



Binocular rivalry with peripheral prisms used for hemianopia rehabilitation

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Citation information: Haun AM & Peli E. Binocular rivalry with peripheral prisms used for hemianopia rehabilitation. *Ophthalmic Physiol Opt* 2014; **34**: 573–579. doi: 10.1111/opo.12143

Keywords: binocular rivalry, hemianopia rehabilitation, peripheral vision, prism therapy

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Received: 17 January 2014; Accepted: 15 May 2014

Abstract

Purpose: To determine the relative binocular signal strength of moving images that are peripherally viewed through a monocular *field expansion prism* as opposed to moving images viewed directly. We hypothesised that prism blur might make prism images predominate less than images viewed directly with the other eye.

Methods: We employed the *binocular rivalry* paradigm to measure the relative binocular effectiveness of directly viewed vs prism images. Four normally-sighted subjects tracked the rivalrous visibility of opponent-coloured targets seen dichoptically in the same part of the retinal visual field, using monocular field expansion prisms to produce the dichoptic display. We analysed the effects of external signal strength (whether or not motion was present in either image), retinal position or eccentricity of the targets, and controlled for target saturation.

Results: We found that prism images predominate less than directly viewed images. When both eyes were presented with pattern in the dichoptic display, direct-to-prism predominance was 51%:31%. When only the direct view was presented with pattern, direct-to-prism predominance was 74%:12%; when only the prism view was presented with pattern, direct-to-prism predominance was 25%:58%. Dominance durations followed established binocular rivalry rules.

Conclusions: The prism image in a monocular, peripheral field expansion prism is perceptually weaker than the corresponding direct image in the other eye. However, the prism image is still seen a significant proportion of the time, especially when no moving pattern is present in the direct view. We conclude that the rivalry ratio of the prism device is sufficiently effective for clinical applications.

Introduction

To regain access to parts of the visual field that have been lost to brain injury, particularly in cases of homonymous hemianopia, *prisms* may be used to shift part of the blind field into view.^{1–3} This ‘field expansion’ approach aims to improve the mobility of patients with visual field loss by providing them with more useful information about obstacles and hazards, since one of the main problems encountered by these patients is trouble with avoiding hazards – static and moving – during locomotion.

There are two major issues distinguishing the various approaches to prismatic corrections for field expansion: where in the spectacle lens the prism should be mounted,

and whether it should be mounted in front of one or both eyes. Prisms placed in the visual periphery can shift the image from lost to functioning regions of the peripheral field. Peripheral visibility allows attention (and then foveation) to be drawn to objects that otherwise would be missed. Prisms mounted in front of both eyes (bilateral fitting) have the advantage of similar content in both eyes, simply producing a local shift of the visual scene, though they will also binocularly occlude a portion of the visual field,⁴ reducing their potential benefit. Prisms mounted only in front of one eye (unilateral fitting) produce localised interocular conflict, which may induce binocular rivalry or complete local suppression. Since prism-shifted images have relatively poorer quality,^{5,6} and binocular

rivalry tends to favour sharper, high-contrast images,⁷⁻⁹ it may be that unilaterally-fitted field expansion prisms produce images that are reflexively suppressed in binocular vision.¹⁰ In the current study, we addressed this question directly: how does interocular conflict play out with unilateral prisms?

We investigated binocular rivalry in a complex and dynamic context designed to simulate real-world vision in a specific clinical case: the use of prisms to extend the visual fields of patients with large-scale field loss from brain injury (e.g. homonymous hemianopia). We measured binocular rivalry for local regions of the visual field while normally-sighted subjects viewed a drifting, high-contrast texture. Interocular conflict was induced by having subjects view the display through a unilaterally fitted peripheral prism. We carried out this study to evaluate the utility of the field expansion prism technique, hypothesising that prism images should be much more frequently suppressed due to their relatively poor contrast and sharpness.

