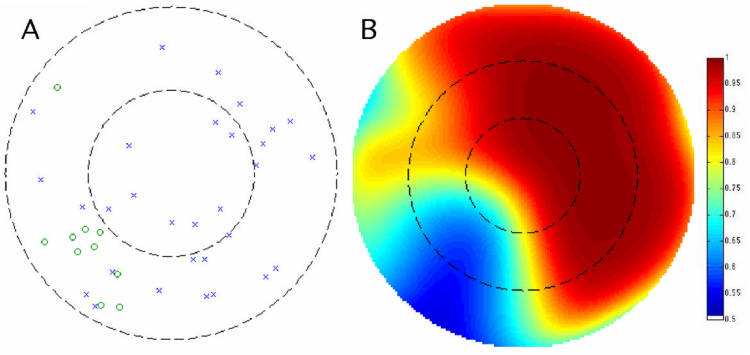

Figure 3.

Computation of sensitivity map. (A) Typical data from one patient is plotted above. The x's indicate "hits" (trials in which the subject saw the target), and o's represent "misses" (trials in which the target was presented, but the subject did not see it). (B) The final sensitivity map showing values of A′ derived from the hits and misses.

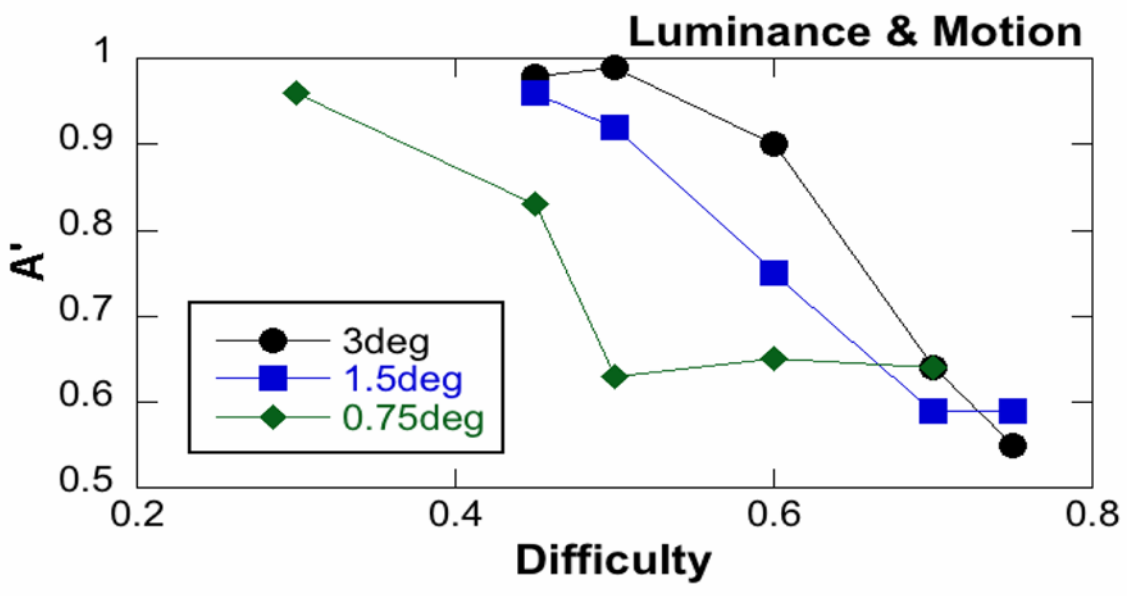

Figure 4.
Example of validation of test difficulty on healthy controls for a target defined by luminance and motion, with a diameter of 3, 1.5 or 0.75deg, from 13 healthy subjects.

