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Deepak Sharma, OD, FAAO; Jessica D Capri, OD,JD; Theresa Zerilli-Zavgorodni, OD, FAAO; Nancy Shenouda-Awad, OD, FAAO
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The Importance of Evaluating and Treating Binocular Anomalies as Part of Low Vision Management for End-Stage Glaucoma: Two Case Reviews

Deepak Sharma, OD, FAAO; Jessica D Capri, OD,JD; Theresa Zerilli-Zavgorodni, OD, FAAO; Nancy Shenouda-Awad, OD, FAAO

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ABSTRACT

Visual Impairment associated with end-stage glaucoma typically manifests as reduced contrast sensitivity, severely constricted visual fields (VFs), and ultimately a loss in visual acuity (VA). It is also not uncommon for these patients to have concurrent binocular vision anomalies. An absence or lack of peripheral VF overlap between the two eyes, secondary to ocular disease, can act as a barrier to motor fusion. Moreover, disparity in VA between the two eyes can interfere with sensory fusion, further preventing binocularity and increasing the risk for binocular dysfunction. The coexistence of binocular dysfunction and vision loss in low vision (LV) patients can further complicate and impair visual performance with activities of daily living (ADL), decreasing one's quality of life. Two cases are presented, both patients have severe-stage primary open angle glaucoma (POAG) with advanced peripheral VF and VA loss, compounded by a concurrent binocular anomaly. In each case, the binocular instability further compromised visual function, especially with near tasks. A functional LV history uncovered asthenopic symptoms with prolonged reading that led to a decrease in reading performance and patient frustration. In both cases, a binocular evaluation revealed binocular instability. Moreover, monocular VF analysis implicated a functional enlargement of usable VFs with binocular vision rather than monocular. Preservation of comfortable binocular vision by successfully stabilizing the instability with prism maximized the usable field of vision and drastically improved overall visual performance in both cases. Patients with peripheral VF loss and/or interocular differences in VA are often more susceptible to binocular dysfunction. In such cases, an analysis of functional VFs and binocular evaluation using modified techniques should be incorporated into the LV exam. Treatment for binocular instabilities with aligning prism should be considered as part of LV management for these patients as it can potentially optimize visual function and comfort.

INTRODUCTION

Binocular vision is the product of both eyes working as a team in order to use the information received from each eye simultaneously. One of the key aspects of binocular vision is known as fusion. Fusion is the act of creating a single image. There are two types of fusion: sensory and motor.[1] Sensory fusion allows the brain to utilize the information it receives from both eyes and create one image.[1] In order to do this, the images from each eye must be equally clear and fall upon corresponding areas of the retina. Motor fusion occurs when the eyes move to align in a way that allows for the enactment of sensory fusion and brings the two images together. This aspect of binocular vision is a function of the extrafoveal peripheral retina, highlighting the importance of intact peripheral vision in the ability to fuse images.[2]

Severe peripheral visual field (VF) loss and/or central visual acuity (VA) loss associated with visual impairment can negatively impact binocularity. Ocular diseases, such as advanced glaucoma may impair fusional ability, motor and/or sensory fusion, resulting in binocular instabilities. Thus, it is not uncommon to see binocular vision anomalies accompanying ocular pathology. Additionally, low vision (LV) patients may describe debilitating symptoms similar those experienced by normally sighted patients with binocular dysfunctions, such as diplopia, asthenopia, words running together, jumbling of print and transient blur.[3] These symptoms may drastically impact a visually impaired patient's ability to function comfortably and efficiently with everyday goals. Consequently, when vision loss is combined with a binocular dysfunction, the impact on visual performance can be compounded. Tasks such as reading, using the computer and even mobility can become extremely frustrating and incredibly challenging for these patients.

The coexistence of binocular dysfunction with ocular disease can be overlooked in the LV population.[3] This may partly be due to the scarcity of information and lack of guidance available in the literature for evaluating and managing binocular anomalies in this population. Hence, this could imply that there is little need to perform binocular evaluations and that these patients can be managed proficiently without considering the status of their binocularity.[3] Furthermore, the commonly accepted presumption that patients who have 3 lines or greater difference in VA between both eyes function monocularly may preclude the need for binocular assessments.[3] Consequently, the LV examination generally focuses on enhancing visual function in the better-seeing eye. Studies have shown that the most frequently prescribed types of LV devices are those designed to be utilized monocularly.[4] Moreover, when patients with visual impairment present with symptoms of near vision disorders, they are commonly attributed to the ocular disease alone and not to a binocular dysfunction.[3] This presumption may prevent unmasking a binocular anomaly that may be partially responsible for causing the asthenopia and decreased near vision performance. Thus, when considering differential diagnoses in LV patients who present with visual discomfort and/or who continue to be unsuccessful with LV aids, it is critical to consider and assess for binocular dysfunction.

