

Similarities in normal and binocularly rivalrous viewing

(visual perception/rivalry/stimulus sets/competition/stimulus fluctuations)

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ABSTRACT We report here a series of observations—most of which the reader can experience directly—showing that distinct components of patterned visual stimuli (orthogonal lines of a different hue) vary in perception as sets. Although less frequent and often less complete, these perceptual fluctuations in normal viewing are otherwise similar to the binocular rivalry experienced when incompatible scenes are presented dichoptically.

The mechanism of normal vision is generally thought to entail binocular cortical neurons that unite the information generated by each eye in a common stream that eventually leads to perception. The success of this conception is best exemplified by present understanding of stereopsis, which depends on the convergence of monocular information onto disparity-sensitive binocular neurons that generate (or at least initiate) a sensation of depth (1, 2). This interpretation of visual processing, however, is not easily reconciled with the experience that arises when two eyes are independently stimulated with discrepant scenes. As Wheatstone (3) first demonstrated, if one stimulus pattern, e.g., vertical stripes, is presented to one eye and a discordant pattern, e.g., horizontal stripes, to the other eye, subjects experience binocular rivalry; in this circumstance, the same region of visual space is perceived as being occupied by vertical stripes or horizontal stripes, but rarely by both. If the two monocular streams were simply united, one would presumably see a grid. This dilemma has led to alternative explanations of visual processing predicated on the suppression of one or the other monocular view (4), or a routine alternation between the two monocular views (5, 6). Such propositions have not found wide acceptance and are in varying degrees incompatible with other evidence (7–9).

Here we describe a series of observations that suggests a resolution of this conflicting evidence; namely, that *all* viewing conditions entail a potential competition between sets of distinguishable qualities in the visual scene. If this assertion is correct, then rivalry and normal cyclopean vision are both manifestations of the same perceptual strategy. The results are presented in three categories. First, we demonstrate that when subjects foveate on a stimulus pattern in normal binocular view, elements that are differentiable as sets tend to fluctuate in visual perception. Second, we compare set competition in normal view to the more obvious competition experienced during binocular rivalry. Third, we show that when binocularly rivalrous stimuli are presented adjacent to similar nonrivalrous stimuli, the perceptual fluctuations in the two regions of the visual scene tend to occur together.

The stimuli used in all these experiments were circumscribed patterns of lines (see Figs. 1, 4, and 5). Parameters that we might have varied to compare normal viewing and binocular rivalry include orientation, hue, motion, size, spatial fre-

quency, shape, contrast, luminance, and disparity. For reasons of simplicity, we chose to vary line orientation and hue to ask how the distinctiveness of the stimulus elements affects their perception in the several viewing conditions. Two other parameters known to affect binocular rivalry—the size and spatial frequency of the stimulus—were also varied to further explore the similarities and differences between the experience of normal and rivalrous viewing.

Fluctuations in Perception During Normal Binocular Viewing

When stimulus patterns comprising elements that can be parsed into sets of differently colored lines are viewed continually, observers begin to experience fluctuations in perception that range from the disappearance of one or a few lines to the complete, if transient, extinction of one set of lines or the other (Fig. 1A; see also refs. 10–12). In presenting these stimuli to colleagues and groups of students, it appears that virtually everyone experiences these phenomena. This competition between stimulus sets takes time to develop, usually becoming apparent only after some seconds of viewing (Fig. 1B).

To explore the basis of these phenomena, we first varied the quality of the set elements by changing their orientation and color; the purpose was to ask if changing the distinctiveness of the competing sets altered the rate of perceptual fluctuation between them (Fig. 2). Subjects (the authors) reported the frequency of perceptual alternation, i.e., the number of transitions per unit time from dominance by one set of stimulus elements (red lines) to dominance by the other (blue lines). As the difference in angle between the line-sets increased from 0° to 90°, the rate of fluctuation increased systematically. Similarly, a systematic increase in the fluctuation rate was apparent when the hue of the line-sets was made increasingly distinct. Thus, the number of fluctuations observed per unit of time is greatest when the variable in question maximally distinguishes potential sets of stimulus elements (see also refs. 11 and 12).

We next examined the rate of perceptual fluctuation between the dominance of line-sets when the overall size of the stimulus or its spatial frequency was varied (Fig. 3). The purpose of these observations was to ask whether the variables, both of which are known to influence the alternation rate in binocular rivalry (8, 13; see also below), affect the alternation rates measured in normal binocular view. Changing these parameters does indeed affect the rate in normal view. These results are compared with parallel observations under rivalrous conditions in the following section.

