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Dichoptic visual field mapping of suppression in exotropia with homonymous hemianopia

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Abstract

BACKGROUND—The purpose of this study was to investigate which portions of the visual scene are perceived by each eye in an exotropic subject with acquired hemianopia. The pattern of suppression is predictable from knowledge of how suppression scotomas are organized in exotropic subjects with intact visual fields.

METHODS—Dichoptic perimetry was performed by having a subject wear red/blue goggles while fixating a cross that was either red or blue. Red, blue, or purple spots were presented briefly at peripheral locations. The subject's identification of the spot color revealed which eye was perceptually engaged at any given location in the visual fields.

RESULTS—A 17-year-old female with a history of exotropia was evaluated after rupture of a right parietal arteriovenous malformation. Dichoptic perimetry showed a left homonymous hemianopia. All stimuli to the right of the right fovea's projection point were perceived via the right eye. Stimuli between the foveal projection points, which were separated horizontally by the 20° exotropia, were perceived by the left eye.

CONCLUSIONS—Perception of the visual scene is shared by the eyes in hemianopia and exotropia. Suppression occurs only in the peripheral temporal retina of the eye contralateral to the brain lesion, regardless of which eye is engaged in fixation. Although exotropia expands the binocular field of vision in hemianopia, it is probably not an adaptive response, even when it develops after hemianopia.

The occurrence of homonymous hemianopia during childhood is associated with an increased risk of subsequent development of strabismus. Bronstad and colleagues[1] have reported a 24% prevalence of exotropia and a 9% prevalence of esotropia in a retrospective survey of 396 children with hemianopia from many different causes. After hemispherectomy for intractable epilepsy, more than 50% of children manifest an exotropia.[2–4] It has been suggested that the emergence of exotropia is an adaptive response, compensating for hemianopia by expanding the visual fields.[5–12] However, no dichoptic perimetric data have been reported from patients with both hemianopia and exotropia to show how each eye contributes to perception of the enlarged binocular field of view.

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We have devised a method for computerized binocular visual field testing in strabismus based on the classical approach of using different colored stimuli in conjunction with bandpass filter goggles to present stimuli dichoptically. Data from two dozen exotropic subjects have shown a consistent pattern of suppression of signals emanating from each eye.[13,14] Perception of the peripheral temporal retinas is suppressed (Figure 1A). The suppression extends to a vertical border located approximately between the diplopia point and the fovea. A slice of temporal retina contiguous with the midline is always spared from suppression. The extent of suppressed peripheral temporal retina depends on the magnitude of the exotropia: the smaller the deviation, the closer suppression reaches to the vertical meridian. These findings are in accord with previous descriptions of the layout of suppression scotomas in exotropia based on manual perimetry.[15–20]

Knowledge of how suppression is organized in exotropic subjects with intact visual fields allows one to predict the pattern of suppression expected after subsequent development of a homonymous hemianopia. For example, if a left homonymous hemianopia occurs, signals from the entire temporal retina of the right eye are lost (Figure 1B). The impact on signals from the peripheral temporal retina is nil, because they were already suppressed owing to exotropia. However, signals from the slice of temporal retina abutting the midline, formerly perceived, are now lost.

In the left eye, output from the entire nasal retina is lost in hemianopia (Figure 1B). Output from the peripheral temporal retina remains suppressed to avoid diplopia, because it overlaps with the misaligned right eye’s nasal retina. However, the extent of temporal retina that is suppressed becomes reduced. A vertical swath of temporal retina in the left eye is released from suppression because the hemianopic lesion destroys signals from the slice of temporal retina abutting the midline in the right eye.

In summary, the combination of left hemianopia and exotropia results in absolute blindness everywhere in the visual scene to the left of the left fovea’s projection point. The visual scene to the right of the right eye’s fixation point is perceived only through the right eye. Perception of the zone between the foveal projection points, formerly shared by both eyes, becomes governed exclusively by the left eye. In this study, we tested whether these predictions are accurate by reporting dichoptic visual field mapping in an exotropic patient who later acquired a left hemianopia.