Although the traditional LV examination does not routinely incorporate a binocular evaluation, it is important that the benefits of binocular vision be considered in the LV population. This can also extend to binocular visual fields as binocular measurements of threshold automated VFs are not typically performed clinically compared to monocular threshold perimetry methods, which may not entirely simulate real world binocular viewing

According to Lovie-Kitchin, a cover test at distance and near is usually sufficient to determine if binocular vision is present or absent. Lovie-Kitchen recommends that if a patient is binocular, convergence should be assessed, as it may influence the selection and prescription of near low vision devices; however the author does not provide further guidance for assessing binocularity.[6] Binocular vision has the advantage of increasing VFs, providing stereopsis and compensating for the blind spot and/or other uniocular scotomas. Due to these factors, preservation of binocular vision by stabilizing an instability with prism should be considered in this population. This is especially important when it has the potential to enlarge usable field of vision and/or compensate for uniocular scotomas. In such cases, assessment of functional fields and binocular status with modified techniques should be incorporated into the LV exam.

This paper presents two patients with end stage glaucoma having central vision loss in the poorer seeing eye, severe peripheral VF loss in the better seeing eye, and concurrent binocular dysfunction. Stabilizing binocularity with compensatory prism maintained comfortable binocular vision without the need for occlusion and optimized usable field of vision. This led to a dramatic improvement in overall visual performance with ADL's, notably reading. Modified techniques employed for binocular testing and the importance of functional field assessment will be highlighted.

CASE 1

A 72-year-old Caucasian male with advanced primary open angle glaucoma (POAG) presented to the Outpatient LV Clinic at the West Haven Veterans Affairs Medical Center (VAMC) for a routine annual LV exam. His incoming chief complaint was difficulty reading and watching television (TV) secondary to experiencing diplopia, asthenopia and increased blur at both distance and near with habitual spectacles. He noted that the diplopia was displaced side by side and denied a vertical component. The diplopia was worse at near compared to distance. At his last LV exam, the patient was prescribed reading glasses with occlusion of the poorer seeing eye. Due to him having similar VAs with eccentric viewing in each eye, the near evaluation was performed comparing occlusion OD versus OS. Occluding his non-dominant eye, OD demonstrated better function with a reading prescription. However, he reported that he was not using these glasses and noted when he did use them, he was more comfortable but still struggled to read and had blurry vision. Instead, the patient preferred to use an older pair of reading glasses without occlusion, even though he could not sustain reading without experiencing intermittent diplopia and discomfort. The patient's goals included reading the newspaper, using the computer, viewing a large distance monitor at church and watching TV.

Ocular history was significant for advanced POAG OU, pseudophakia OU and Charles Bonnet Syndrome. His laser and surgical history consisted of past argon laser trabeculoplasty, trabeculectomy, and tube shunt OU. The patient was followed for his POAG outside the VA and was last seen by his private provider 1 week prior. Current management for his glaucoma consisted of dorzolamide HCL 2% BID OU.

All current LV devices were reviewed to identify which aids the patient was successful with and which ones he was not. The patient reported that he was using but was struggling with the following LV prescriptions: a single vision distance spectacles with 80% grey transmission tint, sun spectacles with 10% transmission amber tint, single vision reading spectacles with an add of +3.75 OU, single vision computer spectacles with an add of +1.50 OU having 70% transmission amber tint and a spectacle-mounted telescope (TS) with a 2.2x Galilean TS bioptically mounted OS with 80% grey transmission tint. Current devices being used successfully and without symptoms included the following LV devices, a 3D OptiVISOR, a 3.25X25 Walters monocular hand-held telescope (HHTS), a 1.7x full-diameter telescope (FDTS) in reverse and an Eschenbach easyPocket 3x/8D hand-held magnifier (HHM).

The patient's BCVA taken with Feinbloom acuity chart was 10/30+ (20/60+1) with a slight 3:00 o'clock eccentric view (EV) OD and 10/25+3 (20/50+3) with a slight 9:00 o'clock EVOS. In primary gaze, using this same prescription his acuity was found to be OD 10/40 (20/80) and OS 10/25- (20/50-). Contrast sensitivity was noted to be reduced when tested with the Pelli-Robson contrast sensitivity chart at 1M. The patient was able to distinguish 6/16 triplets, OD and OS which corresponded to severe contrast sensitivity loss.

In order to better understand why the patient preferred to remain binocular at near despite experiencing asthenopia and diplopia, and yet still struggled to read with occlusion of the non-dominant eye, a VF test was performed. The results of a 24-2 Humphry Visual Field (HVF) (Figure 1 a and b) revealed OD dense diffuse loss with only the inferior nasal quadrant remaining intact and OS dense diffuse loss 360 degrees sparing a small central island having only one viable threshold point (17 decibels) that was approximately 3 degrees in extent just inferior nasal to fixation. The results of the 24-2 HVF clearly showed that the patient's monocular VFs had the potential to increase his usable field of vision when binocular. This added field to the left of fixation from his non-dominant eye could provide an increase in usable central vision critical for reading.

