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ASSESSMENT OF FUNCTIONAL LOSS FROM VISUAL FIELD MAPS

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ABSTRACT

Current methods for assessment of functional loss from visual field maps suffer from inadequate consideration of the third dimension. Most functional field defects produce blindness to a volume of space and not merely to a portion of a two-dimensional surface. The size and location of these volumes cannot be represented adequately in either monocular or binocular field maps, and hence assessments based on such maps will reflect spatial functional limitations inaccurately. This presentation will describe and discuss computerized methods of *volume perimetry* that overcome these limitations, and provide directions for future research in functional perimetry.

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A first step in assessment of functional loss from visual field maps is to determine those areas of space to which an observer has lost sensitivity, given a particular pattern of field loss. Without modification, the ordinary *visual field* (see Figure 1) is inadequate for this purpose, for two reasons. First, it depicts only two of the three dimensions of the functional space in which visual behaviour takes place. Second, it represents only the view from a single eye, whereas the typical observer uses the receptor surfaces of *both* eyes. The *binocular visual field* (e.g. Esterman, 1982), which assesses visibility to points on the test surface with both eyes open, begins to address the second problem, but that representation is also inadequate. Its most important failure is that it can depict but a single surface of visibility - that corresponding to the test distance. It does not indicate the visibility of objects displaced in depth from the convergence distance.

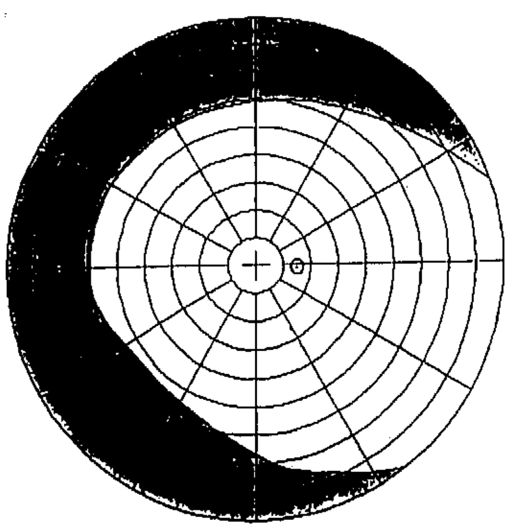

Figure 1 The normal visual field. Shaded field areas indicate the normal blind spots, and field occlusions of the nose, nose bridge and brow.

A solution offered here relies on a graphic construct which depicts aspects of field of view that are useful in delineating and testing hypotheses about visibility of objects in three-dimensional space on the basis of purely geometrical considerations. The construct is called the *volume visual field* (VVF), and is defined as the set of loci in space from which light can impinge on either of the two retinas, given fixed eye positions. The VVF can be computed from two ordinary field maps by a computer program called VP (described in Arditi, 1989; and Arditi, Szlyk and Faye, in preparation), for any position of the eyes. VP yokes a top (or side) view of the eyes in one window (labelled "Volume Visual Field" in Figures 2-5) with superimposed color-coded visual field maps of both eyes in another window (labeled "Retinocentric Binocular Field"), so that motion of the eyes in the former produces movement of appropriate graphic objects (e.g. the facial occlusions) in the latter.