Methods

Subjects

Five normally sighted subjects participated in the experiment, three male, all between the ages of 22 and 32. All five subjects were screened for normal or corrected to normal visual acuity in each eye, normal color vision, and no manifest binocular vision problems (Table 1). Subject S1 was the first author. All subjects went through one or two 1 h sessions of the experiment for training; one of the three male subjects (S5) proved unable to do the task due to inability to maintain binocular fixation (for reasons unknown; he exhibited only a minor phoria), and left the study without providing a complete set of data. The research adhered to the tenets of the Declaration of Helsinki, and all subjects gave informed consent according to a protocol approved by the Schepens IRB.

Apparatus and procedure

Subjects fixated a central region of the display while doing the experiment. The fixation area included a high-contrast

pattern that aided in maintaining binocular fusion lock. A 40Δ press-on Fresnel prism (www.3m.com) was affixed to the outer surface of one of a pair of spectacle lenses. Subjects either wore their own spectacles or (for two subjects not needing spectacle correction) plano lens spectacles. In all conditions, the right side of the display was occluded from direct view, as illustrated in Figure 1. Occlusion of the right field was practically necessary to keep the prism-eye target from being seen double (i.e. seen through the prism

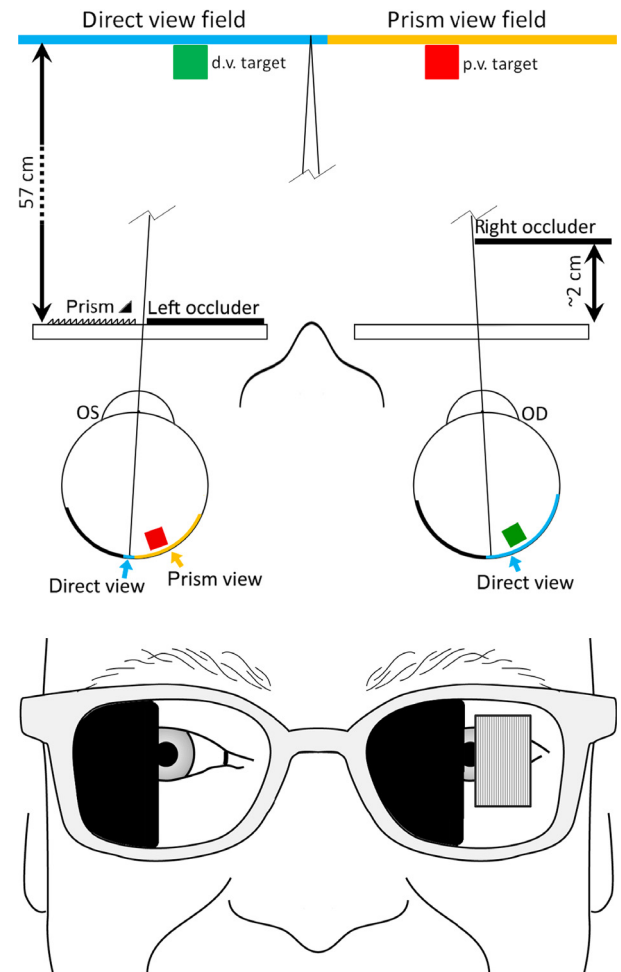


Figure 1. Apparatus. The observer binocularly fixated a region in the centre of the display that was visible to both eyes in the direct view; starting a few millimetres to the right of fixation, the rest of the right half of the display was occluded from direct view, but was (partially) visible to the left eye through the Fresnel prism affixed (base right) to the left half of the left spectacle lens. This arrangement set up a binocular conflict in the non-occluded peripheral visual field between the direct and prism views. The occlusion of the right field served the practical purpose of preventing the prism target from being seen double, and also simulated a homonymous hemianopic visual field. Targets for the binocular rivalry task are illustrated by the coloured squares, placed on opposite sides of the display, but imaged in the same visual field locations. Key. OD: right eye, OS: left eye.