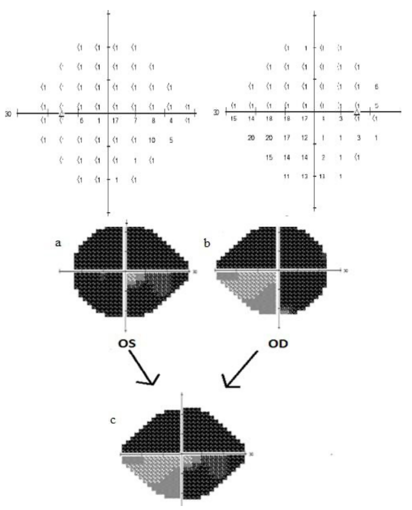

Figure 1. The patient's 24-2 monocular VFs, (a and b) emphasize the constriction and restricted pockets of usable vision. Expected VF when combined (c), showing an increase in usable vision when binocular.

After confirming the potential for an increase in functional VFs using both eyes, a binocular work-up was needed to address the asthenopia, intermittent blur and occasional diplopia experienced when using both eyes. Binocular evaluation was performed at both distance and near in phoropter using a modified von Graefe technique. The patient demonstrated an esodeviation with a magnitude of 2 prism diopters (PD) at distance and an exodeviation with a magnitude of 6 PD at near (Table 1). Vergence ranges were measured in the phoropter at both distance and near. (Table 1) Compensatory base in (BI) ranges for distance showed adequate break but poor recovery. At near, compensatory base out (BO) ranges revealed both poor break and recovery. Due to the patient's symptoms and clinical binocular work-up findings, prism was evaluated and prescribed for both distance and near.

At near, to address the patient's goal of volume reading, an add of +4.75 with 6 PD BI split between the 2 eyes allowed the patient to achieve 1M (20/50) using Sloan continuous text cards. With this add, the patient also obtained a near VA of 3-point (20/20) on the Rosenbaum near acuity card which provided an acuity reserve of 3 lines needed to meet the minimal fluent reading rate with 1M (20/50) newspaper print. Assessing visual function at near with the recommended prism and add using a 1M Sloan continuous text card, the patient demonstrated a significant improvement in reading fluency, speed and ability to track. When this new prescription was compared to his past near prescriptions, both a single vision reader without prisms and a reading spectacle with monocular occlusion OD, he greatly preferred the new reading prescription with prisms due to increased comfort and field of view. Similarly, a computer evaluation yielded maximal function with a +2.25 add and 3 PD BI split between the 2 eyes at his preferred working distance (WD) of 18 inches.

For his distance prescription, 1 PD BO OD was assessed, and the patient reported resolution of blur and noted increased comfort. To address his goal of reading sports or news tickers and resolving detail on the TV without asthenopia or diplopia, a spectacle-mounted TS with a bioptically mounted 2.2x SightScope OU was evaluated with 1 BO prism OD, the same amount of prism recommended for his distance prescription. Although the patient felt his field of view increased and the asthenopia improved using both eyes with the prism, he still reported feeling slight discomfort. Increasing the prism slightly to 1.5 BO OD, the patient noted an improvement in comfort and clarity. The incorporation of aligning prism into all prescriptions at distance and near allowed the patient to remain binocular while eliminating diplopia, blur and asthenopia. (Table 2). At his 6-month follow-up visit, the patient reported that all his symptoms at both distance and near were alleviated with his prism prescriptions and he was successfully meeting all his goals.

Table 1. Results of Binocular Evaluation:

	Distance Results	Near Results
Lateral Phoria	2 Eso	6 Exo
BI Vergence	x/7/0	x/24/6
BO Vergence	x/12/2	x/11/1

Table II: Final Low Vision Recommendations	
Low Vision Goal	Device
Improve comfort and reduce light sensitivity	Tints (See specified tint with each specific spectacle Rx below) 
Improve clarity at distance	Distance spectacle Rx OD:-3.25-3.00x010 with 1 BO OS:plano-3.00x170 Tint: 80% transmission amber
Reading newspaper binocularly	+4.75 ADD with 3 BI OD and 3 BI OS Tint: 70% transmission amber
Computer use for finances	+2.25 ADD with 1.5 BI OD AND 1.5 BI OS Tint: 70% transmission amber
Viewing large screen at church	2.2x SightScope OU over distance Rx with 1.5 BO OD 

CASE 2

A 58-year-old female diagnosed with end-stage POAG OU presented to the Eastern Blind Rehabilitation Center (EBRC) at the West Haven VAMC for a 6-week inpatient LVR program seeking to improve performance with ADLs. At her initial LV evaluation, the patient reported a longstanding decrease in her quality of life secondary to difficulties with reading and ambulation. She noted a drastic reduction in the ability to perform extended reading due to eye fatigue, strain and loss of place. She also noted that in general her eyes did not feel like they were "working together." In addition to her difficulty reading, her loss of peripheral vision had led to multiple falls with injuries. Overall, the patient's primary goals included increased reading fluency and safe independent travel.

