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ORIGINAL ARTICLE

Field Expansion for Homonymous Hemianopia by Optically Induced Peripheral Exotropia

ELI PELI, MSc, OD, FAAO

The Schepens Eye Research Institute, Harvard Medical School and New England Eye Center, New England Medical Center Hospitals, Tufts University School of Medicine, Boston, Massachusetts

ABSTRACT: *Purpose:* To describe a novel method for prism correction of hemianopia that provides field-of-view expansion in a convenient and functional format and to evaluate initial clinical application. *Method:* To expand the upper quadrant of the field, a high power prism segment (30–40Δ) is placed base-out across the upper part of the spectacle lens, on the side of the loss, at about the level of the limbus. A similar prism segment at the lower part of the lens is used to treat the lower field. The peripheral location of the prisms causes peripheral exotropia. As a result a scene segment as high as the vertical span of the prism is shifted laterally by 15 to 20° relative to the view of the other eye. At the edge of the hemianopic field loss, objects that would fall in the scotoma of one eye are seen through the prism in the other eye, providing a simultaneous awareness of details within the otherwise absent field-of-view. An approach for fitting the system to patients with abnormal binocular vision (strabismus and amblyopia, with or without diplopia) is discussed as well. The effect of the prisms was evaluated in a noncomparative case series (12 patients). *Results:* The field expansion is provided at any position of lateral gaze, including gaze away from the side of the scotoma. The effect of this technique on field expansion was demonstrated using standard binocular perimetry. Most patients reported substantial improvement in function and in obstacle avoidance. *Conclusion:* A novel method for the optical treatment of hemianopia was developed and tested. It was found to be effective in expanding the field and helping patients' mobility. (Optom Vis Sci 2000;77:453–464)

Key Words: low vision, neuro-ophthalmology, strabismus, binocular vision, adaptation, rehabilitation

Homonymous hemianopia or quadrantanopia (the loss of half or one quarter of the visual field on one side in both eyes) is a frequent consequence of brain damage from stroke, head injury, or surgery to remove brain tumors. Homonymous field loss may impact mobility and navigation. Patients frequently complain of bumping into obstacles on the side of the field loss and thereby bruising their arms and legs. The number of such accidents may decrease with adaptation to the condition, presumably because patients become more cautious and learn to use head and eye scanning techniques to avoid obstacles. Despite such adaptations, many patients continue to suffer from the effects of limited visual field.[1]

The number of disabled stroke survivors in the U.S. is estimated to be more than 3 million annually.[2] As many as one third of stroke survivors in rehabilitation have either homonymous hemianopia or hemineglect.[3] In the United Kingdom, 50% of neurological admissions are attributable to strokes and 30% of these cases have hemianopia.[4] These numbers are likely to increase with the aging of the population and improvements in emergency care for stroke victims. Despite these numbers and the importance of the problem, a recent review found that research into the rehabilitation of hemianopic patients is notable for its absence and that existing reports are of limited value because of methodological problems.[4]

A number of reports indicate that congenital hemianopes sometimes develop exotropia as a compensating mechanism.[5–8] The exotropia does result in an increased simultaneous field-of-view; for it to be functional, however, the patient needs also to develop anomalous retinal correspondence (ARC).[9] Without ARC, the exotropia will result in diplopia and confusion (similar to the effect of an overall monocular base-out prism). Objects falling in the hemianopic field in the fixating eye will be detected by the deviating eye but will be perceived to be in the wrong direction. They will appear to be superimposed on objects that fall on corresponding points in the fixating eye retina. Although ARC is generally believed to develop only with congenital strabismus, two separate cases were reported in which ARC was found in congenital hemianopes who developed strabismus in later childhood years.[6, 8] A third case, of a patient with left hemianopia from age 14, reported the development of esotropia with eccentric fixation in the right eye that provides the same expanded panoramic view.[10] Whether exotropia (or esotropia on the other side) in congenital hemianopia develops as a compensating adaptation or as a coincidence remains controversial.[7] However, it is clear that when it does develop, it has a beneficial effect, leading surgeons to recommend against strabismus surgery in such cases.[5, 6, 8] There are no known reports of exotropia after hemianopia in adult or elderly patients. Presumably, adults do not develop this adaptation because they can not develop ARC. It seems that if one could provide adult hemianopes with the combination of exotropia and ARC they would enjoy the same benefits of "panoramic vision."

A spatial directional adaptation similar in nature to ARC (but in both eyes together) was reported to take place in adults with the use of partial prisms.[11] Normally sighted subjects constantly wore binocular lateral yoked prisms in the lower half of the spectacle lens for a period of weeks. At first objects seen through the prism at the lower field-of-view were perceived to be shifted in the direction of the prism apex. Long vertical objects such as lampposts and doorframes appeared split as their lower part was viewed through the prism and the upper part through the prism-free upper segment (similar but not identical to the situation illustrated in Fig. 3, middle row). Within weeks, these phenomena disappeared and object perception became veridical again (similar to the illustration in Fig. 3, bottom row). Subsequently, removing the prism spectacles caused an aftereffect that also faded with time. This kind of adaptation within one eye could provide the ARC equivalence needed for the optimal use of the prism correction proposed here, though effective use may be possible even without the adaptation.

Training in scanning and increased awareness are frequently discussed as clinical techniques to treat hemianopia.[4] The value of these procedures has been only partially documented. One study demonstrating enhanced wheelchair function with such approaches was limited to three wheelchair bound patients with deep left hemineglect.[12] No eye or head movements were recorded to demonstrate changes in scanning, and the improvement in wheelchair driving performance might be attributable to functions such as attention rather than to visual scanning behavior. Zihl[13] and Kerkhoff et al.[14] trained patients over dozens of sessions and many weeks to successfully perform large scanning saccades into the blind field-of-view. Such training did improve the patients' responses on similar tasks and reduced their search time for objects on a table. The main limitation of this approach is that it requires intentional scanning and does not increase the instantaneous field-of-view without such eye movements. Patients that develop such scanning behavior either naturally or with training may certainly benefit from them.

Various reports over the years suggest that visual stimulation (similar to visual field testing) may bring on a recovery of the visual field near the midline providing an actual expansion of the field.[13, 15–17] These results were contradicted by others[18, 19] and remain controversial (for a brief review, see Pambakian and Kennard[4]). It is possible that the successful cases reflect spontaneous recovery or are limited to a small minority of patients with reversible damage. A study that followed the natural history of hemianopic patients found that 40% showed some quantitative recovery of the visual fields with no treatment.[20] More than 10% had a complete recovery of one quadrant over a 3- to 24-month period. Such field recovery is more common in traumatic hemianopia than in stroke patients. We also demonstrated some improvements in the fields of some patients within the first few months after the visual loss. Patients whose fields recovered may not need much rehabilitation, but for the majority of patients, who have permanent, complete hemianopia or lower field quadrantanopia, optical correction may offer the only help.