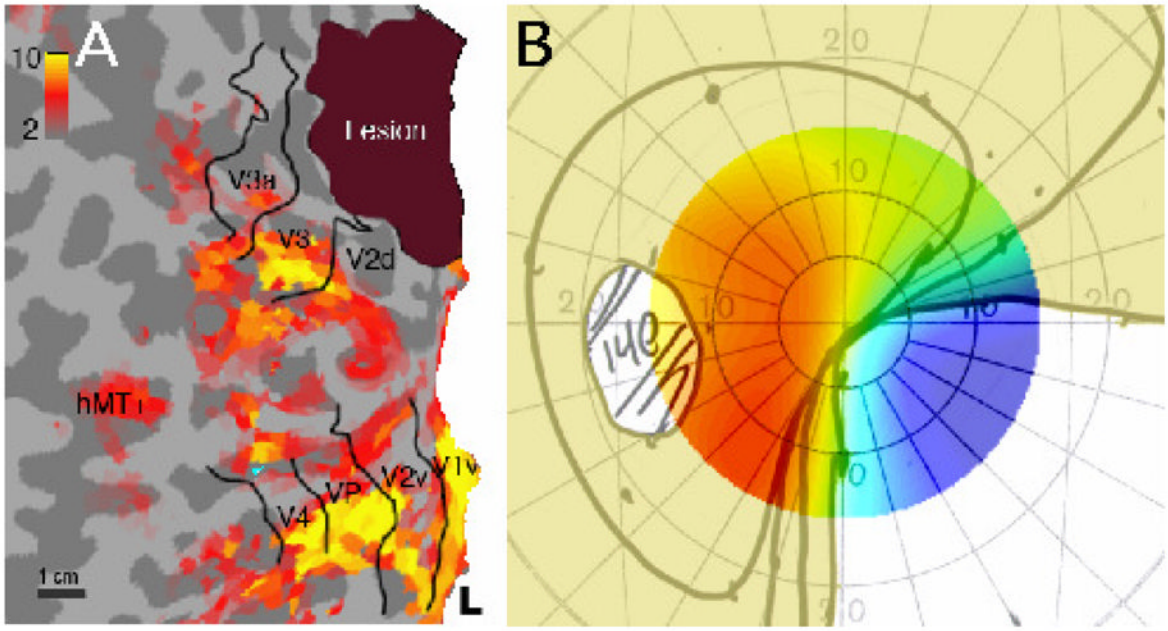

Figure 5.
Patient CS, with a dorsal left occipital lesion. (A) Retinotopic analysis of the cut and flattened left occipital lobe. (B) Combined results from three tasks overlaid on Goldmann perimetry.

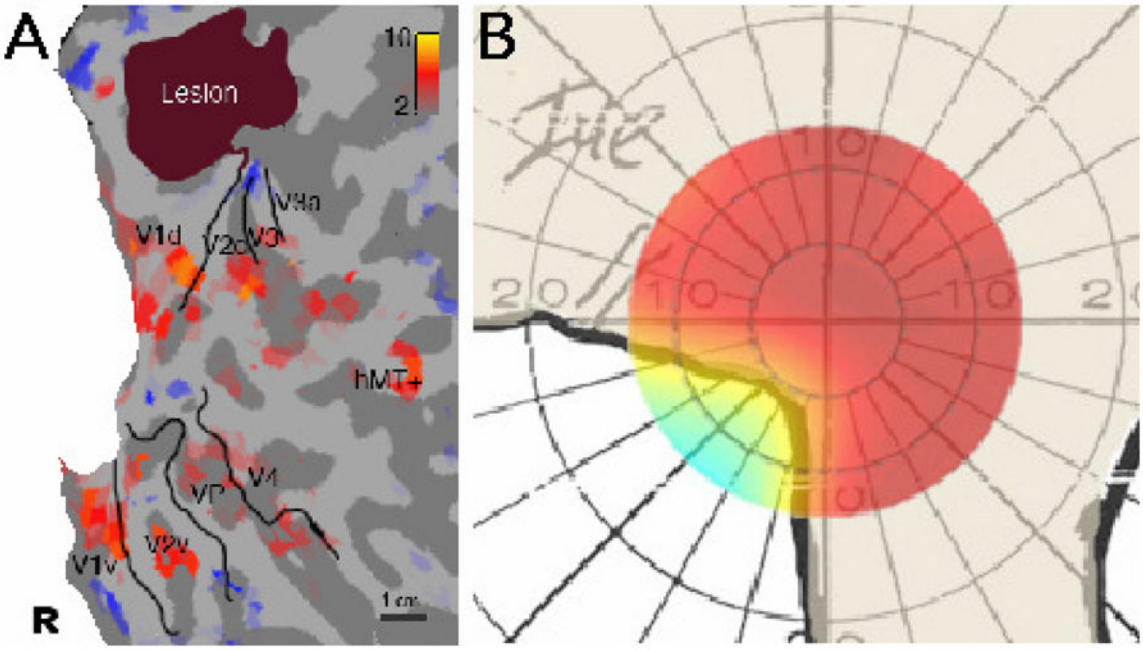

Figure 6.
Patient WR, with a dorsal right occipital lesion. (A) Retinotopic analysis of the cut and flattened right occipital lobe. (B) Combined results from three tasks overlaid on Goldmann perimetry.