Prior to the patient's admission at the EBRC, she received LV devices from her primary VAMC. These devices included +5.00 spherical OU reading spectacle with 60% transmission yellow tint, 3.5x/10D Eschenbach Mobilux LED illuminated HHM, 4x12 Specwell monocular HHTS, Eschenbach 3x Galilean spectacle-mounted TS, and an Acrobat HD ultra-LCD closed- circuit television. At that time, the patient also received orientation and mobility training through her local blind rehabilitation outpatient specialist. Despite receiving training regarding the use of these LV devices and mobility, the patient was still having difficulty achieving her goals of reading and independent travel.

Using a Feinbloom acuity chart, the patient's BCVA was 10/25+ (20/50+) OD with +1.00-0.50x100 in primary gaze, and 10/140 (20/280) OS with -0.50-0.50x060 using a 2 o'clock EV. Her primary gaze acuity OS was 5/700 (20/2800) with best correction. On the Pelli-Robson contrast sensitivity chart at 1 meter, she demonstrated 4 out of 16 triplets or profound contrast sensitivity loss OD and 1 out of 16 triplets or total loss OS. With a tint evaluation, the patient preferred a 70% transmission grey tint for her indoor distance prescription and with this tint, her contrast sensitivity improved to 5 out of 16 triplets OD, while remained 1 out of 16 triplets OS. Additionally, she reported a subjective improvement in visual comfort with the addition of the tint. A separate tint for reading and sun were determined to be 60% transmission grey tint and 30% transmission amber tint, respectively. Due to the large interocular difference in VA and discomfort reported while using her current single vision readers without occlusion, a reading evaluation was performed monocularly with her dominant eye, OD. With a +5.00 over OD only and occlusion OS, the patient achieved 3-point (20/20) VA using the Rosenbaum near acuity card providing an acuity reserve of 3 lines. She was able to obtain 1 M (20/50) VA on the Sloan continuous text card with some fluency. Although her reading speed and accuracy improved slightly, she was still moving her head, losing her place and struggling to meet her volume reading demands.

In order to further evaluate the patient's functional vision, a prior HVF 10-2 was reviewed (Figures 2 a,b) and revealed a dense 360-degree VF constriction with a small island of vision extending from fixation to 3-4 degrees temporally OD and a C-shaped perifoveal residual island of vision approximately 10 degrees in extent superotemporal, inferotemporal and temporal OS.

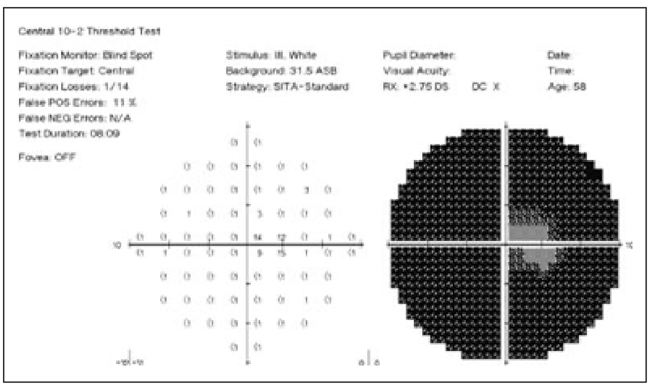

Figure 2a. The patient's HVF 10-2 OD demonstrating an isolated central residual field pocket

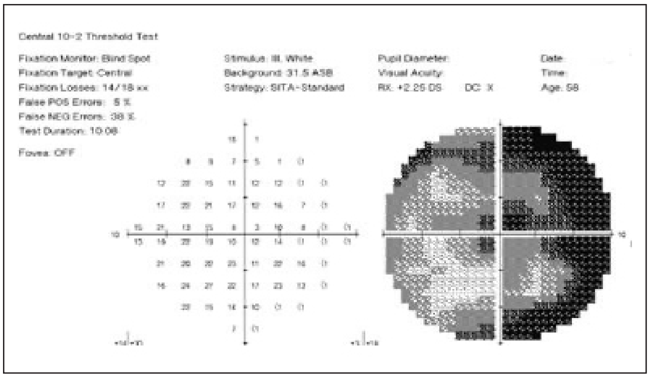

Figure 2b. The patient's HVF 10-2 OS demonstrating a larger, more temporal residual field

The results of the VF showed that the poorer-seeing eye, OS had a larger residual VF and that the patient may benefit from remaining binocular. To compensate for the short comings of the HVF 10-2 which included fixation instability throughout testing, a tangent VF (Figure 3a) was performed OU. Tangent screen testing was able to provide a better objective analysis of the patient's remaining functional binocular VF. The results of her binocular tangent VF indicated that by utilizing the larger remaining VF in OS, in conjunction with the better VA from OD, visual function could potentially improve and allow her to be more successful with her ADLs.