Methods

Approval for this study was granted by the Institutional Review Board at the University of California San Francisco. The patient provided informed consent to participate.

The patient was seated in a dark room with her head in a chin rest facing a translucent tangent screen onto which stimuli were displayed with a digital light projector. The position of each eye was monitored with an independent infrared video eyetracker mounted overhead. The patient wore specially constructed goggles containing dichroic filters: red for the right eye and blue for the left eye. The filters were matched to the spectral transmission properties of the color filters in the digital light projector. Color crosstalk was <0.3%. It was rendered entirely imperceptible by displaying stimuli blended with a fine purple/black textured background pattern. With each stimulus trial, a new textured background pattern was generated.

For dichoptic binocular visual field testing the patient fixated a central cross subtending 1° of visual angle. It was assigned randomly to be either red or blue. Accordingly, she fixated it with either the right eye or the left eye. After fixation was maintained for 500–2000 ms within a ±2.5° window, a 1° spot was flashed peripherally for 200 ms. The peripheral spot was red, blue, or purple. The patient's task was to report verbally its color. If fixation was broken during the trial, the data were discarded. Approximately equal numbers of red, blue, and purple spots were presented. The red and blue spots allowed mapping of the monocular visual field of each eye. Purple spots, a combination of isoluminant red and blue, revealed which eye was engaged in perception at any given location on the tangent screen. For example, if the subject reported "blue" after display of a purple spot, it meant that the location was perceived via the left eye, and the right eye was suppressed. The patient was unaware that some spots were purple.

The peripheral spots were 0.75 log units brighter than the purple background noise pattern, making their color easy to recognize unless they were suppressed. The data provided a screening assessment of which portions of the binocular visual field were perceived by each eye, rather than threshold measurements of the relative strength of suppression. Test stimuli appeared pseudo-randomly within a 5° grid measuring 65° horizontally by 35° vertically, with a slightly enhanced likelihood of presentation near the fixation points. To discourage false-positive responses, no stimulus was presented on occasional blank "catch trials." Further details regarding the equipment, experimental design, and tracker resolution have been published elsewhere.[14,21]

Results

The patient was a 17-year-old female in whom an intermittent exotropia measuring 25^{Δ}–30^{Δ} had been documented by an optometrist at age 10 and on subsequent regular eye examinations. While on a camping trip with friends she collapsed, lost consciousness, and began seizing. She was evacuated to a local hospital where computed tomography showed intracerebral and intraventricular hemorrhage from a right parietal arteriovenous malformation. She underwent emergency craniectomy, hematoma evacuation, and removal of the vascular lesion (Figure 2).

Eight months later, the patient was evaluated in our clinic at the University of California San Francisco. She had a partial left hemiparesis but was able to walk with the aid of a cane. She denied diplopia. Neuroophthalmology examination revealed an acuity of 20/20 in each eye with a correction of −1.50 sphere in the right eye and −1.75 sphere in the left eye. Pupils were normal. The extraocular eye movements were full. There was no head turn. In primary gaze there was an alternating exotropia of 35^{Δ}–40^{Δ}. At distance the exotropia was constant, but at near the patient could, with effort, briefly achieve fusion. She identified a Randot butterfly. By confrontation testing there was a dense left homonymous hemianopia. Humphrey 24–2 threshold perimetry confirmed the presence of a left hemianopia. There was a wedge of preserved visual field along the upper vertical meridian, more spared in the left eye (Figure 3). Slit-lamp and fundus examinations were normal.

Dichoptic binocular perimetry was performed (Figure 4). The patient had an exotropia of about 20°, with a right hypertropia when fixating with the left eye. She executed 297 trials following presentation of a blue cross (left eye fixating) and 300 trials following presentation of a red cross (right eye fixating). She correctly ignored 14 of 16 blank trials while fixating with the left eye and 14 of 14 blank trials while fixating with the right eye.