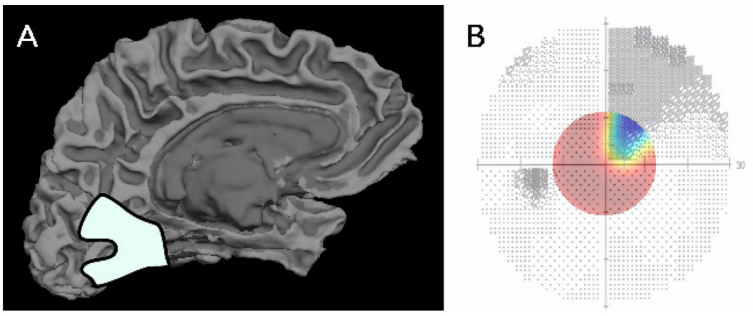

Figure 7.
Patient MP, with a ventral left occipital lesion. (A) Location of the lesion on the left medial surface. (B) Results from the Luminance (Motion) task overlaid on Humphrey perimetry.

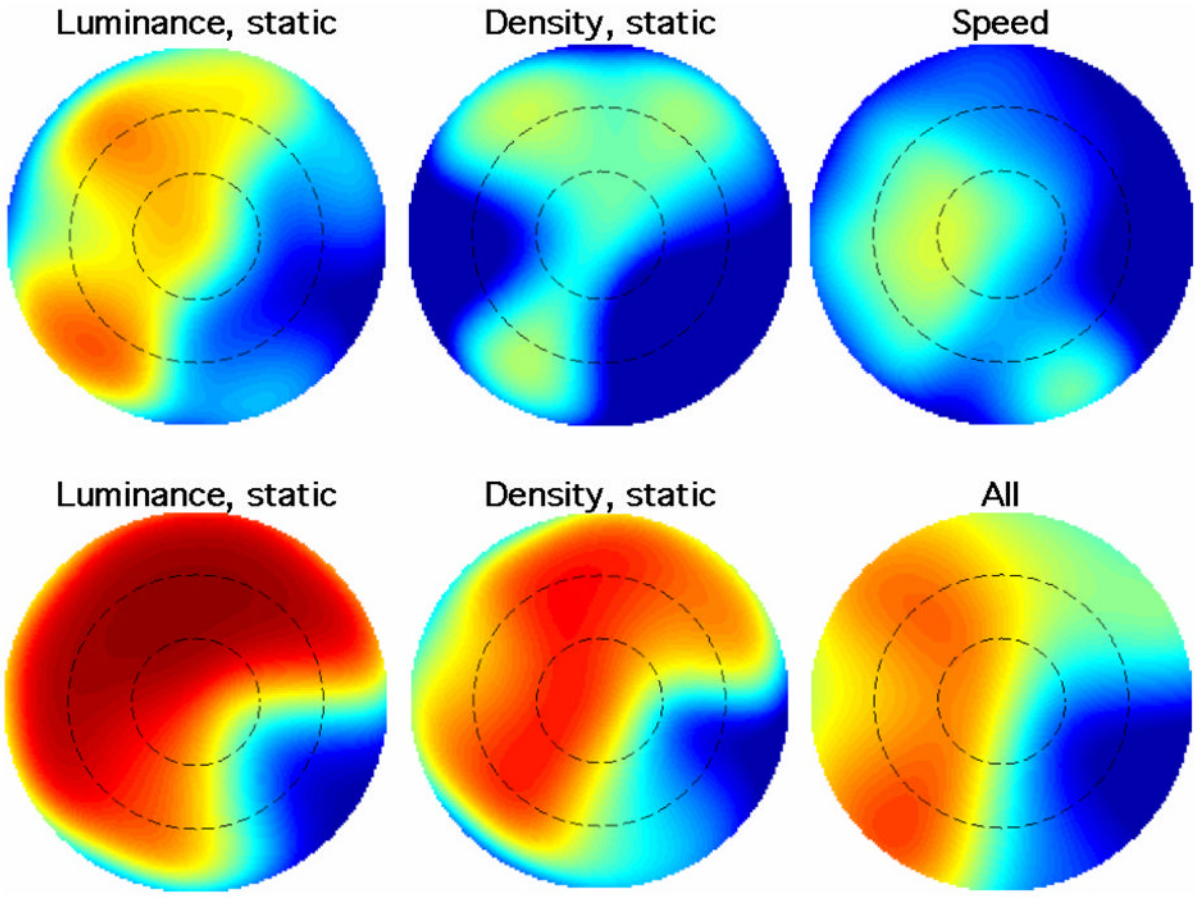

Figure 8.
Differences in sensitivity across types of visual cues for patient CS. Although the patient's visual field cut is in the same location (lower right quadrant) for all tests, there is significant variation in sensitivity for different visual properties.

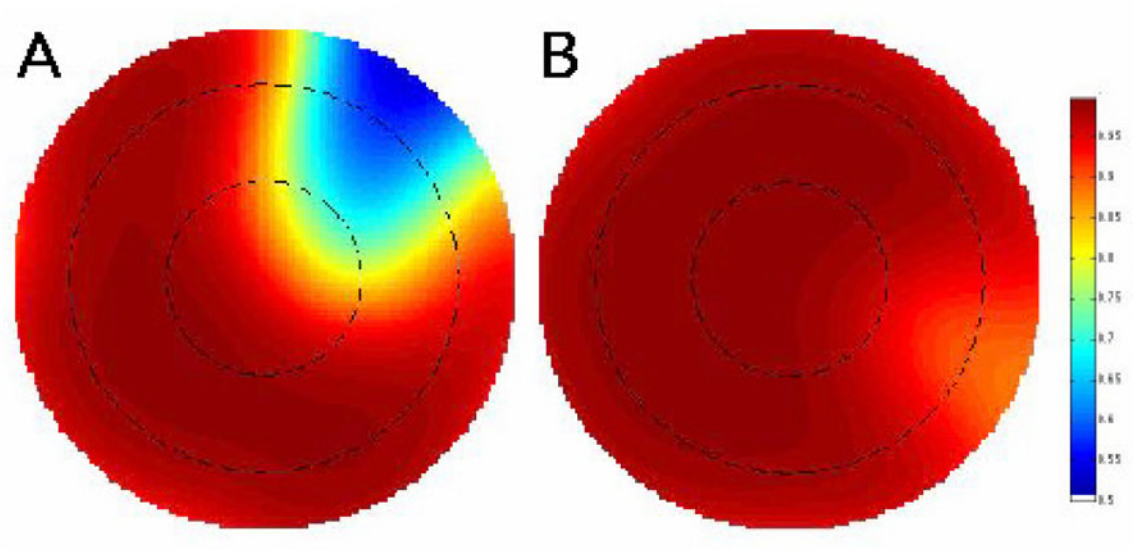

Figure 9.
Visual fields of patient MP are shown for two tests. (A) A luminance defined target, showing a visual field cut in the upper right quadrant. (B) Motion vs noise defined target, which the patient was able to detect throughout the visual field.

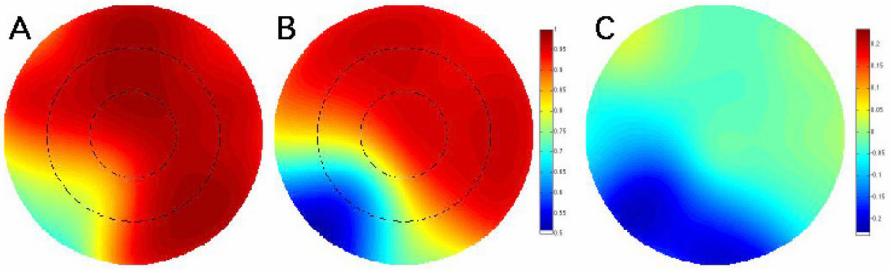

Figure 10.
Results from three tests (Lumnance (Motion), Motion vs Static and Density (Motion)) in patient WR. Data from (A) an initial assessment, (B) a follow-up visit 6 months later, and (C) the change in VF coverage during the period between assessments.