Various optical devices have been considered, applied, and promoted for the management of hemianopic field defects over the years. Those include mirrors, partially reflecting mirrors (beam splitters), and dichroic mirrors (a mirror that causes the reflected image to be red while the transmitted one is green).[21] In addition to mirrors, reversed telescopes[22] and various types of prisms, which are discussed in greater detail below, have been used.

None of the devices (except for minifying telescopes) affects the patient's monocular visual fields as measured by perimetry. The various devices may only affect the field-of-view seen simultaneously and binocularly by the patient. The effects of these devices may be classified as providing either field-of-view relocation (shifting) or field-of-view expansion. Field-of-view expansion is the preferred effect, because the simultaneously seen field-of-view is wider with the device than without it. A wider field-of-view enables the patients to monitor more of the environment at any instant and thus offers safer mobility. Field-of-view relocation only exchanges the position of the field loss relative to the environment or relative to the body's midline. This means that a part of the environment that was invisible because of the scotoma becomes visible, but at the same instant a different part of the environment (of the same angular span), which was visible without the device, becomes invisible. Such exchange may be useful under some unique circumstances and assumptions, but it is inferior to field-of-view expansion. The effects of various devices may apply to the overall field-of-view or only to a sector, they may be episodic (intermittent) or constant, and as discussed here, may be central or peripheral. The method described here affects peripheral field sectors and the effect is constant.

Overall field-of-view relocation occurs, for example, with the use of full-diameter binocular prisms.[23] The binocular yoked prisms mounted in the spectacle frame with the base toward the side of the field loss (usually about 20Δ) shifts the image by about 10°. The technique assumes that the eyes do not compensate for the prismatic effect with a corresponding eye movement of about 10°, which would neutralize the effect of the prism. The effect of the prism on observers with normal vision[24] as well as patients with hemineglect[25] suggests that such compensation, and even adaptation, does take place. There is also a corresponding optical field loss (optical scotoma) in the far periphery on the seeing side even if eye movements negate the beneficial effect of the prism.

Binocular sector prisms,[3, 23] the most commonly used technique for optical treatment of hemianopia (Fig. 1), provide only field-of-view relocation. In this case the yoked prisms (in the form of Fresnel press-on prisms, glued segments, or molded lenses) are limited to the part of the carrier lenses that would be in the scotomatous field when the eyes are in primary gaze position. Their effect, therefore, is limited to instances when the line of sight is directed through the prism sectors of the spectacle lenses. When the patient is looking through the other part of the lenses there is no effect, because the prisms are completely in the scotoma. When looking through the prism sectors, the field-of-view is shifted. Because the patient does not see objects in this part of his field, he is less likely to fixate into this field and intentional self-directed scanning is required. In addition to these limitations, an optical field loss is caused by binocular sector prisms ("Jack-in-the-box" scotoma) in the center of the field of view.[23] Head movements can compensate for this field loss,[26] but it seriously reduces the potential benefit of these aids. The amount of prism typically used with this technique (12 to 18Δ) provides a small shift of the field (6 to 9°).[3] Comparable access to the unseen part of the scene could be achieved simply with a slightly larger eye movement. The binocular sector prisms are often presented as a training device used to teach the patient to scan more efficiently.[26] How and why the prisms serve this purpose is not made clear in the literature. Thus, the only effect of binocular prisms (full-diameter or sector) is a constant or intermittent shift of the full field-of-view, respectively.

Field-of-view expansion may be provided with monocular devices. Monocularly fitted sector prisms[27, 28] expand the field-of-view once the patient changes his fixation to within the field of the prism. This prism is fitted in the same manner as the binocular sector prisms (Fig. 1), except that only one lens on the side of the field loss is fitted with the prism. As long as the patient's eyes are at primary position of gaze or are directed away from the side of the hemianopic field, the monocular sector prism has no effect on the field-of-view. When the gaze is directed into the field of the prism, confusion and diplopia accompany the resulting field-of-view expansion. Confusion refers to the appearance of two different objects at the same perceived direction. Confusion is the intended effect, as it represents the appearance and visibility of an object that would be invisible without the prism. However, the central diplopia associated with the confusion can be very unpleasant and disorienting to the patient and may account for the lack of success.[23, 29] Smith et al.[30] recommended cutting out a small, 1- to 1.5-mm portion from the center of the lens to prevent diplopia. However, this alleviates diplopia only in the primary position of gaze, where it is not a problem with most designs. Smith et al.[30] also recommended the use of high-power prisms 30Δ and higher.

Binocular full prisms and binocular sector prisms do not result in an expansion of the field as measured by perimetry. In fact, binocular sector prisms reduce the field-of-view because they cause an optically induced scotoma at the center of the spectacle lens.[23] Monocular sector prisms do expand the field-of-view when the gaze is directed into the field of the prism; usually, however, this field does not include the primary position of gaze as commonly used in perimetry. Consequently, most previous prism-based treatment methods have not attempted to demonstrate field expansion by standard perimetry. Many clinicians claimed that the prism provided an increase in field "awareness," which could not be measured by perimetry but was noted by the patients. Some investigators reported increased field awareness measured with arc perimetry.[31] However, if the sector prism was placed "within the area of visual field loss" as indicated, perimetric test should not have found an increase in field even with a monocular sector prism. Field enlargement can be documented with monocular segment prism if the patient's head is turned away from the field loss so that his line of sight to the perimetric fixation target intersects the prism segment. Rossi et al.[3] reported tangent field expansion with monocular sector prisms fitted to be in the scotomatous area. Although no such expansion should be expected because of the optical effects, they also found expansion of the fields in seven out of 17 control subjects with no prism. Similarly, Nooney[32] reported field expansion after use of an opaque mirror device. The field expansion was measured without the device. Whether these reported increases in measured visual fields were a result of the aids used is arguable.

Design of a successful hemianopic visual aid ideally requires that it expands the field-of-view rather than relocate it, function in all positions of gaze, and avoid central diplopia. These considerations led me to develop a new method of field expansion described here. This method involves a monocular sector prism that is limited to the peripheral field (superior, inferior, or both). It is placed across the entire width of the lens (Fig. 2) so that it can be effective in all lateral positions of gaze. The prism expands the field via peripheral diplopia and confusion by optically creating a *peripheral exotropia* while maintaining bifoveal alignment. Peripheral diplopia is likely to be much less disturbing for the user than central diplopia because peripheral physiological diplopia occurs in normal vision.[33] Except for objects near the horopter (which occupies a tiny portion of visual space), all objects in the peripheral field are actually seen

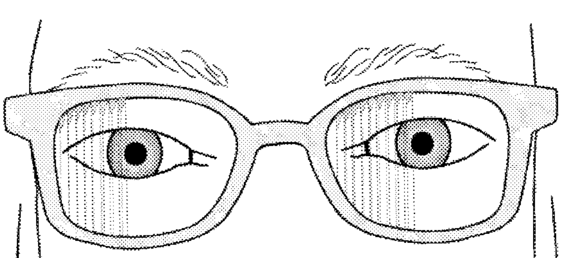

FIGURE 1.