Although the benefits of remaining binocular became clear, the patient still suffered from asthenopic symptoms without occlusion. This led to the addition of a binocular workup as part of the patient's LV examination. With modified von Graefe testing, she demonstrated a 3 PD left hyperdeviation with a 1 PD exodeviation at distance. At near, she demonstrated a 3 PD left hyperdeviation with a 2 PD exodeviation. Vergence testing was attempted but the patient had difficulty appreciating dissociation, likely due to the second image falling outside of her field of vision when fusion was lost (break point). Additionally, the patient did not manifest suppression, as she denied movement of the target to either side as prism was increased. After a prism evaluation at distance and near, the patient was found to have subjective improvement in visual comfort at distance with 1 base up (BU)/1 BI prism OD and 1 base down (BD) OS. At near using a +4.00 with 1 BI/1BU OD and 1 BD/1BI OS, the patient immediately noted resolution of asthenopia and better tracking ability with less head movement.

A tangent VF was performed OU with the prism to determine how the prism would impact her functional binocular VFs. The results showed that with the prism, her VF shifted slightly to the right with approximately 4 degrees lost in the left VF but approximately 20 degrees gained in the right VF. Additionally, both superior and inferior fields were extended by approximately 5 degrees. (Figure 2b).

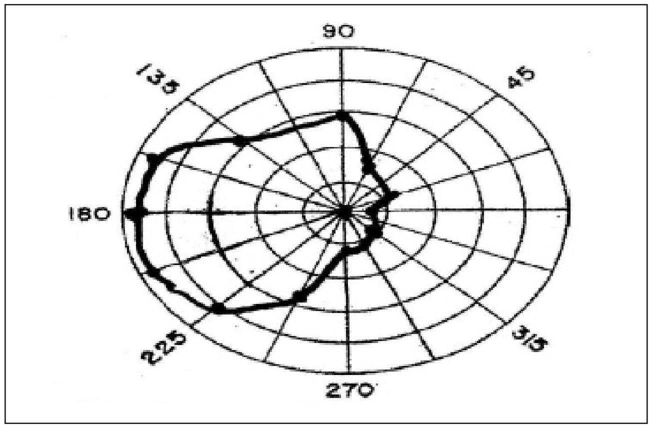

Figure 3a. The patient's binocular tangent VF without prism demonstrating an overlap of functional vision

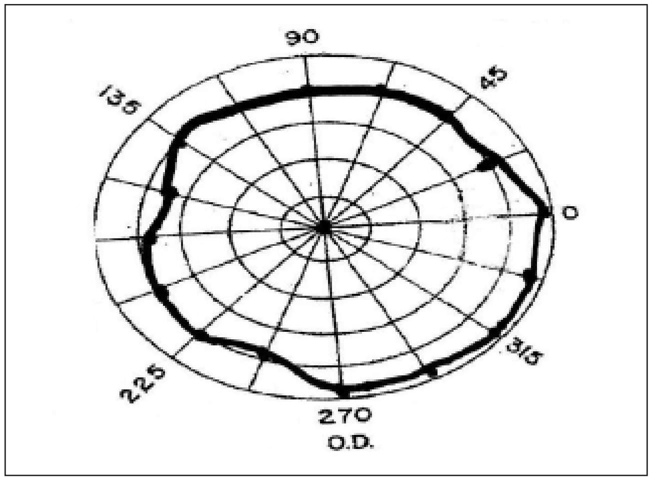

Figure 3b. Binocular tangent VF with prism demonstrating an enhanced amount of functional vision

In addition to an increased amount of functional vision with the prism, the patient was now able to meet her volume reading goals with good fluency, accuracy and speed.

Furthermore, her symptoms of asthenopia fully resolved. Moreover, she received mobility training, in addition, to LV training on the use of all prescribed devices as part of her rehabilitation program at the EBRC. (Table 3) With the incorporation of prism in her glasses at both distance and near, the patient noted a significant improvement in her performance while working with both the LV therapist and certified orientation and mobility specialist (COMS).

Providing the patient with the ability to remain binocular both comfortably and without asthenopia greatly increased her visual function and allowed her to achieve all her initial goals.