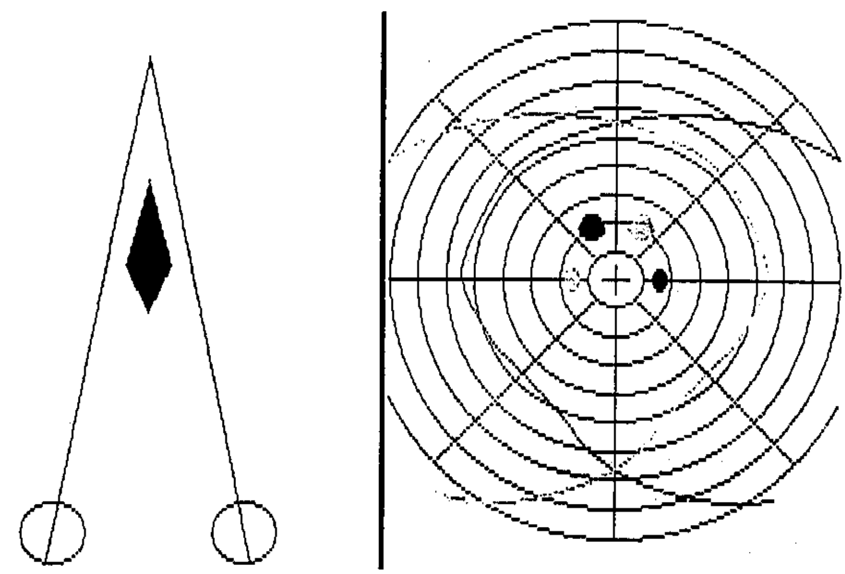

Figure 2 Screen from computer program VP depicting volume scotoma resulting from bilateral nasal field scotomas. In the right window, the left eye scotoma is shown in light shading, while the right eye scotoma is shown in darker shading.

Figures 2-5, which show screens from VP, illustrate some of the basic ideas underlying the VVF (for a more extensive treatment of the underlying theory of volume perimetry, see Arditi, 1988). The right half of figure 2 shows the fields of a hypothetical observer with scotomas located about 20 deg superior and 5 deg nasal to the fovea, in addition to the normal blind spots. These scotomas might be deep and caused by disease, or they might represent areas of temporarily reduced visibility caused by, say, the flash of a camera located nearer the observer than the fixation point. The left half of the figure shows VP's computation of the volume of space to which the observer is rendered insensitive by the scotomas.

Figure 3 illustrates a situation identical to that in Figure 2, but with the scotomas lying in temporal rather than nasal visual fields. The volume of space rendered less visible is now more distant than the fixation distance, and is of a somewhat different shape than that produced by the nasal field scotomas. Note that the volume scotomas in this and the preceding figure would not have been detected by binocular perimetry since they do not intersect the fixation (test) surface.

Figure 4, which shows the fields of an observer with bilateral central scotomas, illustrates the interaction of scotomas with one another in visual space. The volume scotoma that includes that intersection of the foveas in space is produced by the intersection of the central scotomas in the two eyes. It is, however, accompanied by two more distant volume scotomas. If an object falls within these flanking volumes, it is imaged on the normal blind spot of one eye and the central scotoma of the other. The VVF, incidentally, is quite similar in shape to that which we all experience for low luminance stimuli viewed at night, since the foveal region is generally devoid of high-sensitivity rod receptors.

