Clinical and Laboratory Evaluation of Peripheral Prism Glasses for Hemianopia

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Abstract

**Purpose:** Homonymous hemianopia (the loss of vision on the same side in each eye) impairs patient ability to navigate and walk safely. We evaluated peripheral prism glasses as a low vision optical aid for hemianopia in an extended wearing trial. **Methods:** Twenty-three patients with complete hemianopia (11 left; 12 right) with neither visual neglect nor cognitive decline enrolled in the 5-visit study. To expand the horizontal visual field, patients’ spectacles were fitted with both upper and lower Press-on Fresnel prism segments (each 40 prism diopters) across the lens on the side of the visual field loss. Patients were asked to wear these spectacles as much as comfortably possible for the duration of the trial, which averaged 9 (range: 5 to 12) weeks. Clinical success (continuous wear), visual field expansion, perceived visual direction and perceived quality of life were measured. **Results:** Clinical Success: 14 of 21 (67 %) patients chose to continue to wear the peripheral prism glasses at the end of study (2 patients did not complete the trial for non-vision reasons). Visual Field Expansion: Expansion of about 22 degrees in both the upper and lower quadrants was demonstrated for all patients (binocular perimetry, Goldmann V4e). Perceived Visual Direction: Two patients demonstrated a transient adaptation to the change in visual direction produced by the peripheral prism glasses. Quality of Life: At trial end, reduced difficulty noticing obstacles on the blind side was reported (p=0.007). **Conclusions:** The peripheral prism glasses provided reported benefits (usually in obstacle avoidance) to 2/3 of the patients completing the trial, a very good success rate for a vision rehabilitation aid. The limited adaptation of visual direction found may have been due to insensitive measurement
techniques, a trial wearing period that was too short, or suggests that additional training is required. Long-term retention of use of the peripheral prism glasses should be examined.

Key words: low vision, adaptation, rehabilitation, homonymous hemianopia, prism treatment
Homonymous hemianopia is the loss of half the visual field in both eyes on the same side and to the same extent. The visual field loss results from post-chiasmal damage to the optic tract or its cortical projections and is contralateral to the side of the brain injury.\(^1\) The most common cause of hemianopia is stroke with other cases attributable to traumatic brain injury, tumors, and brain surgery.\(^1\) An estimated 682,000 incidents of stroke occurred in the USA in 1995,\(^2\) and a third of stroke survivors may suffer homonymous hemianopia.\(^3\) Many of these patients do not regain their lost visual field. Zhang et al. reported spontaneous improvement of homonymous hemianopia for half of patients when tested within the first month following cerebral injury. At six months, recovery was found among those patients with reversal of the underlying brain injury (e.g., tumor resection), but no patient with stable brain injury showed further improvement after 6 months.\(^4\) With the aging of the population the incidence of stroke and concomitant prevalence of hemianopic visual field disorders is likely to increase. As such, there is a need for rehabilitation efforts to support the large number of people afflicted and the lack of a cure.

Individuals with hemianopic visual field defects report both functional and social impairment to perceived quality of life. Chief complaints are difficulty reading,\(^5\)–\(^8\) loss of driving privileges,\(^9\) and impaired mobility, defined as ability to orient (find where one is), navigate (get from point A to point B based on visual cues), and avoid obstacles (passersby and objects in the blind side encountered while walking). Many people with homonymous hemianopia adapt to their condition and learn to avoid collisions on their blind side, possibly by adopting a scanning behavior similar to that described by Gassell and Williams\(^5\) in which gaze was concentrated towards the blind side when viewing
simple patterns. Similarly, using a scanning laser ophthalmoscope (SLO), Jamara et al.\textsuperscript{10} demonstrated that two of four patients who appeared to show macular sparing using standard visual field testing, were actually scanning laterally. This adaptive scanning behavior is not shown by all patients. Zihl\textsuperscript{11, 12} demonstrated better visual search task performance in patients who reported less real-world mobility impairment (e.g., less bumping into obstacles) than patients reporting greater mobility impairment.

Rehabilitative approaches to homonymous hemianopia typically fall under three categories: (1) Training patients to make better compensatory scanning eye movements;\textsuperscript{13-16} (2) restoring a portion of the blind hemifield through training,\textsuperscript{17} and; (3) The use of optical devices, most commonly prisms.\textsuperscript{3}

The most common optical treatments involve using monocular or binocular sector prisms.\textsuperscript{3, 18} The theoretical limitations of these methods were previously reviewed.\textsuperscript{19} Peli\textsuperscript{19} proposed the use of peripheral prism segments placed on the spectacle lens above and below the line of sight (peripheral prisms). Usually applied monocularly on the side of the visual field loss (Fig. 1), and with the base in the direction of the visual field defect, this method expands the binocular visual field (as measured by perimetry) rather than merely shifts it (Fig. 5). Importantly, the peripheral prism design avoids the foveal double vision (consisting of diplopia, seeing the same object in two different directions, and visual confusion, seeing two different objects in the same visual direction) that is associated with monocular sector prisms\textsuperscript{20} and mirror-based visual field expansion devices.\textsuperscript{18} The prism segments extend across most of the horizontal extent of the spectacle lens and, therefore, are effective at all lateral positions of gaze, while the sector prisms in the other designs are only effective when the patient’s line of sight is through
the prism segment. The central part of the spectacle lens is unaffected, allowing normal binocular vision with the habitual distance prescription (if any). The peripheral prism segments produce peripheral double vision, which is much less bothersome to the patient than foveal double vision.\textsuperscript{19} It is actually the peripheral visual confusion and not the peripheral diplopia (which occurs farther in the periphery with this design) that provides the peripheral visual field expansion. Objects that would normally fall in the blind visual field of the eye on the side of the visual field loss are shifted to the residual visual field and become visible, superimposed with the objects seen by the corresponding retinal area in the other eye. The patient is instructed to use the prism segments only to detect objects in the periphery. Once an object of interest is detected (peripherally) through either prism segment, the patient should then tilt his head up (or down) to view the object through the clear portion of the carrier lens. Peli\textsuperscript{19} evaluated this method in a case series with 12 subjects. Expansion of the binocular visual field (Goldmann perimetry), was shown for all patients, and most (75\%) reported benefit with the peripheral prism glasses, usually reported as better ability to avoid obstacles on the blind side. Although that case series study was deemed clinically successful, no objective functional measures outside of visual field expansion were performed.