The red stimulus trials revealed a nasal hemianopia in the right eye (Figure 4A). The patient was reliable, incorrectly responding "blue" on only 2 stimulus trials. Both of these errors occurred while the left eye was fixating. She failed to respond to a few stimuli in her temporal field, some perhaps falling in her blind spot.

The blue stimulus trials showed a temporal hemianopia in the left eye, with some sparing along the superior vertical meridian (Figure 4B). This feature was also present on the Humphrey 24–2 threshold test (Figure 3). Reliability was good, with only 1 stimulus trial falsely reported as "red" for each fixation condition. It is worth emphasizing that for both red and blue stimulus trials, the monocular visual fields were similar, regardless which eye was engaged in fixation. There was no tendency for perception to be suppressed when stimuli were presented to the nonfixating (deviated) eye.

The purple stimulus trials showed a left homonymous hemianopia, also with sparing along the upper vertical meridian (Figure 4C). In the 20° sector between the foveal projection points, perception occurred via the left eye, and the right eye was suppressed. This was true whether she fixated with the left eye or with the right eye. Under both fixation conditions, a single stimulus point landing in this sector was called "red," perhaps by error. To the right of the right eye's foveal projection point, perception occurred via the right eye and the left eye was suppressed, except for stimuli that landed in the right eye's blind spot. A few tested loci were mistakenly ignored.

In addition to the 597 successful trials (Figure 4), there were 65 aborted trials. These usually occurred because fixation was not maintained for the required duration within the position window. A few trials were aborted because eye tracking was lost temporarily. Thirty-two aborted trials occurred during left eye fixation: 12 for a red stimulus, 8 for a blue stimulus, and 12 for a purple stimulus. Thirty-three aborted trials occurred during right eye fixation: 13 for a red stimulus, 11 for a blue stimulus, and 9 for a purple stimulus.

Discussion

In patients with exotropia the absolute extent of binocular vision subtended by the combined visual fields is expanded—by the amount of the ocular deviation. Diplopia is prevented by suppression of the peripheral temporal retina in each eye and confusion is avoided by anomalous retinal correspondence.[13,14,16,18–20,22–26]

Knowing the organization of suppression scotomas in exotropia,[13,14] one can predict their arrangement in subjects with exotropia and hemianopia (Figure 1). There is a good match between the anticipated result and the actual data (Figure 4). Our findings confirm that the presence of exotropia increases the range of visual space perceived by hemianopic subjects, by exactly the magnitude of the exotropia. Expansion of the binocular visual field comes at a cost: ocular alignment is disrupted in the surviving hemifield, along with stereopsis (except during moments when a patient with intermittent exotropia attains fusion). Signals from the peripheral temporal retina of the eye contralateral to the lesion in the brain are suppressed. Of note, the temporal suppression zone is decreased in width in a hemianopic subject, compared to an exotropic subject with normal visual fields. This reduction in the extent of suppression occurs because there is no longer any competition from the zone of temporal retina located along the midline in the eye ipsilateral to the brain lesion. This zone, which was previously perceived, is now blocked from perception due to onset of hemianopia. As pointed out by Donahue and Haun,[11] there must be anomalous retinal correspondence to avoid visual confusion. We performed the afterimage test in our patient to assess her retinal correspondence, but her responses were inconsistent, leaving uncertainty on this issue.

In our patient, prior optometric records established that she had intermittent exotropia before rupture of her arteriovenous malformation. After she developed a hemianopia, her intermittent exotropia increased in magnitude and became more difficult to control. The majority of patients with hemianopia and exotropia are orthotropic before onset of hemianopia. This inference follows logically from the fact that the prevalence of exotropia in hemianopic subjects is far higher than the prevalence of exotropia in the general population. This point raises the question whether our patient would have displayed the same findings on dichoptic perimetry if her exotropia had emerged only after she developed a hemianopia. There is no way to be sure, but we suspect that the order of events would have made little difference. Although adults with acquired strabismus are typically more likely to experience diplopia than those with childhood-onset strabismus, adults with late-onset exotropia can develop suppression.