Binocular sector prisms in the format commonly prescribed for right homonymous hemianopia. The Fresnel prisms with base to the right are placed on both lenses' right sides with the apex at the pupil edge (or 2 mm to the right of the edge). Note that these prisms have no effect when the patient eyes are at primary position of gaze or are looking left (from where all visual stimuli come). When the patient looks through the prism, the field is just shifted and not enlarged. These prisms cause an optical field loss at the center of the lenses. Even a person with normal visual fields will demonstrate central scotoma in primary position of gaze when wearing these lenses.

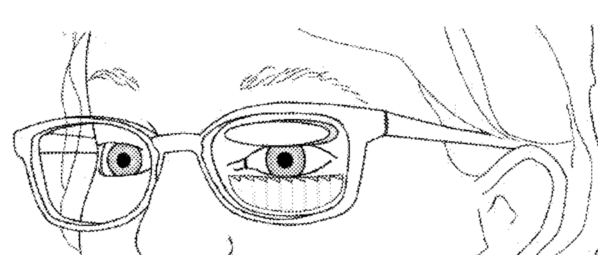

FIGURE 2.

An illustration of the new prism correction for left hemianopia. The prisms are worn only over the left eye. They are restricted to the upper and lower peripheral fields but extend across the width of the lens so that they are effective at any position of lateral gaze. Illustrated are a simple mounted prism for the upper segment and a compound Fresnel press-on prism for the lower segment.

with diplopia. This physiological peripheral diplopia is rarely noticed because of the lack of attention to peripheral objects.[33]

The peripheral-prism design described here provides for a field-of-view expansion that is measurable by standard binocular perimetry because it is effective at all positions of gaze including the primary position. High-power Fresnel prisms of 40Δ have been used, providing a field expansion of about 20° across the midline. Because the prism only affects peripheral vision, a higher power prism can be used despite its inferior optical quality. The field expansion effect of the prism is unaffected by a wide range of lateral eye or head movements to either side. Patients have reported improved obstacle avoidance while walking and an adaptation leading to veridical perception of the direction of objects detected with the prisms. No formal testing of this adaptation has yet been conducted.

METHODS

Patients

Twelve consecutive patients with homonymous field defects (41 to 91 years old) were evaluated. Nine had homonymous hemianopia after strokes and surgeries to remove lesions (seven left hemianopia). Three had homonymous quadrantanopia. Two of theses were only partial and one was limited to the central part of the quadrant. Patient information is provided in Table 1. Most reported occasional or frequent mobility difficulty consisting of bumping into obstacles on the side of the scotoma. Visual acuity was good in both eyes of all patients, varying from 20/15 to 20/30. Patients were free of any signs or symptoms of neglect or hemi-inattention.[34] All patients were ambulatory and had normal use of their legs without support (although two used a short cane to compensate for their visual deficit). A few of the patients had various levels of paresis in the arm ipsilateral to the field defect. Most patients were referred to the vision rehabilitation service from the neuro-ophthalmology department at the New England Eye Center in Boston, but a few were referred from other physicians in the community. Patients were fitted with the prisms as a modification to standard treatment. The data that are reported here (visual field and patients' subjective responses) were obtained by retrospective review of clinical charts.

Prism Placement and Mode of Operation

Separate prism segments are used to expand the upper and lower quadrants. To expand the upper quadrant of the field, the base-out prism segment is placed at the upper part of the spectacle on the side of the field loss (e.g., left lens for left hemianopia). The prism segment is placed across the top of the spectacle lens with its lower edge above the pupil at about the level of the limbus (Fig. 2). Similarly, a prism segment at the lower part of the lens is used to treat the lower field.

TABLE 1.
Patient information and results of correction

Pt #	Age/Sex	Dist. VA Right Eye/Left Eye	Homonymous Field Loss	Etiology	Prism Used	Follow-up	Comments
1	65/m	20/30/20/20	Right hemianopia Macular sparing	PCA Occlusion	30Δ upper fixed insert	12 months	Very pleased, driving
2	60/f	20/20/20/20	Right hemianopia	Surgery for CSM	40Δ upper Fresnel	3 weeks	No effect, reject, 3rd nerve palsy
3	49/m	20/20/20/20	Left quadrantanopia Upper	Surgery to stop seizure	30Δ upper fixed insert	12 months	Very pleased, driving
4	53/m	20/15/20/20	Right quadrantanopia Lower	Seizures	40Δ lower Fresnel	18 months	Very pleased, constant wear
5	56/m	20/15/20/25	Left quadrantanopia Lower/Partial	Surgery for lesion	40Δ lower Fresnel	5 months	Very pleased no cane
6	74/m	20/30/20/30	Left hemianopia Partial lower altitudinal	Stroke	40Δ upper and lower Fresnel	12 months	Very pleased no cane
7	75/f	20/15/20/30	Left hemianopia Strabismus + diplopia	Head trauma Orbital trauma	40Δ upper and lower Fresnel	2 months	Taped central view on left lens
8	61/m	20/25/20/25	Left hemianopia mild cognitive deficit	Surgery for Glialblastoma	40Δ upper and lower Fresnel	3 months	Drives supermarket cart
9	68/m	20/20/20/20	Left hemianopia	Stroke	40Δ upper and lower Fresnel	2 months	Very effective, occasional misdirection
10	41/f	20/20/20/30	Left hemianopia	Stroke	40Δ upper and lower Fresnel	6 months	Doing well back to work
11	71/f	20/30/20/20	Left hemianopia Amblyopia OD	Stroke	40Δ upper Fresnel	1 month	Difficulties with directions, removed
12	91/f	20/20/20/15	Left hemianopia Amblyopia OS Macular sparing	Stroke	40Δ upper Fresnel	3 weeks	No symptoms no effect, removed

PCA, posterior cerebral artery; CSM, cavernous sinus meningioma.

Because the prism is placed across the lens, it is available in all positions of gaze. The patient is instructed to foveate through the carrier lens only and not through the prism. Looking through the prism causes central diplopia, which may be bothersome and uncomfortable. For a patient with normal vision (no hemianopia) the peripheral location of the prism would produce a peripheral diplopic view as high as the vertical field of the prism and shifted by 15 to 20° relative to the field of the other eye. For patients with hemianopia, the perception is similar over a large portion of this field (corresponding to the nonscotomatous field); shifted objects are seen in diplopia providing no particular help. Importantly, at the edge of the scotoma, objects that fall into the scotoma of the eye without the prism (Fig. 3, top row) are seen through the prism in the other eye, providing a real field-of-view expansion of about 15 to 20° (Fig. 3, middle row). This additional field is provided for any horizontal position of gaze, including gaze away from the side of the scotoma (Fig. 3 right column). Rather than diplopia, the objects that come into view due to the prism are said to be seen in confusion, because two objects (seen by the two eyes) are perceived to be in the same direction (Fig. 3, middle row). Confusion always coexists with diplopia and therefore is also part of physiological diplopia. Thus, people are as accustomed to confusion in their peripheral fields as they are to diplopia.