It is interesting to note that visual field expansion has not been demonstrated for any of the sector-prism previous approaches. This is probably because such expansion cannot be measured with either binocular or monocular prism segments fitted in the common configuration. In the case of binocular prisms (full or sector designs) no visual field expansion occurs. In the case of the monocular sector prisms the expansion that may occur, accompanied by double vision, is reported to be transient and thus cannot be
measured. Although Gottlieb\textsuperscript{21} claimed that patients’ visual fields are being restored and expanded by wearing of the prism, that reported curative effect was measured without the prism and results showing visual field expansion were never published. With peripheral prism glasses the visual field expansion is easily demonstrated with standard perimetry.

Our study evaluated functional and subjective rehabilitative effects for patients wearing the peripheral prism glasses in an extended wearing trial. We expected patients to demonstrate visual field expansion as shown by Peli,\textsuperscript{19} and hypothesized that some patients may adapt to the perceived direction of objects seen through the prism segments, as was demonstrated by Kohler.\textsuperscript{22} We wished to know in what daily living situations the peripheral prism glasses were of benefit (or hindrance) to the patient, and whether patients found the peripheral prism glasses of sufficient value that they would continue to wear them after the end of the study.

Most clinical trials evaluate the efficacy of the treatment; whether the treatment has the intended effect. An alternative approach, clinical success, evaluates aspects such as the ability to tolerate, the ease of use or the continued use of the treatment. Many issues beyond measures of intended effect can contribute to the value of the treatment. Since, the efficacy of many low-vision devices and refractive error corrections (such as with contact lenses, where acuity improvement is trivial to show) can be easily demonstrated, clinical success has been assessed by the continued use by the patients.\textsuperscript{23-29} Similarly, continued smoking cessation\textsuperscript{30} and continued weight loss.\textsuperscript{31} In our study, we used continued use of the peripheral prism glasses as our main measure of clinical success.
Methods

Extended Wearing Trial

The peripheral prism glasses were evaluated during a prospective 5-visit, extended-wear trial of a planned 8-week duration (Fig. 2). Following an initial inclusion screening at visit 1, eligible patients returned and were fitted with upper and lower prism segments at visits 2 and 3, respectively. Intentionally, six patients did not attend for visit 4 (Fig. 2). The value of the peripheral prism glasses was evaluated through measures of: Clinical success; visual field expansion; perceived visual direction, and; perceived quality of life.

Eligibility Criteria

Patients were required to have complete homonymous hemianopia, best-corrected single-letter visual acuity of 20/50 or better in each eye, understand verbal directions in English, be able to walk unaided for at least one hour and not have spatial neglect\textsuperscript{32-34} or a significant cognitive disorder.\textsuperscript{35, 36}

Monocular dynamic Goldmann perimetry (target V4e) results taken during visit 1 (Fig. 2) were used to determine complete homonymous hemianopia. Complete hemianopia was defined as no residual vision on the hemianopic side of the vertical meridian of more than 5° within 30° above and below the fovea (Fig. 3a). Homonymous hemianopia was defined as horizontal differences between the two eye’s vertical meridia extending no more than 10° within 30° above and below the fovea (Fig. 3b). In addition, the unaffected visual field was required to have a minimum temporal horizontal visual field of 60° in the eye contralateral to the injured hemisphere and a minimum 40° horizontal nasal visual field in the ipsilateral eye.
Individuals with hemianopia may develop effective lateral scanning strategies which may mislead even careful and experienced perimetrist.\textsuperscript{10, 37} Such scanning movements also make it difficult to determine the presence and size of macular sparing.\textsuperscript{37} To overcome the limitations of standard clinical perimetry we performed retinal perimetry using a SLO (Rodenstock, Inc., Munich, Germany) or a Nidek MP-1 (Nidek Technologies, Vigonza, Italy). The SLO allows the operator to manually indicate the retinal position of the fixation cross following target presentation. The Nidek MP-1 uses automatic eye tracking (at 25 Hz) to calibrate retinal position at the time of target presentation. As described below, we also used the SLO or Nidek MP-1 to determine lateral eye scanning extent.

**Spatial Neglect and Cognitive Status Testing**

Spatial neglect is a frequent co-occurrence of hemianopia, more common with right hemisphere damage. It is characterized by a lack of awareness, or “neglect” of stimuli present on the side contralateral to brain damage. Although 70\% of neglect patients also show hemianopic visual field loss, neglect is not purely the result of visual field loss. We excluded patients with spatial neglect using two pencil paper tests of lateralization.