Table III: Final Low Vision Recommendations

Low Vision Goal	Device
Improve contrast	Tints (See specified tint with each specific spectacle Rx below) 
Improve clarity at distance	Distance spectacle Rx OD:plano-1.00x105 with 0.5 BI & 1 BU OS:-0.50-1.25x060 with 0.5BI &1 BD Tint: 70% transmission grey
Reading books	+4.00 add with 1 BI & 1 BU OD, 1 BI and 1 BD OS Tint: 60% transmission grey
Computer use for email	+2.00 ADD with 1 BI and 1 BU OD, 1 BI and 1 BD OS Tint: 60% transmission grey
Improve mobility	Distance spectacle Rx, white cane training, 1.7x FDTS reverse TS 

DISCUSSION

Binocularity in the LV population is an under researched and rarely explored topic within the literature. This is likely due to the widely accepted assumption that many LV patients tend to essentially function monocularly due to a large interocular VA difference, particularly when the disparity between the two eyes is 3 lines of acuity or more.[7] Despite large asymmetries in visual input between the two eyes, many LV patients still have some form of gross binocular vision.[3] However, they are particularly at risk for having a fragile binocular system. According to Rundstrom and Esperjesi, asymmetric eye disease, whether caused by central or peripheral pathology, can behave as a dissociative factor inhibiting binocular vision.[3] This in turn can cause LV patients to be more susceptible to binocular vision anomalies. In fact, they found that the majority of their studied population, which consisted of 30 LV patients, exhibited at least 1 type of binocular vision anomaly.[3]

The risk for binocular instabilities in the visually impaired population is likely due to the loss of sensory fusion and/or motor fusion caused by the ocular disease itself. Sensory fusion allows the brain to utilize the information it receives from both eyes and create one image.[1] However, when the information regarding the image from each eye is vastly different, sensory fusion is inhibited.[1] In cases of peripheral VF loss, such as advanced glaucoma, there is a lack of VF overlap between the two eyes. This can act as an obstacle for motor fusion. Motor fusion is guided by information received from the peripheral retina and promotes accurate alignment in order to maintain sensory fusion.[1] Impaired sensory and/or motor fusional systems may lead to binocular instabilities and result in symptoms of diplopia, asthenopia, words running together, jumbling of print and transient blur.[1,3] In the cases presented, both patients experienced loss of sensory and motor fusion secondary to advanced POAG. This resulted in visual symptoms when binocular, decreasing the patients' comfort and functional performance. Though it is important to mention that it is difficult to say that the advanced glaucoma in both causes caused the binocular instability. However, if the patients had a prior binocular instability before the ocular pathology but were able to compensate with an adequate motor and sensory fusion, the advanced glaucoma could have disrupted fusion leading to asthenopic and diplopic symptoms.

Identifying LV patients with concurrent binocular vision anomalies may not always be so straightforward. This is partly because LV patients presenting with symptoms suggestive of a binocular vision disorder may not report them or report them nondescriptly blaming the symptoms on their poor quality of vision. Additionally, even when symptoms are disclosed, the clinician may attribute them exclusively to their ocular disease. A thorough history with specific questions targeting binocular dysfunction symptoms is important for unmasking binocular anomalies. Since both ocular disease and binocular instabilities can impair visual performance, distinguishing between the two and determining the primary source for their complaints is important. Aside from the obvious symptoms of diplopia, symptoms of binocular vision dysfunction can be more subtle. Blurred vision, difficulty focusing at different distances, headaches, words running together while reading; there is a wide range of symptoms that may be the result of binocular instability.[3] Rundstrom and Eperjesi evaluated 30 patients from their LV clinic and attempted to qualify visual symptoms and difficulties at near to determine whether the symptoms were related to a binocular dysfunction.[3] They found that symptoms such as, 'jumping print', horizontal diplopia and asthenopia are often more common in the LV population and were more likely related to a binocular abnormality.[3] While symptoms of "small print or patchy vision" were more often caused by ocular disease, blurred vision was found to occur as a symptom of both ocular pathology and binocular dysfunction.[3]

Another aspect of the patient's history that should prompt the clinician to further consider a binocular vision dysfunction as a source of the patient's complaints is the succession of multiple failed LV aids. It is not uncommon for these patients to return to clinic dissatisfied with their devices and with further assessment, they are typically prescribed occlusion of the non- dominant eye. Taking case 1 for instance, the patient continued to return displeased with the devices prescribed based on findings from his LV exam. The patient had previously been prescribed devices, both without occlusion and then using the method of occluding the eye with poorer acuity, at distance and near. However, the patient continued to return disappointed and unable to meet two of his favorite past times, reading and TV viewing. Instead of continuing to make minor adjustments to devices that had not provided success, it may have been more beneficial to perform a binocular vision work-up early on. This patient proved to have significantly greater success with the addition of prism to his appropriate LV devices. Similarly, in case 2 when the patient reported discomfort and poor near performance with reading, the clinical instinct was to try monocular occlusion which minimally improved reading performance. These cases illustrate the importance of recognizing a binocular instability early in the evaluation in order to prevent inappropriate prescription of LV aids and patient frustration. Taking the time to listen to patients and fully assess all their symptoms is critical when determining the best way to manage these cases.