The constant peripheral exotropia provides a field expansion similar to that enjoyed by congenital hemianopes who are exotropic,[5, 6] except that it does not involve central vision. Through the adaptation of peripheral vision and the change in perceived direction reported by Kohler,[11] it should enable the field expansion to be useful and functional (the presumed adaptation is illustrated in Fig. 3, bottom row). Furthermore, the chromatic aberrations of the prisms provide a spectral cue that distinguishes the objects viewed through the prism from those seen through the clear carrier lens. This spectral difference facilitates adaptation to the prisms by reducing the ambiguity associated with the simultaneous perception, clearly marking the objects as to their eye of origin. The geometrical distortions of the high-power prisms[35] also aid in determining the eye of origin and thus facilitate adaptation. After adaptation (which might be likened to the development of peripheral ARC) the objects seen through the prism should be perceived at their veridical direction (Fig. 3, bottom row). A video simulation of the effect of the prisms including the color fringes can be seen at http://www.eri.harvard.edu/faculty/peli/index.html.

Most patients were fitted with removable Fresnel press-on prism segments of 40Δ (3M Press-on prisms, available from most ophthalmic and low-vision products distributors). These soft plastic segments are cut from a larger piece and fitted to the frame shape to cover the full width of the lens. Two patients were fitted with a permanent elliptical prism segment inserted inside the spectacle

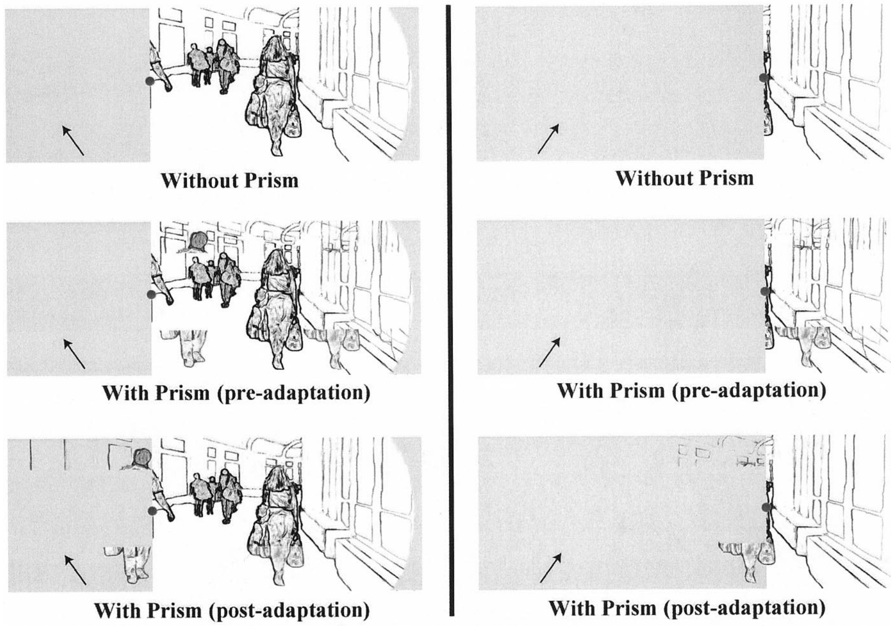

FIGURE 3.

An illustration of the appearance of an airport terminal scene to a patient with left hemianopia without and with the prisms before and after adaptation. Right column: appearance of scene when the gaze is shifted to the right. (Gaze direction may be a result of eye or head movements or both.) Left column: appearance of scene when gaze is leftward as illustrated by the direction of arrow in the bottom left side of each diagram. Top row: the appearance without the prism correction. The small filled circle at the middle represents the point of fixation. Note that a leftward gaze expands the field-of-view for the patient. The gray area to the left of fixation represents an area of no vision and should not imply an appearance of gray field in the patient's view. The curved border gray area represents the end of the normal visual field on the right. It is placed here to emphasize that the hemianopic scotoma is not different in appearance from portions of the field beyond normal vision, such as behind the head. Middle row: appearance with prisms in place before adaptation. In both positions of gaze, the top and bottom of the scenes include diplopic views. Note that chromatic fringes are caused by the prisms. These color fringes can help the patient distinguish the prismatic view from the right-eye direct view. The benefit of the additional field-of-view provided by the prisms is apparent by the additional objects that can be seen in the middle row compared with the top row. Bottom row: appearance with prisms after adaptation. Here, the prism views are perceived in their correct spatial location due to adaptation. This view more clearly illustrates the field expansion provided by the prisms. Note, that the same expanded field-of-view is available preadaptation, only the perceived direction changes. A video simulation of the effect of prisms (including the color fringes effects) at different positions of gaze can be seen at http://www.eri.harvard.edu/faculty/peli/index.html.

carrier lens (Multilens Optical Solutions, Mölnlycke, Sweden) (Fig. 2, upper prism segment). Prism segments of 30Δ are available at a length of 32 mm; segments of 40Δ are limited to 22 mm. This type of segment has better optical qualities than the Fresnel segment, but has a number of disadvantages. The cost is substantially higher, the thick prism base protrudes dangerously close to the eye, and the size of the segment is limited and therefore cannot cover the full width of the carrier lens; however, the available size is quite sufficient. For these reasons and the reduced need for high optical quality in the periphery where the prism is used, Fresnel lenses have been used in most cases. However, Fresnel prisms are usually found to be in poor optical condition at the 6-month follow-up. It may be of value to reconsider a permanent correction using prism inserts of some better design.

Fitting and Training

The patient is instructed to look only through the carrier lens. When an object of interest is detected through the prism (in peripheral vision), it should be examined through the carrier lens by making a vertical head movement. In normal vision, foveating eye movements usually precede such head movements. The patient's training consists of learning to avoid such eye movements or to follow them quickly with a head movement to eliminate the diplopia if it occurs. In many ways the required behavior is similar to that needed with bifocals or progressive addition lenses, where head movements are needed to eliminate the blurry appearance of targets seen through the wrong part of the lens. Similarly, patients using the peripheral-prisms report that the head movements require deliberate attention at first and become almost automatic after some training and practice (usually less then a week).

For the initial trial and training period, patients were fitted with a Fresnel press-on prism segment on the upper part of the lens only. The 40Δ base-out segment is cut to fit the top part of the spectacle lens on the side of the visual field loss. The segment is trimmed to the height of the upper limbus margin. The use of upper segment prism is attempted first. Because the upper field is less important in mobility and usually contains fewer obstacles, adaptation to upper prism segment may be easier. The upper segment prism can help the patients avoid obstacles in the upper field, such as kitchen cabinet doors, and overhanging tree branches. They are also effective in avoiding obstacles that extend to both the lower and upper field, such as utility poles, tree trunks, and bus and traffic signs.