The *Bells Test*\textsuperscript{32} is a cancellation test in which 315 common small object figures were dispersed over an area of 20 by 27 cm. Thirty-five (11\%) of these figures were bells, distributed about equally on the right and left halves of the page. The page with figures was centered directly in front of the seated patient, who circled, or “canceled”, as many bells as they could find in a non-timed test. The patient reported when “all” the bells had been found. The test was scored by recording the number of bells missed on each side of the page.
The Schenkenberg Line-Bisection Test\textsuperscript{33,34} consisted of a set of 20 horizontal lines (equally spaced, and of different length and position) over an area of 15 by 22 cm. Length of the lines varied from 100 to 200 mm. Eighteen of these lines were used for testing (two were used for demonstration of the task) and consisted of 3 sets of 6 lines per set which differed in spatial organization on the page: One set was on the left side of the page, one set on the right side of the page and one set was primarily in the middle of the page. The lines were pseudo-randomly distributed with respect to size and primary position. The page was centered directly in front of the seated patient who marked with pencil the center of each line, starting from the top-most line and proceeding to the bottom-most line. The exam was scored by computing the percent deviation of the perceived center of each line from the true center, and then averaging the percent deviations for all lines marked by the patient. The number of “missed” lines was also recorded.

Our criteria for neglect and hence exclusion from the trial was finding two or more of the following outcomes with the same lateralization:

1) Bells Test: A difference in number of missed bells between the left and right sides of the page of four or more;

2) Line-Bisection Test:
   a) The number of “missed” lines on one side of the page exceeded the number of missed lines on the opposite side by two or more; or,
   b) The average percent deviation of the patient’s perceived center all lines was greater than 10%, right or left biased.

Cognitive and perceptual disorders often accompany stroke or other brain injuries. An estimated 75\% of stroke victims have some residual cognitive impairment.\textsuperscript{36} We
excluded patients with significant cognitive deficits as determined by the Mini-Mental State Exam Psychological Assessment Resources, Inc, Lutz, Florida) using a score of 24 or more of 30 questions correct for inclusion in the trial (mean score for a healthy comparison group was reported as 26). 

**Patients**

Twenty-eight patients, referred to us by local neuro-ophthalmology clinics and deemed suitable based upon an initial telephone interview with the prospective patient, were screened for participation in the trial. Four patients did not meet the visual field criteria (Fig. 3), and one did not meet a “walk unaided for 1 hour” criterion. The 23 (14 male, 9 female) that were enrolled had an average age of 46y (range 16 to 72 y). Etiology of the hemianopias included stroke (16), brain tumor resection (4), traumatic brain injury (2), and congenital hemianopia (1). Only three patients demonstrated macular sparing, as assessed by retinal perimetry. The median binocular single-letter visual acuity of enrolled patients was –0.10 logMAR (20/16; range -0.48 to +0.20 logMAR).

    No enrolled patient missed more than one target on the Bell Test. On the Line Bisection Test only one patient missed more than one line, and only three patients showed more than 10% mean deviation in marking the center of lines (average absolute deviation 5.3%, range 0.2 to 10.6%). The average Mini Mental State Exam score was 28 (range 24 to 30).

    The trial protocol was approved by the Schepens Eye Research Institute Institutional Review Board. All patients read, or were read, the Consent to Participate form, and had all questions answered prior to signing the Informed Consent form.
Peripheral Prism Glasses Description, Fitting and Training

As described by Peli\textsuperscript{19}, we used 40 prism diopter (Δ) Press-On\textsuperscript{TM} Fresnel prisms (3M Health Care, St. Paul, MN) made of soft plastic that clings to the back surface of the spectacle lens. Separate prism segments were used for the upper and lower visual fields. Both prism segments were placed base-out (the base of the prism positioned toward the temple) on the spectacle lens on the side of the visual field loss. Prism segments were cut to the shape of the spectacle lens from the press-on material and placed across the top and bottom of the spectacle lens. The straight, lower edge of the upper prism segment was placed aligned with the superior limbus (about 6 mm above the center of the pupil). To determine the position of the lower prism, an object (e.g., pen) was placed on the floor about 4 meters from the patient, (in the seeing side of the visual field) and the patient was directed to fixate an eye level target placed on a more distant wall while noting the object on the floor with their lower peripheral vision. A sheet of paper was brought from below the spectacle lens and slowly raised up until it blocked the view of the object on the floor. The position of paper’s edge on the spectacle lens was marked and was used as the position of the straight top of the lower prism segment. By coincidence, this was typically 6 mm below the pupil center, which is the lower limbus.

Patients had to have suitable spectacles or obtained new spectacles. Patients with no prescription glasses and those with frames that were too small or fitted too low to enable placement of the upper prism segment required a new pair. They were provided with instructions to the optician regarding the required frame dimensions (vertical B measure of at least 40 mm and the top eye wire splitting the eyebrow). Patients were
provided $100 towards the purchase of a frame or could choose from a limited selection of frames that we had available.

Patients were fitted with the upper prism segment at visit 2, and with the lower prism segment at visit 3 (Fig. 2). This order allowed the patient to use the upper prism segment in familiar surroundings for at least one week to become accustomed to and gain experience with the upper prism segment before being fitted with the lower prism segment.

At each prism fitting, the patient was reminded to look through the clear (non-prism) central part of the spectacle lens and not through the prism segments. The patient was directed to make a vertical head movement so that an object of interest detected with the prism segment was viewed through the central portion of the carrier lens. In normal vision, foveating eye movements usually precede such head movements. The patient was instructed to limit such eye movements to avoid foveal double vision (similar alterations in behavior are usually required for successful use of multifocal spectacles). We instructed patients that initially these head movements would necessitate conscious behavior, but over time they should become automatic.