The notion that the advent of strabismus following hemianopia is an adaptive response to expand the visual fields is belied by the fact that a substantial minority of patients develops esotropia rather than exotropia.[1–3] The maintenance of bifoveal fusion requires feedback from cortical neurons sensitive to retinal disparity that project to brainstem centers controlling ocular muscle tone.[27,28] In hemianopia, half this input to the brainstem is cut off, weakening the drive to fuse corresponding images. For unknown reasons, exotropia is more common than esotropia in subjects with impaired ability to fuse caused by sensory visual loss. Thus, the advent of exotropia may simply represent the most common response to a weakening of fusional forces, rather than a specific adaptation intended to compensate for reduction of field of view in hemianopia.

A nearly universal adaptation to hemianopia is the tendency to make “surveillance” saccades towards the blind hemifield.[29–32] Our patient frequently made small saccades to her left while trying to maintain her gaze on the fixation cross during dichoptic perimetry. This behavior is essentially involuntary. The eye trackers identified the trials during which fixation was broken, allowing us to discard them. If they are not eliminated, the hemianopic defect appears to recede from the vertical midline. This phenomenon produces the false improvement in hemianopia promulgated as “vision restoration therapy.”[33]

Regardless of any potential benefit from expansion of her binocular visual fields, our patient was disturbed by the breakdown of her ability to fuse and the appearance of her large horizontal ocular deviation.[34] She elected to undergo eye muscle surgery. A 7 mm resection of the medial rectus muscle was performed in each eye. After surgery her ocular alignment was orthotropic, and has remained so during a 6-month follow-up period. Dichoptic perimetry has not been repeated, because it is not useful in orthotropic subjects. When the eyes are aligned, subjects experience color rivalry to purple stimuli and simply respond randomly either "red" or "blue" during testing.[13]

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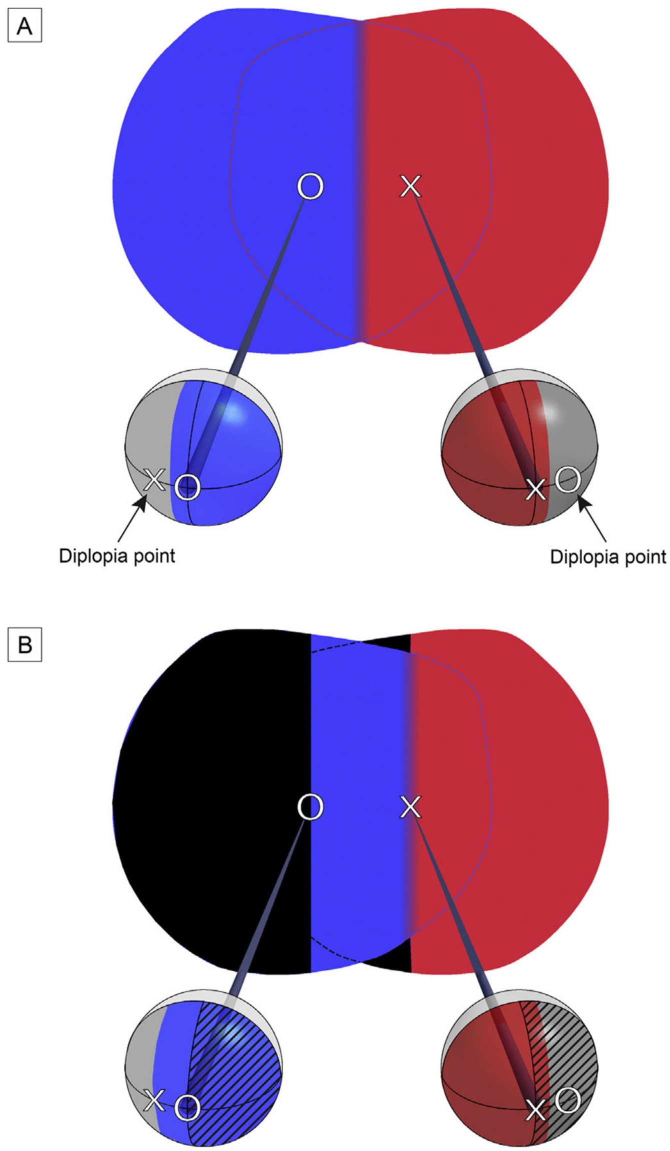

FIG 1.