On a follow-up visit at the conclusion of a 2- to 3-week trial period, the patient was interviewed about the effect of the prism and their experience with it, and the patient's binocular visual field with the prism segment was tested (see field testing procedure below). If the patient's experience has been favorable (noting no ill effects or difficulties with the prism, whether or not the positive effect of the prism on avoiding obstacles was noted), the patient is fitted with the lower segment prism. Patients with quadrantanopia were fitted with only one segment, either upper or lower depending on the field loss.

The lower prism segment is cut to fit the lower edge of the lens. The upper edge of the prism is positioned to intersect the line of gaze from standing position to a distance of about 4 m on the ground in front of the patient. This is done with the patient standing up, holding the head straight and looking straight ahead at a target at eye level. An object (a pen or pencil) is placed at the 4 m distance on the floor (in the seeing side of the field). The patient is asked to continue to look at the eye level target. This fixation helps to maintain the head posture. The patient is asked to note the object on the floor with his peripheral vision. A piece of paper is brought from below and slowly raised up in front of the lens until it obscures the inferior peripheral view of the object on the floor. The paper's edge position on the lens is marked and the mark is used for the upper position of the prism. If the patient has difficulties with the peripheral task the same can be done while the patient is foveating the object on the floor. However, care should be exercised to assure that the head position remains straight ahead.

The patient is then instructed in the use of the lower prism segment. When an object is noted through the prism, a vertical head motion is required to examine the object through the carrier lens and avoid diplopia. Lateral eye movement into the side of the field loss is required as well, but patients need no instruction to initiate this eye movement once an object is detected. The patient is taken for a trial walk with the lower prism. Walking a path through a waiting room with many chairs and small tables is particularly useful in training the patients in the use of the prism and noting its effectiveness. The patient is further instructed in the use of the prism while going down stairs, which requires head lowering to see the stairs through the carrier lens. The use of hand rails, whenever possible, to improve stability and safety is recommended.

The patient is instructed in the care and cleaning of the prism and in reinstalling the prism segment in case it peels off the lens while being cleaned. Patients are scheduled for an additional follow-up visit when the binocular field is measured with both segments and the experience of prism wear is further investigated. Semiannual visits are scheduled thereafter to examine and replace the prism if necessary and to continue to monitor the patient's progress.

Visual Field Testing

The peripheral prism design described here provides for a field-of-view expansion, which should be measurable by standard (binocular) perimetry. In addition, the magnitude of the expansion can be predicted based on the prism power (about 20°) and can be tested by the perimetry. The field expansion should occur at all positions of gaze; therefore, it should be measurable at the primary position of gaze.

We first measured patients' fields monocularly using standard perimetry techniques to obtain a description of the field loss. After prism prescription, the patients' fields were measured binocularly with and without the prism. Binocular field measurement in homonymous hemianopia should reveal hemianopia as well. Other parts of the field such as the blind spot will be affected by nonoverlapping field limitations. Two types of procedures were used: a standard Goldmann screening procedure and the Humphrey Esterman Binocular test. The Goldmann fields were measured using a standard screening procedure consisting of dynamic mapping and static perimetric probing within identified nonscotomatous areas. The patient viewed the fixation target binocularly and the chin rest was centered to keep the head in the center of the bowl. Fixation was monitored through the observation tube in the standard way. A special low magnification tube is necessary to enable view of both eyes when the chin rest is centered. Without such a low magnification tube, the binocular field can still be recorded with one eye centered as in the standard procedure, leaving the fellow eye uncovered. The error induced by this slight change in position is negligible. Three to five isopters were measured using the range of targets from I1e to V1e. Technicians who, in most cases, were unaware of the purpose of the prisms conducted the perimetry. They were asked to center the patient in the perimeter and apply the same procedure they used normally for diagnostic perimetry testing.

The Easterman binocular test available on the Humphrey perimeter is a screening test designed for binocular measurements. A wide field is tested up to 80° of eccentricity on both sides using a total of 120 test points, most in the lower field. The points are tested at a single intensity. To confirm the objectivity of the field expansion measurements several of the patients where evaluated with the Easterman test. The small number of test targets in the central 40° (which may be affected by the prisms), especially in the upper field, limited the usefulness of this test. Binocular fields can be tested also with other Humphrey programs; however, they lack fixation tracking when used this way.

Some patients with hemianopia develop such effective scanning eye movements that they can defeat even the fixation checks of automated perimeter and experienced perimetry technicians. Whenever there was doubt about a feature of the monocular fields, the patient was also tested with the scanning laser ophthalmoscope (SLO).[36] The scotoma border was determined using dynamic perimetry and the position of a retinal landmark relative to the fixation target was used to correct for eye movements. This procedure provides the examiner with a confident and clear field boundary. Patients with visual field loss in general and hemianopia in particular adopt scanning eye movements,[37] which may prevent accurate assessment of the scotoma in standard perimetry.

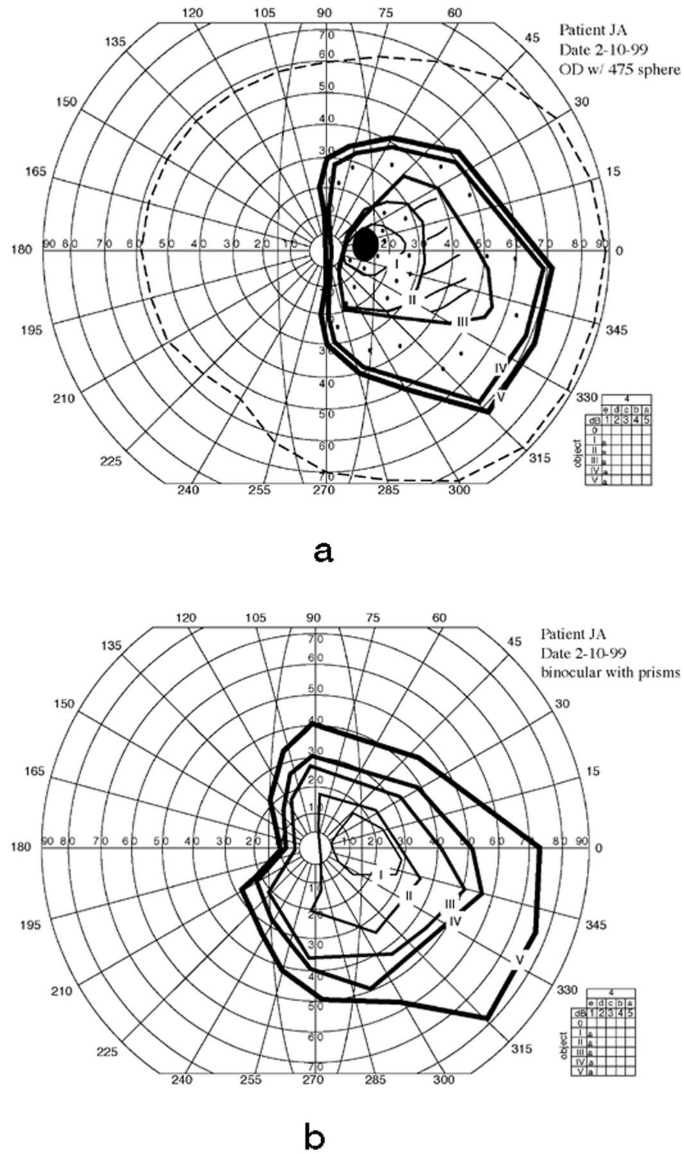

FIGURE 4.