At visit 2, the experimenter conducted a training exercise in which the patient’s gaze was directed at the experimenter’s nose, while the experimenter’s hand was moved on the blind side so that the patient could detect it peripherally through the prism segment. The patient was instructed to reach for the experimenter’s hand, ballistically (i.e., rapid movement with no opportunity for visual feedback). Initially reaching was inaccurate, as might be expected with vision through prisms, but it became accurate after a few trials, as is common in prism adaptation experiments. Though these hand
movements were ballistic, the response was closed loop (i.e. there was visual feedback following completion of the hand movement). The experimenter then walked with the patient through clinic corridors while wearing the upper prism segment and instructed the patient to pay attention to potential obstacles such as door frames and furniture. Finally, the patient was asked to walk up and down a flight of stairs, to confirm that the upper prism segment would not impede mobility (for safety, the patient was encouraged to always make use of handrails).

The patient was instructed on two brief training tasks which were to be performed at home times every day:

a) Reaching and touching task that utilized the prism segment and its altered perceived direction, and

b) Detecting and head movement task, designed to train the patient to avoid foveal double vision by fixating through the prism segments.

At visit 3, training in the use of the lower prism segment was similar to that of the upper prism segment; however, the patient was informed that adjustment to the lower prism segment might require more time, as it may initially impair mobility tasks such as stepping off curbs or ascending and descending stairs. The patient walked up and down a flight of stairs, and was instructed to tilt the head down so as to use the central portion of the carrier lens, again using handrails whenever possible. The patient was reminded of the two training tasks and further instruction and training was provided if necessary.

**Extended Wearing Trial Procedure**

The effect of the peripheral prism glasses on several functional performance measures was evaluated during a 5-visit extended wearing trial intended to be of 8 weeks duration.
(median = 9, range 5 to 12 weeks) (Fig.2). No patient had more than 0.1 logMAR (one line) difference in visual acuity except for two patients who showed slightly better visual acuity at visit 5 due to a change in their prescription glasses following visit 1. No patient showed in visual fields (5-degree in monocular visual field extent) between visit 1 and visit 5.

Clinical Success

We measured clinical success as the percent of individuals who chose to continue to wear the peripheral prism glasses after the wearing trial (i.e. at visit 5). At visit 5, at 3 month follow-up and at long term follow-up (Fig.2), the investigator recorded responses to formal questions covering peripheral prism glasses use, benefits and difficulties attributed to the glasses and willingness to pay for a pair of permanent peripheral prism glasses (Chadwick Optical, White River Junction, Vermont). During the interviews, the investigator could elicit additional descriptive responses to open-ended questions that would prompt further questions. At the visit 5 interview, a joint decision was made based upon the patient’s perceived benefit from the prism glasses and the clinician’s opinion, as to whether the patient should continue to wear them. If the patient and clinician thought continued wear was indicated, the patient was shown a sample pair of permanent peripheral prism glasses which the patient could order.

We asked patients to wear the peripheral prism glasses as much as possible during the course of the study. Following fitting of the upper prism segment (visit 2) patients were given a take-home wearing diary to record the number of hours per day that the peripheral prism glasses were worn. The form also had an open-ended comments section in which patients could record any difficulties or benefits experienced with the peripheral
prism glasses. Patients were asked to return the diary to us at the subsequent visit and were given a new diary at visit 3 and visit 4 with the same instruction. During the interview at each visit, the investigator asked the patient for an estimate of the hours worn per day since the last visit, and these responses were used as data also. Of the 46 diaries provided, 29 were completed and returned (63%). The average number of hours per day that the peripheral prism glasses were worn was calculated from these two sources of data.

**Macular Sparing and Lateral Scanning**

We hypothesized that macular sparing would have an impact on the clinical success of the peripheral prism glasses. We hoped to recruit equal numbers of patients with and without macular sparing to explore this hypothesis. A Rodenstock SLO or Nidek MP-1 was used to determine macular sparing. Both these instrument compensate for eye-movements. Goldmann visual fields do not provide sufficient resolutions and cannot control for eye-movements. Measurements were made on 15 patients who progressed to visit 2 (upper prism fitting). Only three of these patients showed macular sparing of 3° to 5°.

Lateral scanning, a normal compensatory eye-movement pattern, may affect the perceived benefit of the peripheral prism glasses. We measured the horizontal extent (in degrees) over which eye movements occurred when the patient was asked to fixate a 1° cross during the monocular fixation exams using SLO or the Nidek MP-1.
Visual Field Expansion

Dynamic perimetry was conducted using a V4e target on a Haag-Streit Goldmann perimeter. Binocular visual fields were measured at visits 2, 3 and 5: at visit 2, with and without the upper prism segment; at visit 3, with and without the upper and lower prism segments, and; at visit 5, with and without the upper and lower prism segments. Visual field expansion was measured as the horizontal distance (in degrees) between the unaided (no prism) vertical visual field border and the same point measured with the prism segment (Fig.5). The expected expansion for the 40Δ prism segments was about 22°.

Change in Perceived Direction

We defined perceived direction as the perceived (angular) position of an object relative to the line of sight. Prisms alter the apparent visual direction of objects. Initially, the perceived direction of an object seen through a prism is not veridical (correct). People can adapt the perceived direction of objects seen through a full lens binocular prism. Kohler, who wore a binocular half-prism every waking moment for 10 days, reported a “dual” adaptation to the view through the prism and to the view through the prism free lens. We hypothesized that patients wearing the (monocular) peripheral prism glasses might adapt in a similar manner.

We measured perceived direction using a pointing task at visits 2, 3, 4 and 5. Viewing was always binocular. Patients were seated one meter from a wide rear projection screen (81° by 64°). Large head movements were restricted by a chin-rest and a tight headband. Patients indicated the perceived direction of stimuli (2° blinking, black circles) on the screen by pointing a computer mouse held in the hand over a large graphic
bitpad (90 by 120 cm). Testing was open-loop as a wooden box over the bitpad prevented the patients’ view of their arm, hand or mouse and the mouse icon was not visible on the display. Patients wore a brace to limit flexion of the elbow and were asked to not flex the elbow or the wrist, so that pointing was only from the shoulder. A pointing calibration step adjusted for individual differences in response. During pointing calibration the patients could turned their eyes (but not head) towards each approximately eye-level target.