Table 1. Right and left eye (RE/OD, LE/OS) refractive error correction (Rx; worn during the experiment) and corrected visual acuity (logMAR) for all five subjects

	Rx (RE/OD)	Rx (LE/OS)	VA (RE/OD)	VA (LE/OS)
S1	-2.25	-2.00	-0.12 (6/4.5)	-0.12 (6/4.5)
S2	Plano	Plano	-0.12 (6/4.5)	-0.12 (6/4.5)
S3	Plano	Plano	0.0 (6/6)	0.0 (6/6)
S4	-5.25	-5.25	-0.12 (6/4.5)	-0.12 (6/4.5)
S5	-4.75	-4.25	0.0 (6/6)	0.0 (6/6)

in its shifted position *and* seen directly in its actual positions), and also effected *in situ* simulation of right homonymous hemianopia during the experiment. The left eye's view of the right side of the screen was occluded with an opaque material affixed to the lens; the same part of the right eye's field of view was occluded with an adjustable shutter 2–3 cm in front of the lens. The shutter was used to maintain the day-to-day alignment of the occluders for each subject, being easily adjustable in comparison to the opaque tape affixed to the lens. The lens-prism-shutter configuration was as illustrated in *Figure 1* (with the prism in the left eye). The prism was alternated from eye to eye between sessions, but the occluded side of the field was always the right side. Note that clinically the prism may be fitted on either eye, though the default is to fit on the side of the field loss.¹⁰ A chinrest and forehead bar were used to keep the head position stable.

The rivalry task (described in the following section) was increasingly difficult with increasing eccentricity, so we settled on a target eccentricity range between 10° and 15° (with ° denoting degrees of visual angle; *Figure 2a*), which required that the prism edge be set <10° from fixation, whereas it would usually be placed clinically at least 15° away.^{3,11} This is not a severe compromise: peripheral vision may be qualitatively different from central vision in several ways, but compared with itself at different eccentricities, performance differences are mainly matters of scaling.¹²

Before each block of experimental trials, the binocular correspondence pattern in the prism conflict field (the part

of the visual field where one eye saw directly and the other saw a prism-shifted view) was re-mapped with a dichoptic alignment task (similar to the method of Satgunam and Peli¹³). In the alignment task, the most recent set of direct-view target locations was outlined one-by-one with square boxes, while the subject used the computer mouse to move a cross symbol, viewed through the prism, so that it sat within the box. Four matches were performed at each peripherally-viewed location, while the subject fixated the centre of the screen. Consistency with previous positions was also checked; this was how we determined that S5 was not maintaining binocular fixation. Mapping and re-mapping verification was of utmost importance to minimise the effects of small (in mm, but large in visual angle) changes in head position over the course of the experiment, which could easily throw the display out of alignment.

Stimuli

The background stimulus was monochrome (greyscale) 'edge noise' which drifted across the screen at a constant rate of 2.8° per second (Video S1). The stimulus moved both to simulate the natural motion of features in normal visual experience, and also to prevent fading of the peripheral targets during the fixation periods. The noise was constructed by taking 1/f noise, low-pass filtered at 2.25 cycles per degree with a rectangle filter, and increasing its amplitude so that most pixels exceeded the display range, clipping the image and creating random smooth patches of