The Goldmann visual field of a patient (#10) with left hemianopia (a) measured in the right eye (left eye similar) and (b) measured binocularly with the prism correction (40 Δ) in both upper and lower segments before the left eye. Note the additional field extending about 20° left of the midline. The dashed line in (a) shows the normal visual field. Thicker lines represent larger targets; a relative scotoma by hatched lines; and an absolute scotoma by a filled region, dots represent points tested and confirmed with static presentations within the seeing field.

RESULTS

Field Expansion

For all but one patient (#2 in Table 1), the field measured binocularly with the prism segment demonstrated the expected field expansion in the corresponding quadrants. A field expansion of about 20°, as is expected with a 40Δ was found in all cases. Fig. 4 illustrates the typical field expansion found in most patients, and Fig. 5 illustrates a case in which the homonymous scotoma was only about 20° and thus it was completely eliminated by the prism correction. The field expansion could also be demonstrated with binocular confrontation-field testing, where it also illustrated to the patient (and their present family members), the extent of the field expansion and the potential effects on obstacle detection in free space.

Visual fields for some of the patients were tested with the SLO to resolve doubts raised by the standard perimetry. Patient 3 had an unusual diagonal cut of the field as a result of his surgery that was confirmed with the SLO (Fig. 6a). In some patients the monocular perimetry show a preservation of the field that did not respect the vertical meridian. These patients were tested with the SLO to confirm or reject the existence of the field preservation. Fig. 6b demonstrates that patient 1 had a macular sparing as noted on his Goldmann field. Similar confirmation of the existence and the large size of macular sparing was reported recently.[38] Patient 11 had a preservation of vision across the midline above and below the fovea as measured by binocular Goldmann perimetry (Fig. 6c). The preservation could be confirmed with the SLO (Fig. 6d). However, for another patient (not reported here), a similar field preservation both centrally and peripherally measured by automated perimetry (Fig. 6e) could be rejected with the SLO (Fig. 6f) and was clearly shown to be a result of active scanning eye movements.

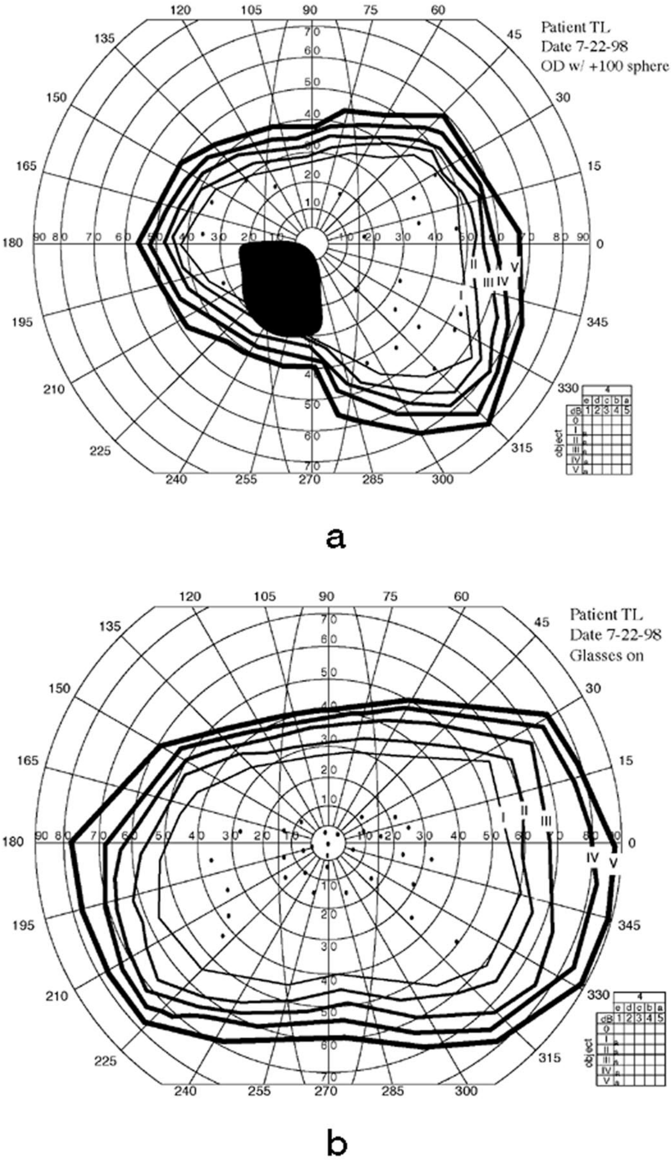

FIGURE 5.

Visual fields of a patient (#5) with partial left lower quadrantanopia secondary to surgery to remove a brain tumor. a: the visual field of the right eye was similar to that of the left eye (not shown). The fact that this patient had serious difficulties avoiding obstacles, despite an almost complete field, emphasizes the importance of the para-central field. b: the visual field measured binocularly with the prism correction (40Δ), in the lower segment only, resulted in complete elimination of the scotoma and relief of symptoms. The prisms, by compensating for the scotoma, provided safe mobility.

Subjective Effect

One patient with hemianopia and macular sparing (#12) had no subjective complaints before treatment. She knew of her field loss from her doctors' reports, and could demonstrate it for herself. However she had adapted to the condition to such an extent that she had experienced no limitation of function. The patient, nevertheless, was fitted with an upper segment prism to see if any improvement might be noted. The field expansion with the prism was demonstrated with perimetry as with the other patients. This patient, however, reported no benefit from the prisms though she had no particular difficulty with the prism. Because no positive effect was achieved, the prism was discontinued.

Three patients treated have been followed for more than 1 year. All (one with hemianopia and two with quadrantanopia) reported pleasure with the beneficial effect of the prism. After a short adaptation period of 2 weeks, they could use the prism segment as instructed and noticed that it expanded their field and prevented accidents. Two of these patients were fitted with permanent prescription incorporating the elliptical prism segment. After more than 1 year, they remain very pleased with the correction. Both patients are now driving. One is driving after a Department of Motor Vehicles evaluation. The upper partial quadrantanopia patient (#3) has been approved for driving because his horizontal visual field was sufficient, and he has been free of seizures for more than 6 months. He still feels safer and more comfortable driving with the prism segment. The third patient (#4) had right lower quadrantanopia as a result of seizures. This patient is emmetropic and needed to wear plano spectacles to be able to use the prism. The patient is very pleased with the effect and continues to wear the plano correction on a full-time basis. He experienced a substantial improvement in obstacle avoidance and requested a spare pair.