After pointing calibration, the locations of the prism edges were located on the screen coordinates. A staircase procedure was used, in which stimuli (2° blinking black circles) were presented along a vertical line 6° to the left or right of the vertical midline on the hemianopic (blind) side of the fixation cross. While fixating the cross, the patient would respond when the target became visible. This process located the edges of the upper and lower prism segments in the visual field. As the screen position of these landmarks would change with vertical head movement, head position was stabilized (described above).

Once the location of the prism segments were mapped, stimuli (2° blinking black circles) was presented in one of eight zones as shown (Fig. 4) in random order. Stimuli presented in zones A and D should be visible as they were presented in the normal hemifield. Stimuli in zone D could be perceived as doubled, as one eye saw it through the prism. Stimuli presented in zone B were not expected to be seen as they were presented in the blind hemifield and not within the prism segment field. Stimuli appearing in zone C were expected to be seen through the corresponding prism segment. Twelve stimuli were presented in each zone (3 vertical by 4 horizontal positions). For each trial the
patient maintained central fixation. If the patient detected the stimulus (either through a prism segment or via the normal hemifield), he shifted his outstretched arm over the bitpad until he was pointing in the perceived direction of the stimulus. For stimuli seen as doubled (i.e., those presented in zone D), the patient was instructed to point in the “correct” direction.

To determine adaptation, perceived direction was plotted against real direction (Fig. 6), and data for zone C (prism) and zones A and D (no prism) were fitted with separate straight lines with the same slope. The difference in y-intercept between the perceived direction for stimuli presented in the prism zone (zone C) and those presented in the seeing hemifield (zones A and D) was used as the outcome measure. Adaptation of perceived direction would appear as an overlap of these two lines with no difference in the intercept (Fig. 6b).

Quality of Life

To assess how the peripheral prism glasses affected perceived quality of life, we administered two questionnaires at visits 1 and 5. Both questionnaires, National Eye Institute Visual Function Questionnaire-25 (NEI-VFQ-25, version 2000) and the Independent Mobility Questionnaire (IMQ), contained items relating to daily living activities. The patient reported their perceived level of difficulty for each item. In addition to analyzing all questions of both questionnaires, we conducted planned analyses of responses to subsets of questions that we expected would be sensitive to the effects of the prism glasses. These questions related to mobility and obstacle avoidance: NEI-VFQ-25 questions 7, 10, 14, 15c, 20, 24, A2, A7, A11a & b, and A13; and IMQ questions 1, 2, 4, 6-8, 10, 13-17, 24-33, and 35 (Appendix). A modified Rasch analysis, which
estimates interval scales for ordinal data, was used to transform the raw scores of responses to the items of each questionnaire. Non-parametric tests were used in the data analysis. The Wilcoxon test was used for paired comparisons and the Mann-Whitney test for unpaired comparisons. We report results with a significance $\leq 0.1$.

**Results**

**Clinical Success**

Of the 23 patients who met the eligibility criteria (Fig 2), all were fitted with the upper prism segment at visit 2. Two patients did not complete the study for non-vision-related reasons, leaving 21 patients. A further two patients did not complete the study for vision-related reasons. Two patients left the study before visit 3; one did not find the upper prism segment to be of value and the other due to ill health. One patient left the study before visit 4 due to a lack of perceived benefit. One patient moved out of state before visit 5. Thus, 19 patients completed the study. Unless otherwise noted, analyses of data on subsequent measures were restricted to this group for which we had almost complete data.

Fourteen of the 19 patients were still wearing the peripheral prism glasses at the end of the study and wished to continue to wear. Of these 14 “successful wearers”, two patients eventually purchased the permanent peripheral prism glasses (described later). Of the five “non-successful wearers”, two patients discontinued using the peripheral prism glasses before visit 5, but did complete the study visits. Three patients were wearing the peripheral prism glasses at visit 5, but chose to discontinue wear at the end of the study. Thus, excluding the 2 patients who left the study for non-vision reasons, two-
thirds (14/21) of patients chose to continue to wear the peripheral prism glasses at the end of the study. At the nominally 3-month follow-up (range 20 to 26 weeks) 13 of these 14 successful wearers were still wearing the peripheral prism glasses. At long term follow-up (median 64, range 33 to 219 weeks), we were able to contact 11 of the 13 subjects who continued to wear the peripheral prism glasses at the 3-month follow-up interview. Of these 11 subjects, four had discontinued wear due non-vision problems, three discontinued due to a loss of the perceived visual benefit, and four were still wearing the peripheral prism glasses. Later, the patient who reported discontinued wear at the 3-month follow-up interview, restarted wearing the peripheral prism glasses again independently.

Analysis of patient responses to the open-ended questions of the visit 5 interview revealed that perceived benefits typically fell into only a few broad categories. For successful wearers, 10 of 14 (70%) reported a perceived benefit in “walking”, 3 of 14 (20%) reported a benefit in “crowd” situations, and 3 of 14 (21%) found the peripheral prism glasses useful in “supermarkets” and “shopping” malls. One successful wearer found the peripheral prism glasses useful in “searching” for objects on his desk. Only one non-successful wearer reported perceived benefits, namely “watching” sporting events and “driving” (all patients were advised about the safety and legality of driving).