Layout of suppression scotomas in exotropia. A, In a patient with intact visual fields the two eyes share perception of the scene (blue = perceived by the left eye, red = perceived by the right eye). The peripheral temporal retina is suppressed (gray shading) in each eye up to a vertical border about half way between the diplopia point and the fovea.[35] *O*, left fovea; *X*, right fovea. B, In a patient with a left hemianopia (black), signals from the left eye's nasal retina and the right eye's temporal retina are lost (black stripes). As a result, the zone between the fixation points is perceived by the left eye, while the region to the right of the right eye's fixation point is perceived by the right eye.

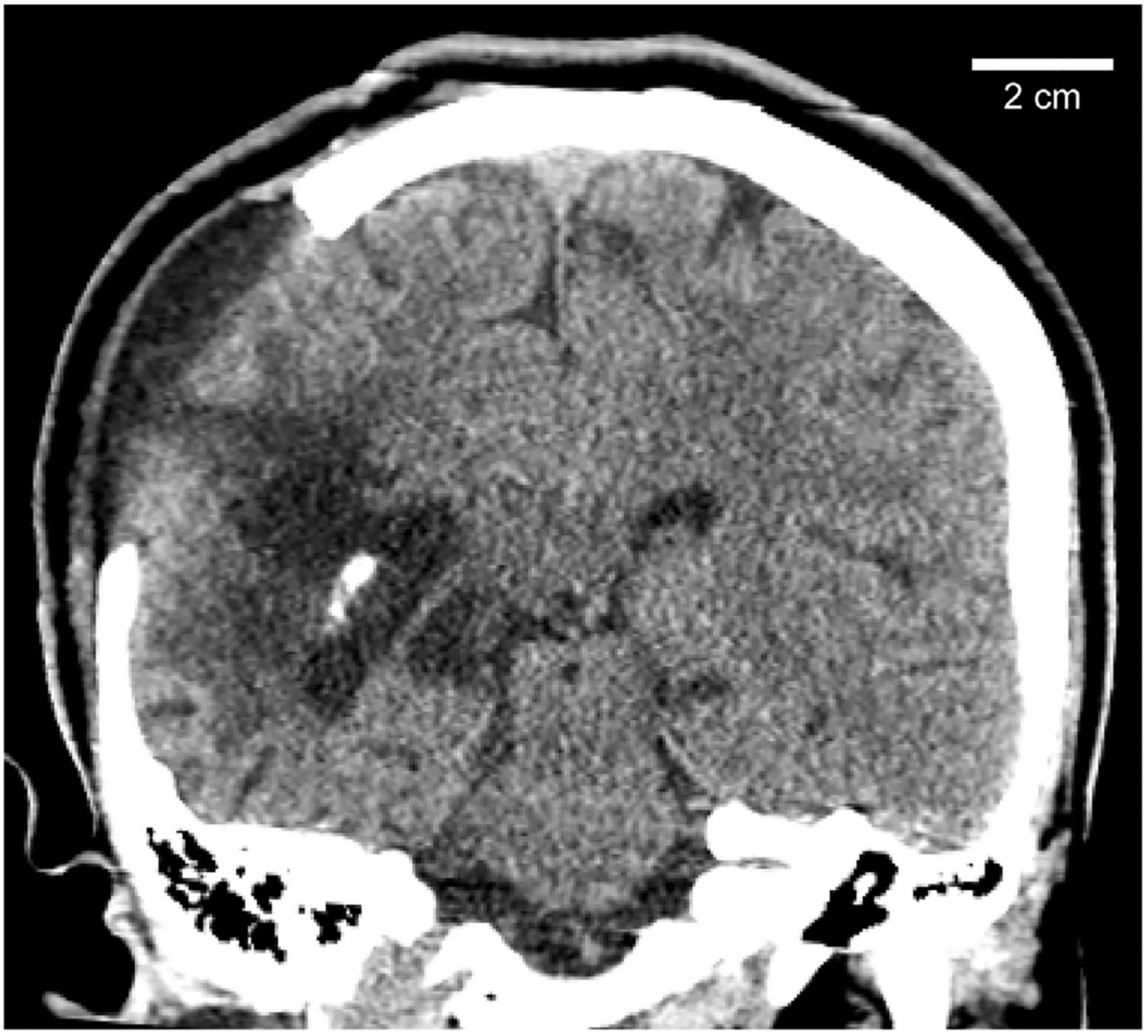

FIG 2.
Postoperative coronal computed tomographic image showing right craniectomy and extensive damage to the right optic radiations following resection of the arteriovenous malformation.

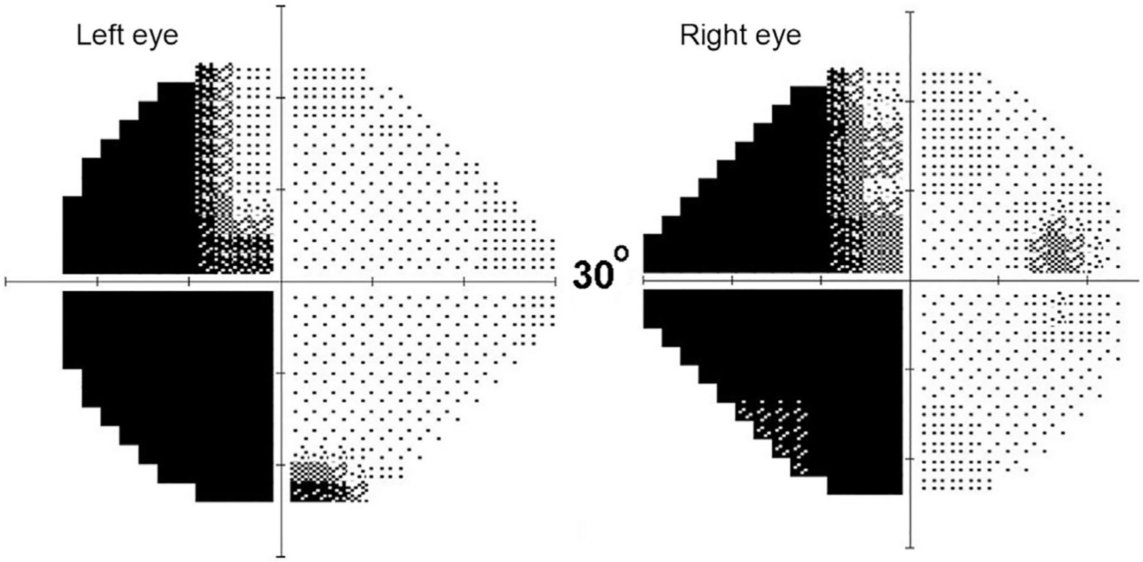

FIG 3.
Humphrey 24–2 visual field tests. There is a left homonymous hemianopia, with a sector of residual visual field along the upper vertical meridian, that is better preserved in the left eye.