Except for the two patients discussed below (#2 and #11), all of the other patients reported rapid adaptation to the prisms (within 2 to 3 weeks) and experienced significant improvement in obstacle avoidance. Two patients (#5, #6) have discontinued their use of (short) canes as their mobility confidence increased with the prisms. One of these patients (whose fields are illustrated in Fig. 5) helps to demonstrate the importance of the paracentral 20° provided by these prisms for safe mobility. This patient's visual loss was a homonymous partial lower left quadrantanopia (Fig. 5a). Despite a complete peripheral field, this patient reported substantial difficulties with bumping into obstacles, especially furniture. This is reasonable to expect. Obstacles for mobility are likely to be fairly close to the midline and to the line of heading of a walking person or they will not intersect with the path. That this is the case also explains why the patients find the prisms, which expand the field only by 15 to 20°, to be effective.

Patients with Abnormal Binocular Vision

One patient with right hemianopia, who had severe visual complaints (#2), returned after an initial trial period with prisms and reported neither subjective improvement with the prisms nor any difficulties wearing them. Surprisingly, this patient demonstrated little change of the binocular field measured wearing the prisms. This patient had a right third nerve palsy as another consequence of her stroke. She had constant strabismus and was found to suppress the eye on the side of the scotoma. The lack of functional binocular vision may explain the lack of effect of the prism designed to work under binocular conditions.

A second patient with left hemianopia (#11) had a history of amblyopia in the right eye, no strabismus, and only weak intermittent indications of central suppression. During the trial period, she reported that the peripheral view through the prism segment on the left lens was dominant and resulted in erroneous perception of the direction of objects in the upper field. The effect was bothersome when traveling as a passenger in a car and when walking in

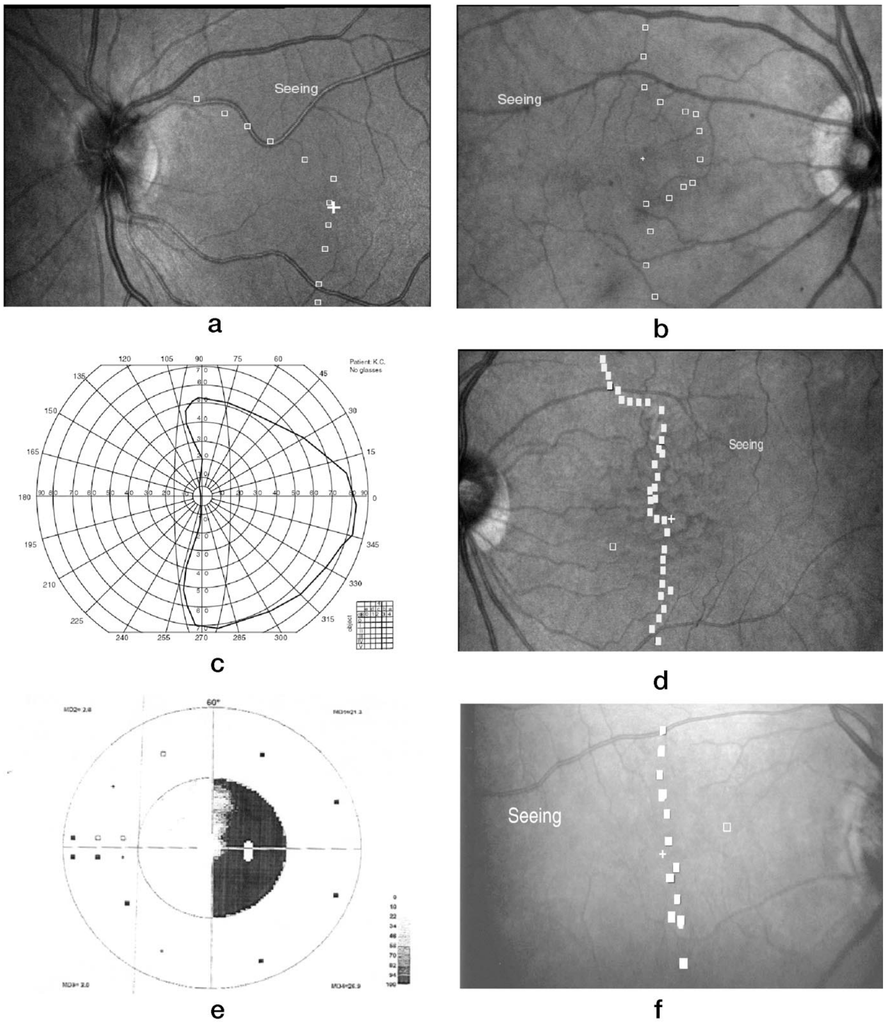

FIGURE 6.
Visual fields measured directly on the retina using the Scanning Laser Ophthalmoscope (SLO). A dynamic perimetric procedure was used with a target of the size shown. Stimulus retinal location was corrected for eye movements by referring it to a retinal landmark after each response. a: the superior left quadrantanopsic field of patient 3 left eye shows the same diagonal cut as measured with the Goldmann test. b: the right hemianopic field of patient 1 right eye shows a clear macular sparing. The spared area is similar in dimension to the optic nerve head. The presence of the sparing was not noted in the Goldmann fields. c: the binocular Goldmann field of patient 11 shows a left hemianopia with some preservation of vision to the left of the midline. d: the preservation of vision to the left of the midline was confirmed by SLO of the left eye. e: macular sparing and upper peripheral preservation recorded with an Octopus field provided for this patient by the referring physician. f: SLO of this patient's right eye shows no macular sparing, nor was any preservation noted in the upper field with the SLO. This patient exhibited continuous scanning movements, clearly visible with the SLO, which could account for the apparent sparing noted on the Octopus records of both eyes. Note that in the SLO images, the top part of the image shows upper retina (lower field) and the right side of the image shows the left retina (right field). The + marks are the foveal fixation targets used.

the forest. This patient decided not to continue the trial. The results with these two patients seemed to indicate that the method might not be effective for patients with abnormal binocular function.

A third patient (#7) with severe diplopia raised a possible solution for this limitation. This patient had left hemianopia caused by head trauma as a result of a bicycling accident. The same injury also caused left orbital trauma and scarring resulting in a noncomitant alternating hyper/hypotropia (with small component of exotropia) and diplopia. To resolve the diplopia, this patient's left lens had been frosted with nail polish. The nail polish was left at the center but was removed from the peripheral portions of the lens where the prism segments were fitted. This arrangement provided for the peripheral field expansion as in the other cases but avoided the central diplopia caused by the orbital injury. This system worked satisfactorily for the patient and may be useful in other cases of binocular dysfunction. In fact, in cases of exotropia together with hemianopia, which are quite common, the treatment may include only the blocking of the central portion of the lens with a translucent tape or nail polish coating. This will both provide peripheral field expansion and resolve the central diplopia. Note that the patient in such a case will continue to have central vision from the fixating eye and will only lose the central vision in the deviating eye.