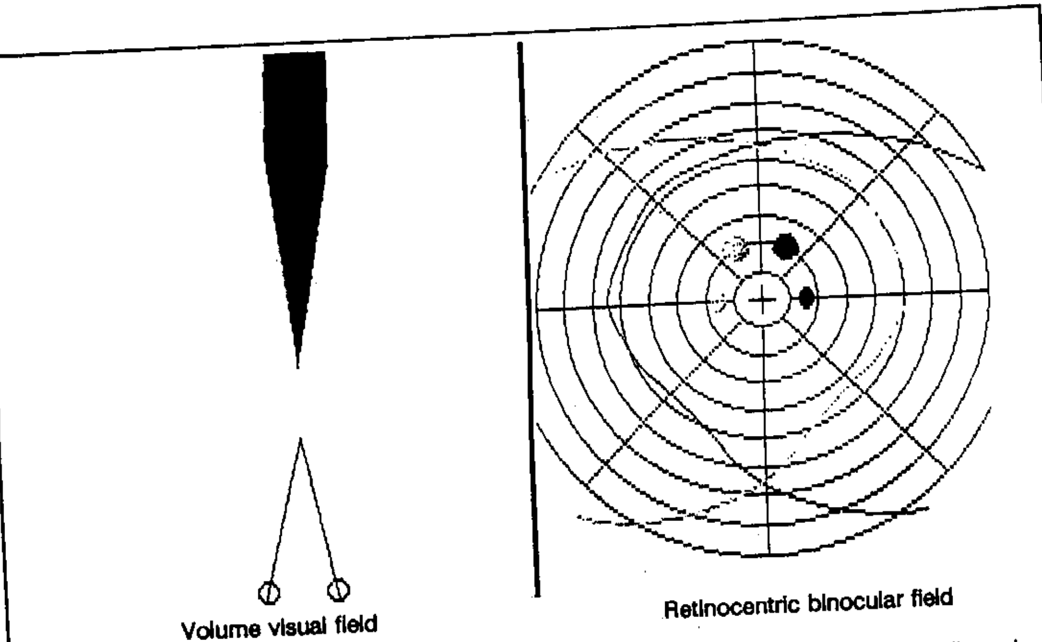

Figure 3 Screen from computer program VP depicting volume scotoma resulting from bilateral temporal field scotomas. In right window, the left eye scotoma is shown in light shading, while the right eye scotoma is shown in darker shading. The resulting volume scotoma is more distant than the fixation distance.

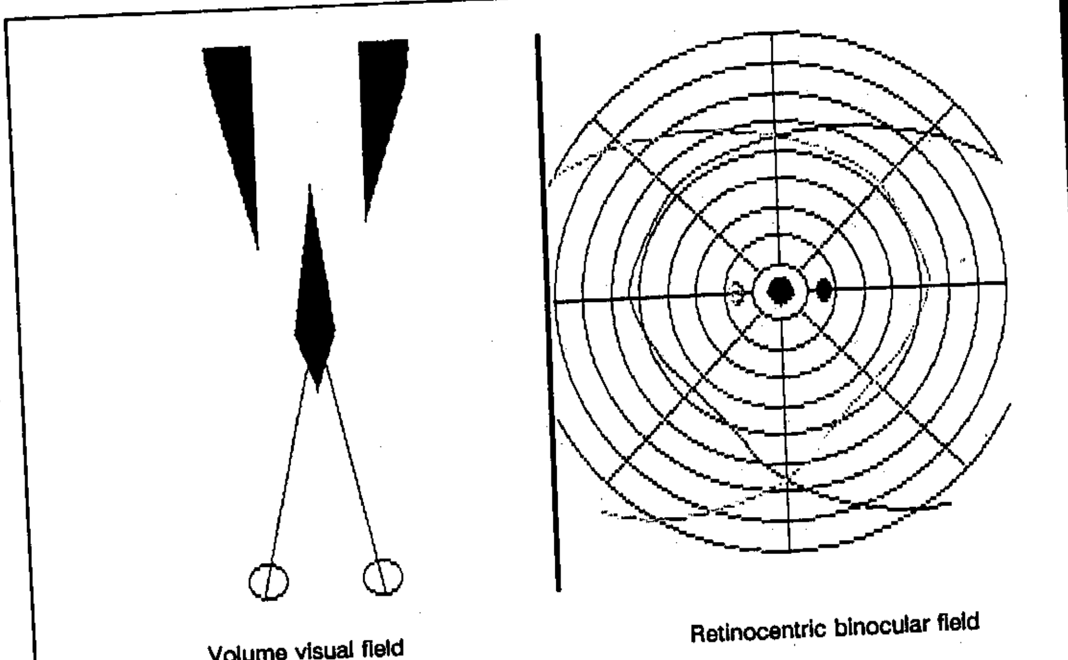

Figure 4 Volume scotomas resulting from the intersections of bilateral central scotomas and the normal blind spots.