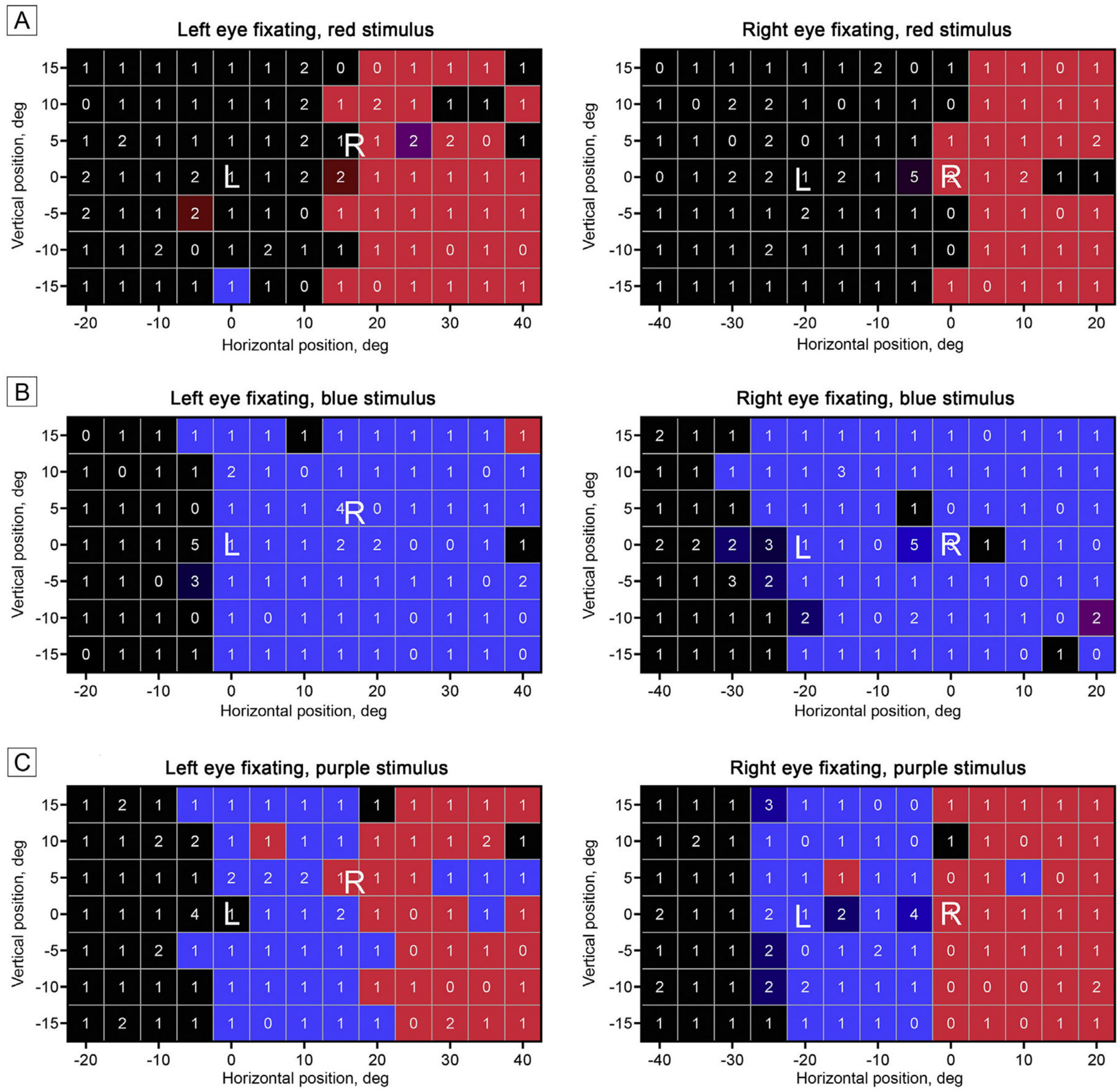

FIG 4.

Dichoptic visual field maps compiled with the patient viewing with the right eye through a red filter and with the left eye through a blue filter. The number in each box indicates how many times the location was tested. The color represents the subject’s response (black = none). Intermediate colors denote a mixed response, eg, dark red signifies red on one trial and no response on another trial. For untested boxes (0), the color represents an interpolation based on nearest adjacent boxes. Mean position of the foveal projection point for the left eye (L) and the right eye (R) is shown. The patient had a 20° exotropia, with a right hypertropia of 4° only when fixating with the left eye. A, Responses to red stimuli, revealing a nasal hemianopia in the right eye. Missed points in the temporal field may be due to the blind spot. B, Responses to blue stimuli, showing a temporal hemianopia in the left eye with sparing along the upper vertical meridian. C, Responses to purple stimuli, defining regions perceived by each eye. The zone between the foveal projection points is perceived by the left eye. To the right of the right foveal projection point, perception occurs via the right eye, except in its blind spot.