Despite large asymmetric interocular differences, many LV patients still utilize information from their non-dominant eye and may benefit from using both eyes to perform many of their ADLs.[8] In fact, there has been evidence to show that the function of binocular summation, which refers to increased visual performance with the use of both eyes compared to that of the better seeing eye alone, can still persist even when the visual input is considerably different between the two eyes.[8] Tarita-Nistor et al., were able to demonstrate the presence of binocular summation in a good proportion of their age-related macular degeneration patients having interocular VA disparity.[8] In addition to binocular summation, binocular vision has the potential to provide LV patients with an increase in useable VFs, compensation for uniocular scotomas and some degree of depth perception.[8,9] Recent literature has been able to provide evidence to support that the worse seeing eye can contribute to the binocular VF despite asymmetric VA or VF differences.[9] Chow-Wing Bom et al. were able to demonstrate with their study that participants were slower to find everyday objects and made more head and eye movements, when they increasingly simulated peripheral vision loss in the worse seeing eye, even when vision in the better seeing eye remained stable.[9] Such findings contrast with prior studies that noted binocular peripheral VF sensitivity is predicated by the better seeing eye alone.[9] Recognition that the poorer seeing eye can contribute to improving visual performance in some LV patients highlights the need to evaluate binocularity in this special population.

However, further investigations are still needed to better understand how LV patients combine input from both eyes and how this process can impact visual function.

When specifically looking at central VF loss in end stage glaucoma and its impact on reading function, severe bilateral VF loss near fixation has been found to negatively influence reading speed.[10] More specifically, the size of the visual span has been demonstrated to significantly influence reading speed and fluency.[10] The visual span, which is defined as the size of the area in the VF where the letters can be recognized reliably, when increased in size improves reading speed.[10] This span is very important as it is involved in controlling saccadic eye movements that are essential for fluent reading. Visual spans smaller in size typically result in numerous fixations and saccades compromising reading efficiency.[10] Kwon et al., were able to demonstrate that the size of the visual span measured within the central 10 degrees of the VF of their glaucoma patients was significantly smaller resulting in fewer letters being recognized and poorer oculomotor performance in comparison to the normal cohort.[10] Corroborating with these findings, Smith et al. found in their study that patients with restricted VFs typically exhibited additional or compensatory saccades that impaired reading speed compared to controls.[11] Furthermore, Fujita et al. concluded in their study of glaucoma patients, that a central VF defect with an absolute scotoma involving more than 2 adjacent quadrants and within the central 3 degrees was associated with poor reading performance.[12] In both cases presented, VF loss was characterized as bilateral, severe and involving central 3-4 degrees of their remaining island in their better seeing eye. By becoming binocular and combining VFs, their visual span increased in size resulting in an improvement in word recognition and oculomotor tracking ability, leading to better reading efficiency.

Since visually impaired patients are particularly susceptible to binocular anomalies that can lead to impaired visual efficiency, addressing these anomalies, especially in advanced glaucoma, can be crucial in maintaining the benefits of binocular vision. Preserving binocular central/ peripheral VFs will in turn maximize visual function with ADLs. These two cases highlighted how asymmetrical central VF loss in end stage glaucoma with a concurrent binocular dysfunction, impaired their reading ability and comfort. These patients suffered through much smaller VFs when they were monocularly occluded, yet also had discomfort when they were binocular. The addition of prismatic correction first expanded their VF span, in addition stabilized their binocular anomaly, hence improving comfort and ocular movement. Finally, they were exhibiting less saccades, better fixation and improved reading fluency.

The importance of VF assessment in LVR and its role in helping to determine the benefit of usable field of vision should not be overlooked. Monocular and binocular VF analysis helps to explain functional abilities and guide LVR recommendations.[12] Although, it has been shown that basic psychosocial tasks such as static VFs do not always provide a perfect model of an individual's ability to perform real world perceptual judgments, it still can provide important information regarding the extent of the VF.[9] A tangent screen is a good option to use in LV patients as it can be easily modified with large, high contrast targets to ensure resolution and stabilize fixation. Additionally, tangent screen testing provides a quick, easy and accurate functional representation of monocular and binocular central VFs. In case 1, evaluation of the patient's monocular VF clearly showed that preserving binocular vision for TV viewing and reading was paramount for maximal visual function. It also explained why this patient did not like occlusion. This patient was able to obtain a larger VF when binocular as opposed to approximately 3 degrees when solely using the dominant eye. This also holds true for case 2, occlusion of her non-dominant eye afforded her with only approximately 3 degrees of central VF field, significantly compromising both reading spans necessary for fluent reading. The additional field expansion in almost every direction of the VF when binocular substantially improved this patient's reading performance. Amsler grids are not recommended for VF assessment as there are too many false negatives as they patient may shift fixation and cortically interpolate within the field to fill in the gaps.[6] Lovie-kitchen recommended a modified tangent screen technique to identify areas of intact field as it would provide sufficient information on the nature of the VF loss to make vision rehabilitation decisions.[6] This VF assessment technique can be used to assess the binocular field size as well as demonstrated by case 2.[6]