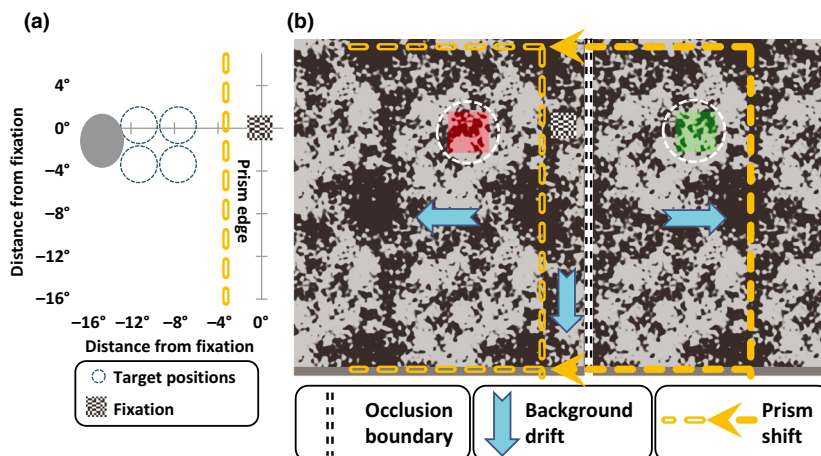


Figure 2. (a) Target placement during one trial for Subject S1. For three of the subjects, the target locations were directly left of fixation as illustrated, between the edge of the prism and the left eye blind spot (gray ellipse). (b) Stimulus configuration, shown to similar scale as (a). In the 'both fields' condition, the stimulus was similar to what is shown here: the 'bar code' pattern in the center of the screen was the fixation target, which also helped to enforce central fusion lock. The central strip of the display, 'behind' the fixation pattern, drifted constantly downwards. To the right side of the downward strip was the *prism view*, which was occluded from direct view but visible through the prism, shifted 20° leftwards; the pattern in this region drifted constantly *rightward*. To the left of the downward strip was the *direct view*, whose pattern drifted constantly *leftward*. Although presented 20° apart, the desaturated green and red coloured patches (in the circled regions; colours are exaggerated for illustration) were perceived by the subject in the same visual field location, in different eyes.

white and black (as shown in *Figure 2b*, and in Video S1). This was an arbitrary stimulus, providing many high-contrast edges and regions of constant luminance (facilitating the color marking technique).

The targets were square regions within the background noise, presented in desaturated red or green, 3.5° across, spatiotemporally continuous and individually equiluminant with their surround (circled in *Figure 2b*). The target patch positions were placed, during the dichoptic alignment task, near the horizontal meridian in groups of four at an average distance of about 10° left of fixation as illustrated in *Figure 2a* (except for subject S4, for whom the targets were placed about 8° below and 6° left of fixation). The target locations were actually 20° apart on the display, though they were seen in the same position. Target saturation was set by each subject individually before the experiment (through binocular direct view), by adjusting the relative saturation of red and green patches so that they were equally salient, straddling a mean saturation of 50%; all subjects set the red to be more saturated than the green, in a ratio averaging 55:45. Without this adjustment, the green patch tended to predominate disproportionately. Pilot experiments established that saturation around 50% was sufficient for most observers to do the task for 30 s trials, without the colours fading from view; we confirmed this with a subsequent control experiment, described below.

Three stimulus conditions were tested, to establish that we were measuring the effects of binocular rivalry caused by moving structure in the prism conflict region. In the 'both fields' condition, the display was filled with drifting noise, so that both the prism and direct views were exposed to moving contrast. As illustrated in *Figure 2b*, the prism and direct view fields drifted in opposite directions, guaranteeing a strong interocular conflict. In the 'prism field' condition, the directly-viewed field was set to mean luminance (contrast was 0), so that the prism view had a stronger stimulus; the 'direct field' condition was the opposite, with drifting contrast only in the directly-viewed field and mean luminance in the prism-viewed field. In all conditions, a central strip of noise drifted downwards, visible binocularly in the direct view. This strip served to segregate the dichoptic stimulus fields, making it less likely that the occluded right side of the display might slip into view and, through lateral interactions,^{14,15} unintentionally facilitate the visibility of the prism view.

Task

The subjects performed a peripheral binocular rivalry tracking task. While fixating centrally, subjects attended to a cued peripheral location (the cue was a target-sized marker presented before the subject initiated a trial) and

indicated whether in that location they were seeing the colour red, green, or a mixture of the two (both colours at once, or indistinct colour), by holding down the corresponding button ('red', 'green', or 'mixed'); if no colour was perceived or subjects could not tell what they saw, no button was to be pressed. For data analysis, red/green colour was recoded into prism view or direct view. Targets were placed at one of four locations, which were alternated from trial to trial to decrease the potential for adaptation to the colours (*Figure 2a*). Each recording period lasted 30 s; these were run in blocks of 12 periods (four target locations, repeated three times each), with dichoptic colour (red/green in OD/OS vs green/red) counterbalanced within these blocks. For each condition, four blocks of trials were collected, so there was a total of 6 min of tracking data for each discrete location.