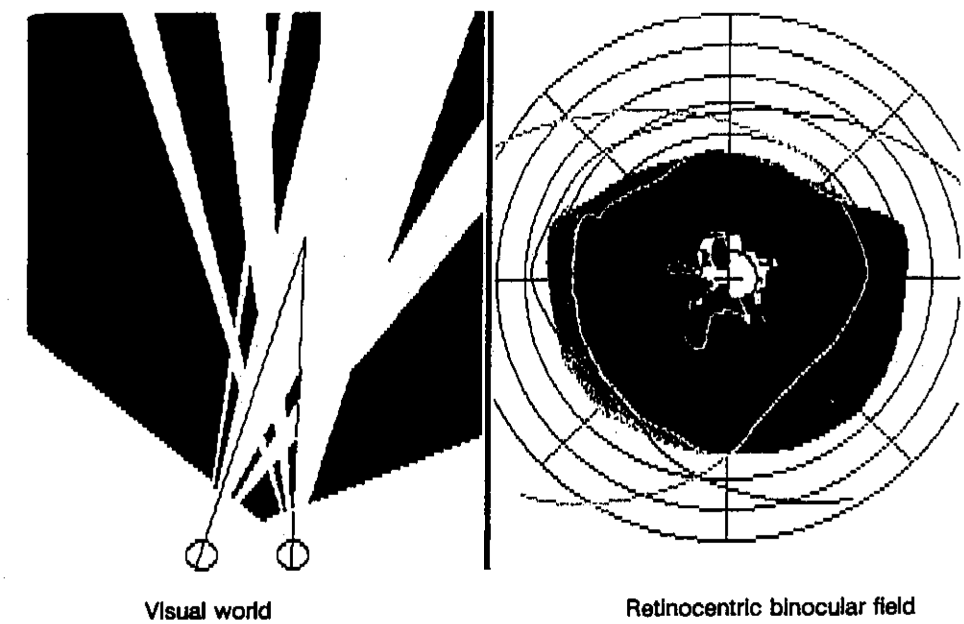

Figure 5 Volume scotomas of a person with advanced open-angle glaucoma.

Figure 5 shows the fields of an advanced glaucoma patient, and illustrates how complex such interactions between scotomas can be. It underscores the perceptual difficulties that such patients must cope with, in viewing small objects that disappear and reappear over time, in a labyrinth of scotomatous space.

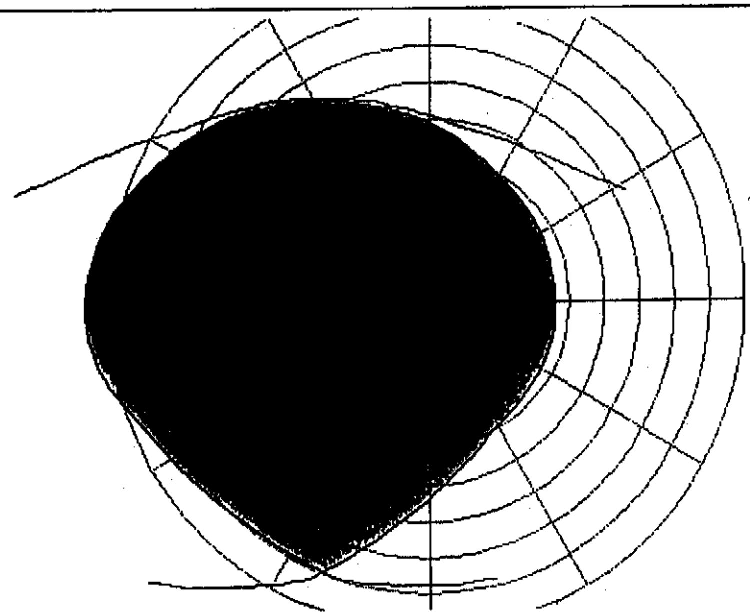

Figure 6 Leftward shift of the area of binocular overlap with rightward gaze.

The impact of field defects in the two eyes varies with eye position as well as with location on the retinas. Conjugate eye movements can have two main effects. First, since they shift the area of binocular overlap (see Figure 6), they can alter the functional visual field, because the area of binocular overlap is the region in which defects in one eye can be compensated for by healthy retina in the other. By moving the eyes laterally and vertically, a person with field defects in one or both eyes can strongly affect their VVF.