Perceived difficulties with the peripheral prism glasses were more varied than perceived benefits. Two of 14 (14%) successful wearers reported difficulty in “crowds”, and two more reported difficulty with descending “stairs”. One non-successful patient also reported navigating “stairs” as troublesome when wearing the peripheral prism glasses. Other reported difficulties included: “glare”, which we suspect is a consequence
of the optical quality of the press-on Fresnel prism segments; “anxiety” or “startle” associated with the sudden appearance of objects detected through the prism segments (i.e., jack-in-the-box effect), and; “reading” and other near-vision activities for which the peripheral prism glasses not intended.

The 14 successful wearers wore the peripheral prism glasses more hours per day (median 4.1, range 1.0 to 13.8 hours/day) than did the 5 non-successful wearers (median 2.0, range 0.4 – 4.6 hours/day)(Mann-Whitney $Z_{18} = 1.95, p = 0.05$).

**Visual Field Expansion**

As 40Δ prism segments deviate light approximately 22°, we expected visual field awareness to extend laterally into the blind hemifield by about that amount, and to extend vertically by the height of the prism segment (which varied with the frame size). All patients showed the expected visual field expansion for both the upper and lower prism segments. The median measured horizontal visual field expansion for the upper prism segment was 23° (range 20 to 24°, measured following the upper fitting) and lower prism segment was 22° (range 20 to 24°, measured following the lower fitting).

**Lateral Scanning**

We hypothesized that those patients who showed a larger degree of lateral scanning – a typical adaptation by persons with homonymous visual field defects – might find the peripheral prism glasses less beneficial than those who scanned less, as they had already developed compensation methods to support their visual field loss. Comparing “successful” and “non-successful” prism eyeglass patients, we found a weak correlation for “successful wearers” to scan to a lesser degree (Mann-Whitney $Z_{11} = 1.75, p = 0.08$)
We also noted that during monocular SLO scanning tests patients scanned further with the eye on the side of the visual field loss than with the contra-lateral eye, with more triangles below the line and more squares above the dashed line in figure 8 (Wilcoxon $Z_{13} = 2.51, p = 0.01$).

**Change in Perceived Visual Direction**

We hypothesized that patients who wore the peripheral prism glasses for the duration of the trial would develop an adaptation of the perceived direction (i.e., the perceived direction of objects seen through the prism segments would become veridical, schematically illustrated in figure 6). No patient in the trial showed a consistent adaptation to the prismatic image displacement. Twelve patients were tested at visits 2, 3, 4 and 5, one patient at visits 2, 3 and 4 only and six patients not at all as the previous patients showed no adaptation to perceived direction. Only two patients showed a transient ability to correct for the displacement. Figure 7 shows visual direction testing data for one such subject. At visit 2 (fitting of the upper prism segment) the perceived direction was the prism induced visual direction (i.e., the perceived direction was about $22^\circ$ to the right of the real position: Fig. 7a). At visit 3 the patient demonstrated a reduction of the perceived direction to about $5^\circ$ to the right of the real position (Fig. 7b). On the subsequent visit (visit 4), some stimuli were coincident with the real position while the rest were scattered between the real position and the prism displaced image. On questioning, the patient reported making conscious adjustments to the reported position based upon where he thought the stimulus should actually be located in real space. Possible reasons for the lack of adaptation are addressed in the discussion.
Quality of Life

We hypothesized that the peripheral prism glasses would affect the reported quality of life for patients, by either aiding or hindering them in mobility situations. Seventeen of the 19 patients who completed visit 5 completed both QOL questionnaires. Analyses were performed for all 17 patients who completed the visit 5 and for the 13 “successful wearers”. There was no significant difference between the visit 1 and visit 5 average questionnaire scores for all patients completing the study (NEI-VFQ-25, Wilcoxon Z_{15} = 0.41, p = 0.68; IMQ, Wilcoxon Z_{16} = 0.16, p = 0.87), or for the “successful wearers” (NEI-VFQ-25, Wilcoxon Z_{12} = 0.35, p = 0.97; IMQ, Wilcoxon Z_{13} = 0.28, p = 0.78). Planned analyses were performed on specific questions within each questionnaire (see Appendix for list). For NEI-VFQ-25 question 10, a decrease in difficulty noticing objects off to the side while you are walking along, was found to be significant for all patients completing the study (Wilcoxon Z_{15} = 2.70, p = 0.007) and for “successful wearers” (Wilcoxon Z_{12} = 2.98, p = 0.003). When comparing results between visit 1 and visit 5 several other questions approached significance (.05 < p < .10). For the “successful wearers”, these were question IMQ 14, walking down steps, which demonstrated an increased difficulty when wearing the prism glasses, (Wilcoxon Z_{12} = -1.63, p = .10); IMQ 24, being aware of another person’s presence, which decreased in difficulty, (Wilcoxon Z_{12} = 1.60, p = .10); IMQ 28 avoiding bumping into shoulder-height objects, which decreased in difficulty, (Wilcoxon Z_{12} = 1.60, p = .10) and IMQ 30 avoiding bumping into knee-height objects, which decreased in difficulty (Wilcoxon Z_{12} = 1.60, p = .10).
Discussion

One of the main complaints of patients with homonymous hemianopia is difficulty experienced in mobility situations. Patients may collide with objects not detected on their blind side, though collisions on the other side are reported as well. In our extended wearing trial, 14/21 (67%) patients were clinically successful, choosing to continue to use the peripheral prism glasses. This clinical success rate is similar to that found by Peli,\textsuperscript{19} who reported 9/12 (75%) of patients continued to wear the peripheral prism glasses at the last follow up (2 to 18 months).