Results

We computed predominance – the proportion of recording time that a given percept was reported – and dominance duration – the average duration of these reports – for each subject, pooled over the four test locations, as shown in *Figure 3a*. The predominance values indicate the proportion of the 24 min recording time that a given percept was reported: for what proportion of time did they see the prism view (gold bars), the direct view (blue bars), or a mixture (gray bars – this was rarely reported). Null reports are represented by white space between the bars (indicating when subjects saw no colour, or could not tell what they saw). For each subject, there was a general bias in favor of the direct view: in the main condition, where there was moving contrast in both eyes' views, the direct view was seen on average 53% of the time, and the prism view was seen on average 31% of the time, with considerable differences between the four subjects. When there was moving contrast only in the direct view, that view was seen on average 74% of the time; when there was moving contrast only in the prism view, that view was seen on average 58% of the time. *Figure 3c* shows the change in predominance relative to the 'both views' condition, due to removing contrast from one or the other view; for each subject, presenting contrast only in one field increased predominance of the corresponding view, and decreased predominance of the other view.

The bias in favor of the directly viewed image is consistent with the prism image being blurred, and thus a weaker stimulus. The dominance results, in *Figure 3b*, support this interpretation, and align our findings with typical binocular rivalry results: reducing contrast in one eye's view has the effect of increasing the other eye's dominance (consistent with Levelt's law of binocular rivalry⁹: 'dominance of one eye's image is inversely proportional to the strength of the

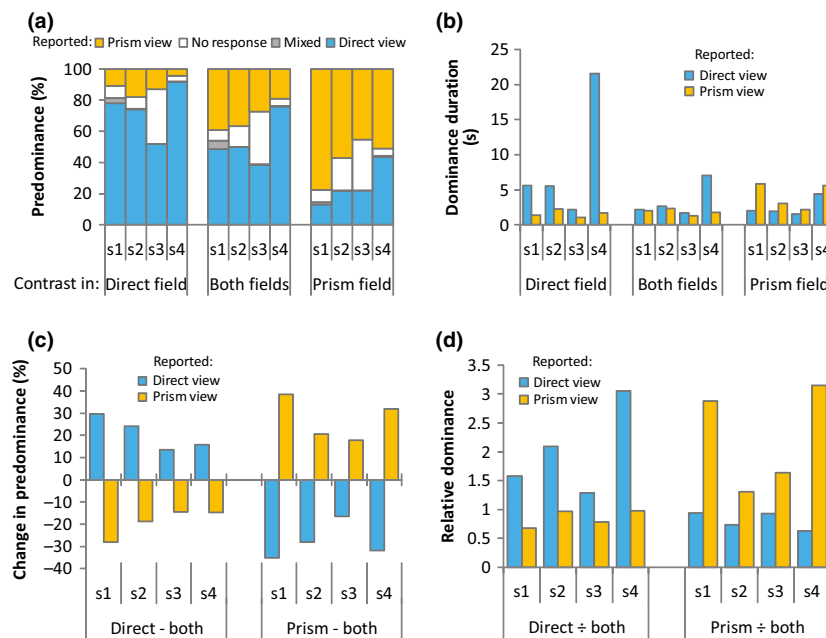


Figure 3. Rivalry statistics for four subjects (S1–S4). ‘Direct field’, ‘both fields’, and ‘prism field’ refer to the different experimental manipulations of the display, where moving contrast was presented only in the directly-viewed or prism-viewed halves of the display, or in both. ‘Direct view’ and ‘prism view’ refer to the percepts reported by the subject at the target location. (a) Rivalry predominance, the proportion of recording time that a given response was made (or that no response was made, indicated by the white spaces). Data are averaged over the four test locations. Gold/blue bars, at top/bottom of the plot, indicate predominance of prism/direct views respectively. Grey bars, when visible, indicate the predominance of ‘mixed’ percepts. (b) Rivalry dominance duration, the average number of seconds that a given view was reported as visible. When there was contrast only in one view, that view had longer predominance periods. (c) Change in predominance relative to the ‘both fields’ condition. Presenting contrast only in the direct field increased predominance of the direct view and decreased predominance of the prism view; presenting contrast only in the prism field had exactly opposite effects. (d) Relative dominance duration, the change in dominance period relative to the ‘both fields’ condition. Presenting contrast only in one view tended to strongly increase dominance durations in that view, with much weaker suppressive effects (decreases in dominance of no-contrast views).

other eye’s image’). Based on this result, we can be confident that we were indeed recording binocular rivalry. *Figure 3d* shows the relative dominance duration for each subject, relative to the ‘both views’ condition; for each subject, which reveals a more regular pattern across subjects. *Figure 4* shows the same predominance data as in *Figure 3a* (excluding subject S4, who was tested in a different region of the visual field from the other three subjects), as a function of target eccentricity rather than subject identity. With increasing eccentricity, the two views become more competitive, tending towards mean predominance.