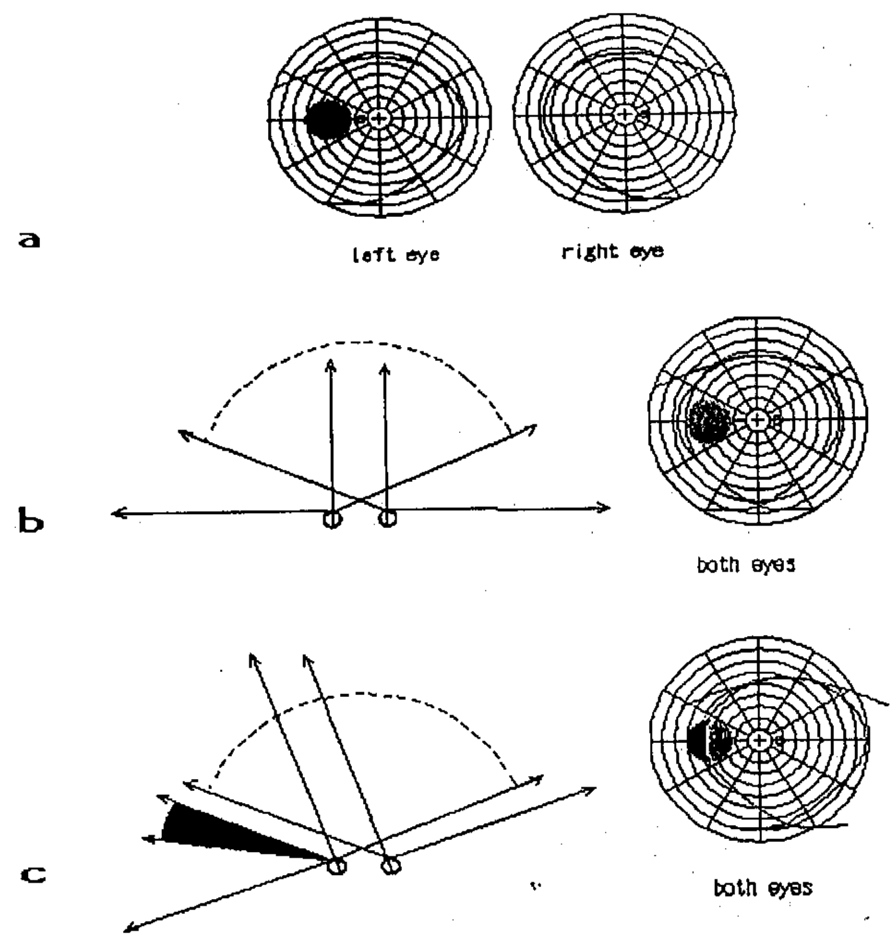

Figure 7 Fixation-dependent volume scotoma. (a) shows fields of a person with monocular temporal field scotoma. (b) Since the scotoma falls in the binocular overlap area (right side of figure), the entire volume field is functional. (c) Leftward gaze shifts the area of binocular overlap right, producing a volume scotoma.

Figure 7 illustrates the case of a patient in which a movement of the eyes to the right results in a volume scotoma that does not exist with straight ahead or leftward gaze.

Convergence eye movements can impact functional loss in three ways. First, they affect the size of the area of binocular overlap (Figure 8), and hence the probability that objects that fall on defective retina in one eye will fall on healthy retina in the other.

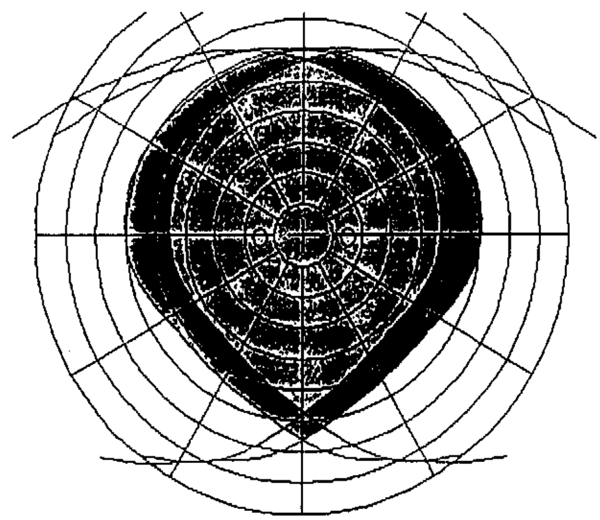

Figure 8 The lighter shaded area shows area of binocular overlap for a typical observer converging to 14 cm. The dark shading indictes an incremental functional field area (about 37%) gained by convergence to an infinite viewing distance.