We believe that some patients stopped wearing the peripheral prism glasses due to the degradation of the optical quality of the temporary Fresnel material over time. After months of exposure to ambient ultra-violet light, dust, skin oil and facial lotions, the optical performance of this soft plastic degrades sufficiently to undermine its functional value. Recently, in collaboration with Chadwick Optical, we developed a permanent prism lens using a more durable plastic (PMMA) which, in addition to providing better initial optical quality, is easy to clean and maintains image quality for an extended period. In a follow up to a multi-center clinical trial of the peripheral prism glasses,\textsuperscript{45} 15 patients were dispensed these new permanent peripheral prism glasses. More of these patients continued to wear the peripheral prism glasses than those who patients remained with the temporary prisms. While routine replacement of temporary press-on prisms every 3 to 4 months is an alternate option, it is certainly not a convenient or practical long-term solution. Despite being advised of this need, after completion of the wearing trial (visit 5), none of these patients contacted us to request replacement Press-on prism segments.
and none reported receiving replacement prisms from other sources. However, at least two patients were fitted for permanent peripheral prism glasses.

As expected, all patients demonstrated a binocular visual field expansion of about 22º, which is approximately 4 times greater than the average improvement reported for patients who have undergone vision restoration therapy. In vision restoration studies, increases in visual field expansion were reported to be greatest for patients with least visual field loss. Our patients, with complete homonymous hemianopia, would expect to gain much less than the average 5º improvement reported. Regardless, the use of peripheral prism glasses does not preclude additional therapy with visual restoration training or training of compensatory scanning eye movements, and should supplement any beneficial effects of either of these therapeutic approaches.

Multiplexing with low-vision aids may occur at different levels. For example, detection of objects of interest (perception) may occur with or without a response (action) that may or may not be veridical (calibrated and valid). Perception or action multiplexing might be found in simple, visual environments (e.g. over a blank test field, as in perimetry), but not in more complex visual environments (where visual masking, rivalry, or inattentional blindness might interfere). While complete multiplexing leading to veridical action in complex real world situations, may be ideal, perception alone may still be an effective aid. For example, the peripheral prism may provide the patient with a warning about the presence of an object that could represent an imminent collision, then a response may be initiated once the object is fixated through the (non-prism) center of the carrier lens.
The peripheral prism glasses provided for perceptual multiplexing in simple visual environment as evident by the visual field expansion. Wearing the peripheral prisms improved obstacle avoidance in real life as reported by the patients and thus supported perception multiplexing in complex visual environment and also allowed for action multiplexing. Based on the finding of Kohler and others, we hypothesized that patients would obtain veridical direction perception of objects seen through the prism segments and thus benefit fully from calibrated action multiplexing. None of the patients in our trial demonstrated such veridical perception of objects in our pointing task. Two patients demonstrated consciously corrected responses to the changes in visual direction induced by the prism segments. That patients failed to adapt to the change in visual direction may have been due to: (1) a relatively short and intermittent wearing period (median 4.1 hrs/day, compared with Kohler’s full-time wearing schedule), (2) that our prism segments were fitted monocularly and not binocularly like Kohler’s subjects (though our design may be fitted binocularly and still be effective), (3) a reported failure to practice the ballistic reaching exercises, and, (4) the higher power of our prism segments which was more than double the prism power used by Kohler. Another reason for the lack of adaptation might be our instructions to patients to avoid looking through the prism segments. Adaptation of perceived direction may not occur when the non-veridical visual direction is in peripheral vision only. In Kohler’s experiment, the prism was worn so that objects seen through the prism were viewed intermittently by central vision. We are aware of no study in which subjects adapted to segments of a high power prism placed peripherally. As we believe the peripheral prism glasses will be of greater value to the patients if they are able to adapt their perceived direction, we will develop
training and fitting methods that may provide for such adaptation. Our clinical recommendation is that patients should initially be fitted with the press-on Fresnel prisms, and instructed to wear them for a period of two months to (1) become adjusted to the change in peripheral visual direction and (2) decide whether they find the peripheral prism glasses of functional value. Then, patients who decide to continue using the prism glasses should be fitted with permanent peripheral prism glasses.

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Dr Peli has a financial interest in a patent application the use of peripheral prisms assigned to Schepens Eye Research Institute and licensed to Chadwick Optical. Chadwick Optical funds research by Dr Peli and uses Dr Peli as a consultant.
Appendix

Listed below is the text of questions in the Quality of Life questionnaires that we hypothesized would be affected by the peripheral prism glasses.

National Eye Institute Visual Functioning Questionnaire\(^{40-42}\) (NEI-VFQ-25)

7. Because of your eyesight, how much difficulty do you have finding something on a crowded shelf?

10. Because of your eyesight how much difficulty do you have noticing objects of to the side while you are walking?

14. Because of your eyesight how much difficulty do you have going out to see movies, plays or sorts events?

15c. If currently driving: How much difficulty do you have driving during the daytime in familiar places?

20. I stay home most of the time because of my eyesight?

24. I need a lot of help from others because of my eyesight?

A2. How would you rate your eyesight now (with glasses or contact lens on, if you wear them)?

A7. Because of your eyesight, how much difficulty do you have taking part in active sports or other outdoor activities that you enjoy (like golf, bowling, jogging, or walking)?

A11a. Do you have more help from others because of your vision?

A11b. Are you limited in the kinds of things you can do because of your vision?

A13. I don’t go out of my home alone, because of my eyesight?

Independent Mobility Questionnaire\(^{43}\) (IMQ)

Patients rated the following questions in terms of degree of perceived difficulty.