Controlling for target saturation

While we are confident that our subjects were tracking binocular rivalry fluctuations, it may be argued that we were measuring rivalry between the dichoptic colour patches, rather than the drifting pattern fields. This could still be consistent with the results shown in *Figure 3*: the predominance of the pattern view in the blank-side conditions could be due to spontaneous fading of the equiluminant colour patches against the constant background (Troxler

fading). It is important to account for this possibility, since we want to know whether or not the moving pattern was suppressed; a colour patch, relatively unaffected by the prism, might ‘punch through’ an otherwise suppressed prism view, and if so we might be overestimating that view’s predominance.

To control for the effects of colour rivalry, we repeated the ‘both fields’ condition, varying target patch saturation over a wide range. We reasoned, again on the basis of Levelt’s law, that if the dichoptic opponent colours drove the observed rivalry, decreasing saturation (signal strength) should induce slower rivalry alternations (longer dominance duration periods), while increasing saturation should induce faster alternations (shorter durations). Two of the original subjects (S1 and S2) participated in this experiment: *Figure 5* shows the results. As saturation decreased from the level used in the main experiment (49%, average of the red and green target saturations), the task became much more difficult: when saturation was 28%, most of the recording time was spent without giving any response (*Figure 5a*), and estimation of dominance duration was inaccurate (*Figure 5b*). As saturation increased, predominance

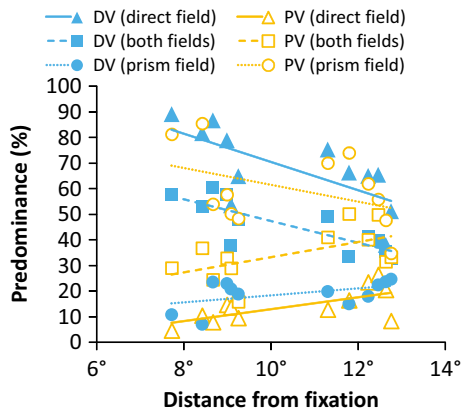


Figure 4. Effect of target eccentricity (position). The same data shown in Figure 3a, except not averaged over target position, and subject S4’s data (collected in a different region of the visual field) are not included. Symbols represent both different test locations and different subjects. Solid blue symbols are for targets seen in the direct view (DV), open gold symbols are for targets seen in the prism view (PV). Square targets are for the ‘both fields’ condition, triangle and round symbols are for the ‘direct field’ and ‘prism field’ conditions, respectively. With increasing target eccentricity, relative biases in predominance decrease, with predominance converging towards the overall average predominance of 40% (which excludes mixed- and no-report periods).

stabilized, and, crucially, so did dominance duration (Figure 5b). This supports the notion that, in the main experiment, the main driver of the observed binocular rivalry was not the dichoptic opponent colours, but rather the drifting noise patterns, as we intended. Note that the modest bias in favour of the direct view is present and stable.

Discussion

The results of our experiments show that while the view through a Fresnel prism field-expansion device is relatively

weakened in binocular competition with a direct view, it is still able to compete for visibility. So, the monocular prism image is not severely disrupted by interocular suppression. We might further argue that in clinical application, the interocular imbalance would be even less: The PMMA Fresnel prisms used in permanent prescription of such field expansion devices¹ are of better optical quality than the temporary press-on prisms we used in this study, and are usually placed at larger eccentricities, where lower visual resolution might make the blur of the prism image even less of an issue. We should note that sensory eye dominance, which modulates binocular rivalry,¹⁶ may be an issue in peripheral placement of a dichoptic display. One of our subjects (S2) displayed a consistent bias towards the right-eye view in all conditions (the mean predominance is shown in Figure 3), despite her having ‘normal’ binocular vision according to standard (central vision) screening procedures. This may be explained by retinotopically local variations in eye dominance.¹⁷