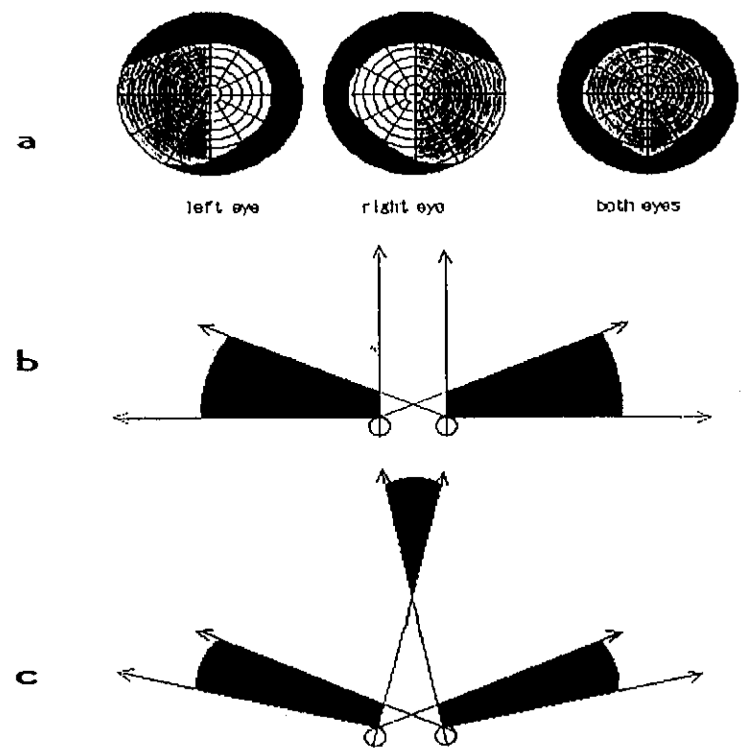

Figure 9 The bitemporal hemianope (a) has normal functional fields within the area of binocular overlap when converging to infinity. (b) but has a significant volume scotoma extending from the fixation point to infinity, when converging to near.

Second, like conjugate eye movements, they can determine the existence and/or size of a volume scotoma. A particularly dramatic example is the bitemporal hemianope shown in Figure 9, who has a normal volume field in the area of binocular overlap while converged to infinite distance, but a devastating volume scotoma receding into the distance from the fixation point, when converged to a close distance.

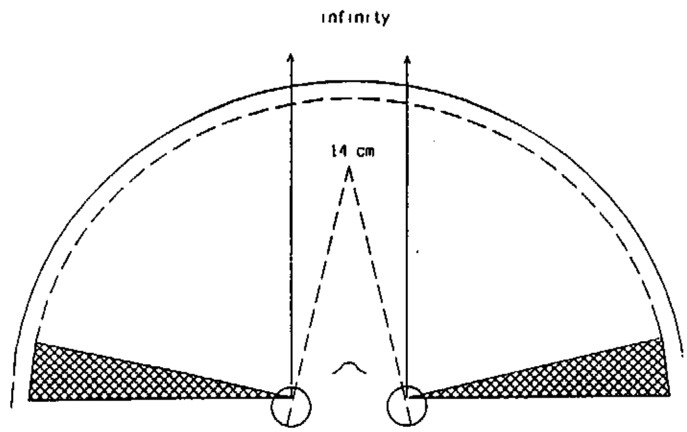

Figure 10 The effect of panorama on changing convergence position. The hatched wedges show a top view of the additional volume in the VVF that is gained by convergence to great distance.

Third, convergence affects the horizontal extent, or *panorama* of the functional field (Figure 10), by about 26 deg over the range of possible convergence distances. For a normally sighted person, 26 deg lost in the far periphery has little functional impact. For the person with restricted "tunnel" fields, however, such a loss can have a marked impact on detection of obstacles and mobility.

In order to provide a firm geometrical foundatión for functional perimetry, I have omitted discussion in this paper of many other important factors contributing to visibility and visual function such as retinal inhomogeneity, adaptation level, and binocular summation effects. Predicting typical visual functioning from visual field maps will be a formidable task even after such factors are considered. The constructs discussed above consider vision in the same three-dimensions of space in which visual behavior is carried out rather than the two dimensions of a single retina. However, it seems clear that they, or some variant, must be considered in the future.

ACKNOWLEDGEMENT

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