1. Walking in familiar areas?
Walking in unfamiliar areas?
Moving about at work?
Moving about stores?
Moving about outdoors?
Moving about in crowded situations?
Moving about using public transportation?
Walking up steps?
Walking down steps?
Stepping onto curbs?
Stepping off curbs?
Walking through doorways?
Being aware of another person’s presence?
Avoiding bumping into people?
Avoiding bumping into walls?
Avoiding bumping into head height objects?
Avoiding bumping into shoulder height objects?
Avoiding bumping into waist height objects?
Avoiding bumping into knee height objects?
Avoiding bumping into low lying objects?
Seeing cars at intersections?
References


Figures

Figure 1. Peripheral prism correction for a right hemianopic patient wearing spectacles with upper and lower 40Δ prism segments affixed base-out (towards the temple) to the back of the right spectacle lens. Each prism segment expanded the peripheral binocular visual field by 22°, allowing the patient to detect objects that would otherwise fall into the blind hemifield. Each prism segment was cut to the shape of the spectacle lens, with the straight, lower edge of the upper prism segment and the straight, upper edge of the lower prism placed at the height of the top and bottom of the limbus, respectively.
Figure 2. Flow diagram showing the timing of visits, the main procedures at each visit and the numbers of patients. Numbers on the left of the flow diagram are the median time in weeks (range in parentheses) relative to the first fitting of a peripheral prism (upper at visit 2). Numbers next to the down arrows of the flow diagram show the numbers of patients moving to the next stage of the study. The numbers next to a right pointing arrow show the number of patients who discontinued wear of the peripheral prism at each stage. Intentionally, six patients did not have a visit 4, shown by the asterisk.
Figure 3. Illustration of the visual field inclusion criteria. The inclusion criteria were applied only to the area of the visual field 30° above and below the horizontal midline. (a) Complete hemianopia shown in a schematic binocular visual field. As the lower visual field extended less than 5° beyond the vertical midline within that zone, that quadrant was acceptable. However, the upper visual field extended greater than 5° making this hypothetical patient ineligible for the study. (b) Homonymous hemianopia illustrated with this schematic left eye monocular visual field. For this illustration, the right eye is assumed to have “ideal” hemianopia following the vertical meridian, hence a difference between the two eyes above or below 30° lines extending greater than 10 degrees beyond the vertical midline was acceptable, whereas the same difference within 30 degrees of the horizontal midline was not acceptable. A difference between the two eyes extending less than 10 degrees from the vertical midline in the latter zone was acceptable.
Figure 4. Perceived Direction testing. Patients were presented twelve stimuli in each of eight zones, four zones in the blind side (left of vertical midline, 2 upper and 2 lower) and four zones in the seeing side (right of vertical midline in, 2 upper and 2 lower). Stimuli presented in zones “A” and “D” were detected in the seeing hemifield and were expected to be reported by the patient in the real direction. Stimuli presented in zones “B” were not expected to be detected by the patient, as these were presented in the blind hemifield not covered by prism. Stimuli presented in zones “C” were expected to be detected through the prism segments shown as dashed lines and reported in the visual direction, demonstrating no adaptation of perceived direction, or in the real direction, demonstrating adaptation of perceived direction. The “X” represents the fixation target.
Figure 5. (a) Binocular visual field of a patient with right homonymous hemianopia is shown enclosed by the thick solid line. For comparison, the dashed line shows the binocular visual field of a normally-sighted subject. Stimuli presented in the grey portion were not seen by the patient. (b) Binocular visual field of the same patient wearing peripheral prism glasses. The difference in the visual field plots represents the visual field expansion provided by the peripheral prisms glasses. V4e target used for Goldmann perimetry.
Figure 6. Idealized schematic data showing “no adaptation” and “adaptation” of perceived direction with prism segments worn by a patient with left hemianopia. In (a), stimuli detected in the sighted hemifield are reported in the real direction (i.e., the patient points correctly to the stimulus presented on the screen). Stimuli presented in the non-seeing hemifield and detected through prism segments have a visual direction that is shifted about 22° relative to the real direction by the 40Δ prisms. The perceived direction is the visual direction indicating no adaptation to the prism shift. In (b), stimuli seen in sighted areas are reported as in (a), but stimuli seen through prism segments are reported in the real direction despite the prism shift of visual direction, showing adaptation of perceived direction.
Figure 7. Perceived direction of stimuli presented to the upper half of both the seeing and non-seeing hemifields for one patient with left hemianopia. (a) Results on the day of the upper prism segment fitting show no adaptation to the change in visual direction due to the prism segment. Stimuli seen through the prism segment (triangles, C Upper, Fig. 4) were perceived about 22° to the right of the real direction, the expected deviation for the 40Δ power of the segment. Three of these stimuli, presented close to the hemianopic field border were detected by “peeking” into the non-seeing hemifield (dashed ellipse). Stimuli presented to the non-seeing hemifield in the non-prism zone (diamonds, B Upper) were not seen except for one stimulus again detected by “peaking” (dashed ellipse). Stimuli presented to corresponding zones in the seeing hemifield (squares, D Upper and circles A Upper) were perceived in the real direction. (b) Results eight days after the upper prism segment fitting in which the patient reported wearing for an average of six hours per day. For stimuli seen through the prism segment the patient reported the stimuli direction as close to the real direction, demonstrating an “adaptation-like” response. However, the patient reported that he was making conscious, compensatory motor responses, which in (c), another eight days later are no longer reliably demonstrated. No adaptation was seen at visit 5 (data not shown).
Figure 8. Lateral scanning behavior of right (triangles) and left (squares) hemianopic patients. Open (not consistent with labels within the figure) symbols represent “successful wearers” and closed symbols represent “non-successful wearers” of the peripheral prism glasses. Under the monocular test conditions, patients scanned more with the eye ipsilateral to the visual field loss (p=0.012). Most triangles (right hemianopic patients) are found below the dashed line, indicating greater scanning with the right eye, while most squares (left hemianopic patients) are found above the dashed line, indicating greater scanning with the left eye.