As shown in Figure 4, the predominance bias in favour of the direct view decreased with increasing target eccentricity. The reason for this is not clear, but there are two likely explanations (not mutually exclusive). First, with increasing eccentricity, the resolution of spatial vision decreases continuously, so a blurred stimulus is visually relatively less blurry as it is presented more eccentrically. So, a more eccentrically viewed prism image should compete in rivalry more effectively, having better relative signal strength than the same image viewed less eccentrically. Second, the display apparatus confounded target eccentricity with distance from the prism edge. Prism images seen near the edge of the prism are subject to greater blur due to pupil vignetting, which would make them weaker competitors in binocular rivalry. Stimuli presented closer to the interior of the prism area are less

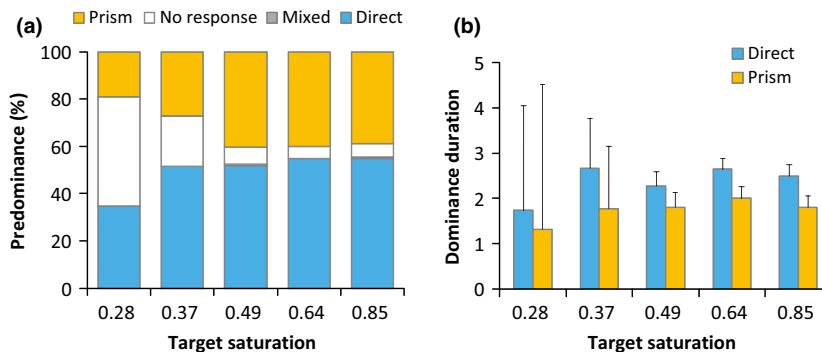


Figure 5. Controlling for the effect of the saturation of the target patches. (a) Predominance of the different perceptual alternatives (direct/prism views, top/bottom bars, gold/blue) or of uncertain null responses (white bars), as a function of target patch saturation. (b) Mean dominance duration periods as a function of target patch saturation. There is no indication that durations decrease with increasing saturation, meaning that colour does not constitute a significant component of ‘signal strength’ for our stimuli. Data are averaged over two subjects (S1 and S2). Error bars were calculated as the total null response duration divided by the number of reports of either ‘direct’ or ‘prism’ view – so, these error bars reflect the margin of uncertainty beyond the mean measurement, rather than measurement variance.

blurred/distorted, and would be relatively stronger in rivalry.

Our stimuli and results can be understood as relating to the practical context of natural vision. In our main experimental conditions, we covered three idealised situations: moving spatial structure everywhere ('both fields'), moving structure only in the prism view ('prism field'), and moving structure only in the direct view ('direct field'). In the real world, the strength of the image will vary substantially over time in both fields. Ideally, the view that is seen by the prism wearer will be the view with the stronger image. It is unlikely that when the prism view is static and contains little or no contrast structure (as in the direct field condition) it contains a serious risk to the user. Rather, an obstacle or hazard is likely to be of higher contrast and, often, to be moving (as in the both fields or prism field conditions), and thus will have a better chance to be detected despite the relative disadvantage of the prism image.

By measuring binocular rivalry with the unilateral peripheral prism configuration, we can make the aforementioned inferences about the relative signal strength, and consequent suppression, of the prism image. However, none of this means that rivalry actually ensues when the field expansion prism is used as intended. Recent studies indicate that binocular rivalry in the peripheral visual field only occurs when the conflict is attended.^{18,19} Without attention, what happens is unknown, but Brascamp and Blake¹⁸ suggest that the winner-take-all aspect of binocular rivalry may depend on attention – so, *both views* might be simultaneously visible in a state of unresolved *binocular confusion*. From the point of view of the intended usage of the field expansion prisms, this would be ideal – objects, most importantly moving hazards, that have a chance of capturing attention, if they pass through the prism field, would be available to visual consciousness. We therefore conclude that, at present, interocular suppression does not pose an obvious threat to the utility of field expansion prisms.

Acknowledgement

Supported in part by NIH grants R01EY05957 and R01EY12890. Thanks to Jenny Shen for help in arranging the experiment apparatus.

Disclosure

The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

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