Once it is established that the LV patient has symptoms suggestive of a binocular vision disorder which may be contributing to the patient's complaints and decreased visual performance, a binocular work-up is a must. It is important to remember that alterations to binocular vision testing must be made for this population. Large, high contrast targets for both distance and near will need to be employed to ensure the target can be resolved by each eye. Example targets are shown in Figure 4 and can easily be made in office. It is recommended that the assessment be completed in-phoropter in order to easily modify each test. The typical dissociating prism required to test phorias using the von Graefe method, 12BI and 6BU, will likely need to be modified, especially in small-fielded patients to ensure the targets are not placed outside of their field of view. Performing smooth vergences in-phoropter allows the clinician to move the prism slowly and in smaller increments. Out of phoropter fusional vergence testing with prism bars should be used with caution. Large prism step increments may cause the image to jump quickly outside of the patient's remaining field of vision or into a scotoma, making it more difficult to appreciate the loss of fusion and achieve accurate measurements. In both cases, the eye with the smallest field of view was about 3 degrees, therefore measuring vergence ranges utilizing - prism bars could potentially displace one of the images into the non- seeing VF, leading to a false interpretation of suppression and the absence of binocularity. .

The smooth vergence method was employed in both cases presented to provide more accurate results.

Figure 4. Modified distance and near targets used for binocular workups during LV examinations. They include a large, high contrast X at distance and large, high contrast box at near

When prescribing prism in the LV population to compensate for a binocular instability, traditional methods of selecting prism to trial using Sheard's or Percival's formula should not be rigidly observed. This is due to LV patients typically having very fragile binocular systems often from having poor sensory and/or motor fusion. As a result, the full amount or close to the full amount of prism to compensate for the tropia or phoria may be required. Moreover, the use of a rule-of-thumb prism prescription criterion in LV patients with binocular dysfunction can be limiting and less accurate as they only represent approximations without clinical measurements.[3] Considering each patient's binocular needs individually and customizing the prism based on actual measurements is generally more successful. In case 1, the patient did prefer almost the entire amount of prism noted from the binocular work-up to correct his phoria at distance and required the full amount of prism at near. Similarly, in case 2, the patient preferred the full amount of horizontal prism and nearly the full amount of vertical prism for both distance and near.

Although these cases demonstrated the success of prism utilization in LV patients with concurrent visual impairment and binocular instabilities, prism may not always be successful with every patient. Even when a patient is motorically aligned, sensory fusion may still not be possible preventing comfortable binocular vision. In such cases, where the visual input from the 2 eyes is vastly different, binocular summation can be inhibited and visual performance using both eyes can be worse than that of the best eye alone. Thus, when evaluating prism, if fusion cannot be maintained comfortably for a prolonged period with the correct aligning prism, monocular occlusion should be considered.

By incorporating prism into the LV recommendations in the presented case reports, each patient was able to meet their primary goals. Maintaining binocularity increased their overall amount of functional vision and allowed the patients to experience improved comfort with ADLs along with increased reading speed and fluency. Additionally, in case 2, mobility was enhanced by stabilizing the binocular anomaly. Comparison of binocular tangent screen VF with and without prism clearly demonstrated the benefit that the prism had in enlarging the patient's functional vision.

Consequently, the combination of prism and training by a COMS augmented the patient's mobility skills allowing for safe and independent travel. In each case reported, correcting the binocular dysfunction with prism, allowed them to comfortably use their eyes while performing ADLs; thereby maximizing visual function and improving quality of life.

CONCLUSION

Glaucoma is one of the most common causes of peripheral VF loss, often resulting in restricted fields compromising the integrity of the peripheral motor fusional system. Furthermore, in advanced glaucoma VA can be reduced asymmetrically which may further impair the sensory fusional system and act as a barrier to binocularity. For these reasons, binocular vision anomalies can profoundly impact visually impaired patients and can result in symptoms such as diplopia and asthenopia. However, in cases where the use of both eyes can potentially enlarge the visual span and/or compensate for uniocular scotomas, stabilizing binocularity may prove advantageous versus occlusion. Since we understand now that although not studied extensively, the binocular status of LV patients can strongly influence their rehabilitation; an assessment of functional fields and binocular status with modified techniques should be incorporated into the LV exam prior to diagnosis and management. Treatment for the binocular instability with conventional prism in addition to traditional LV recommendations, should be considered as it can potentially provide optimal visual function with all ADLs.

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