DISCUSSION

Although the disability of patients with hemianopic field loss may be relatively mild, the problems of obstacle avoidance and safe mobility are not minor. At the moment optical treatment remains the only viable option available to these patients. Previous methods using prisms for such correction (i.e., monocular sector) frequently fail (especially with elderly patients).[29] The reasons for this failure should be apparent from the analysis provided above.

The novel method presented here for applying a prism device to treat hemianopia has the potential to provide actual binocular field-of-view expansion in a convenient and functional format. Using the approach in both the upper and lower peripheral fields can expand much of the peripheral field over a wide range of lateral gaze. The method has been tested with patients with varying homonymous field defects and etiologies. It provided relief of symptoms to hemianopic or quadrantanopsic patients with normal binocular vision who reported mobility difficulties because of the field loss. Patients with strabismus may benefit from occluding the central part of the lens on the side of the field loss, or on the other side for exotropia and esotropia, respectively. This approach may be used with or without prisms depending on the magnitude of the deviation.

This new method is successful because it expands the field-of-view and respects the underlying structure and function of the visual system. It maintains the separation of central and peripheral vision, leaving the functional central vision in its natural state and without the challenge of diplopia. The approach further takes advantage of the ability of peripheral vision to tolerate diplopia and confusion and the ability to adapt to optically induced changes in direction. Most importantly, the approach does not restrict the visual system in its normal use of eye movements.

Although these preliminary clinical results are encouraging, future work will require formal controlled evaluation of treated patients in mobility trials to verify the reported anecdotal effect of increased obstacle avoidance. Proper use of the prism in mobility requires adaptation to the visual anomalies induced by the prism. The confirmation that such adaptation occurs should be determined and the presence of aftereffects evaluated. Because the use of the lower segment will interfere with the use of bifocals, separate reading glasses are usually needed. Evaluation of adaptation should also address alternations between prescriptions so that when the patient switches to the reading pair he is not affected by the aftereffect. Patients in the reported group did not report such difficulties when changing to reading glasses.

Safe locomotion requires an accurate perception of self-motion in the environment. The direction of self-motion is believed to be derived from the optical-flow, the pattern of motion of objects generated on the retina.[39] Wearing a partial prism as used here changes the optical-flow seen in peripheral vision (where the optic-flow is strong) but not centrally. Such a split image might pose a problem for the perception of heading during walking. Wearing full diameter binocular prisms has been shown to affect locomotion of normally sighted subjects, causing them to walk a curved, veering course to targets.[40] Such effects on locomotion are likely to disappear after prism adaptation.[40] The effects on locomotion of full-diameter prisms is caused by a change in perceived location of the target seen through the prisms. If perceived location of target guides locomotion our prism should not cause such a disruption.

Although the existence of macular sparing has been questioned,[10] SLO-based retinal perimetry makes it clear that it is present in some patients. As seen here (Fig. 6) and reported elsewhere[38], the size of the macular sparing, when it occurs, is substantial (2 to 3° in radius). Although it is clear that such sparing is beneficial and may be important in reading, its impact on mobility is not known. Patients with tunnel vision (due to retinitis pigmentosa or glaucoma) with similar sparing on both sides of the midline still have major difficulties with obstacle avoidance, suggesting that a central field of this magnitude may be insufficient. Future studies of hemianopia should evaluate sparing status in all patients and compare performance across groups.

The differences between right and left hemianopia should be considered as well. In particular, left hemianopia is three times more frequently associated with spatial neglect than right hemianopia.[34] Even in the absence of neglect, a right hemisphere lesion may result in loss of spatial orientation and may therefore affect mobility more than a left hemisphere lesion. The value of our prism correction for hemianopic patients with neglect needs evaluation and comparisons with previous approaches.[3, 25] The prism method presented here may provide visual stimulation from the hemianopic part of space that may affect neglect as well.

Fresnel press-on prisms were useful for both the evaluation of the effect and for constant wear making the technique very inexpensive. A permanent prism inset (non-Fresnel) can be prescribed for successful users. The use of a multi-segment inset that can cover wide field of gaze with high power prisms needs further development. Because the prisms are used in peripheral vision, even stronger prisms than the currently used 40Δ may occasionally be valuable. Such prisms need to be designed, constructed, and evaluated. Most obstacle avoidance requires vision near the body midline or direction of heading, it is not clear that stronger prism power will be beneficial in most situations. A higher power prism may be of value only in situations in which a panoramic field of view is presumably required, such as in driving.

The peripheral prism proposed here also will increase the peripheral field-of-view if fitted binocularly. In this case, the result will be only a scene shift, but the shift will be applied to the peripheral superior and inferior fields-of-view relative to the foveal view. Thus, it should provide the patients with awareness of objects that would fall into the hemianopic scotoma in the inferior and superior fields without the prism. Although this design does not increase the instantaneous field-of-view (as does the monocular design), it may still be effective in providing awareness, because many objects that represent obstacles are large enough to be included in both the central and peripheral views and have these objects be noted. We already know from Kohler's[11] work that adaptation to this design is possible and not difficult. In addition, it has the advantage that it does not induce diplopia in any part of the field-of-view, even before adaptation and even if foveation through the prism segment is attempted. This binocular design has to be compared with the current design.

Of great concern to many patients and vision rehabilitation personnel is the question of driving with hemianopic field defects. In all states in the U.S. where visual field requirements for driving are legislated, hemianopia is a disqualifying condition, unless the patient is approved by special testing and licensing. Driving with hemianopia is also prohibited in all provinces of Canada, in the UK, and Australia, although there is little evidence that driving with hemianopia is not safe. A number of studies examining the relationships between visual field defects and road performance fail to show any significant correlation (see review by North[41]). A large controlled study by Johnson and Keltner[42] did find accident and conviction rates to be doubled among patients with binocular field loss. However, they did not distinguish the various types of losses so the contribution of hemianopia to this statistic is not known. Studies reported at the recent conference on Vision in Vehicles[43–45] claim to show that hemianopia impedes driving, but none of them presented a strong case. The retrospective study by Racette and Casson[43] found that only 23% of hemianopic subjects were deemed to be unsafe to drive in their first evaluation. Munton[44] argued that hemianopic patients do not scan the road as much as a normal observer. However, the normal observer was not naïve, as was the hemianopic subject, and the simulated driving task did not require the caution and care that would be required in an actual or simulator driving test. No evidence was provided that the scanning performed by the hemianope was in any way less compatible with safe driving than the strategy taken by the normally sighted observer. Although it does stand to reason that restricted field of view may represent a compromise for safety in some situations, a recent controlled driving simulator study found no difference between the driving performance of hemianopes and normally sighted subjects on a number of performance measures.[46] If further studies do show that hemianopes performed worse in driving tasks, field expansion with prisms could be attempted as a remedy. However, such testing is futile before a clear difference in performance can be shown without the prisms.

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Eli Peli
The Schepens Eye Research Institute
Harvard Medical School
20 Staniford Street, Boston, MA 02114
email: eli@vision.eri.harvard.edu