As a control for any specific effect of binocularly, we also viewed the same stimuli with one eye closed. There was no obvious difference, either qualitatively or quantitatively, in the monocular experience of line-set fluctuation compared with binocular viewing (Figs. 2 and 3, compare *Left* and *Right*).

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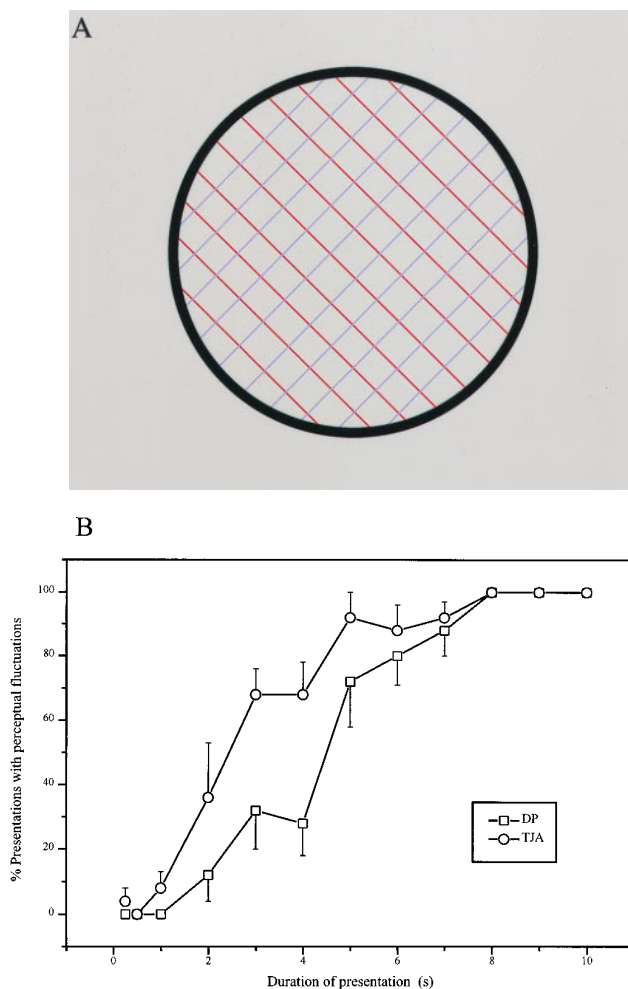


FIG. 1. Perceptual fluctuation of stimulus elements during normal binocular viewing. (A) Subjects viewed a 45-cm, high-resolution monitor at a distance of 30 cm, with the head stabilized by a chin rest and forehead bar. The stimuli consisted of red and blue lines (thickness = 0.1°) on a grey background; all components of the stimulus were equiluminant (10 cd/m²). (The equiluminance in the journal reproduction is necessarily approximate; this deficiency, however, does not seriously affect any of the phenomena we describe.) Because some subsequent observations entail the superimposition of dichoptic stimuli by divergent fusion (see Fig. 4), all stimuli were delimited by a black circle (thickness = 0.5°). In the configuration illustrated here, the circled area subtended 16° on the monitor, the different colored lines being oriented at 45° and 135°; the spatial frequency was 0.75 cycle per degree, and no specific point of fixation was provided. When such stimuli are viewed continually, a curious phenomenon is observed that readers can appreciate even in this much-reduced version of the actual stimulus. After a variable period of continuous viewing, the intensity of the red and blue lines begins to fluctuate such that portions of a line, several lines belonging to the same set (i.e., the red lines or blue lines), or even an entire set of lines begin to disappear and reappear in a highly dynamic fashion. (B) Delay in the onset of these perceptual fluctuations. To measure the delay, the stimulus was presented for intervals ranging from 0.25–10 sec, in random order; at the end of each interval the observer had to indicate (by pressing a key) whether or not a change in the dominance of red or blue lines had occurred. A trial comprised 5 presentations at each of 12 different intervals for a total of 60 presentations. The graph shows the averaged results of five such trials for each observer (bars show standard errors).

Comparison with Binocular Rivalry

Although less striking, fluctuations in the perception of line-sets in normal binocular (or monocular) view are qualitatively similar to those that occur when binocular rivalry is elicited by divergent (or convergent) fusion of differently colored orthog-

onal lines. (To appreciate this point, the reader should judge the experience elicited by Fig. 1A with that elicited by Fig. 4A). We therefore compared the effect of changing the various parameters tested in normal viewing with the effects of the same stimulus changes under conditions of binocular rivalry (Fig. 4; compare Figs. 2 and 3). Varying the distinctiveness of the line-sets by changing their orientation and color influenced the frequency of set alternation similarly in the two circumstances (compare with Fig. 2). Changing the overall size and spatial frequency of the stimulus also influenced the alternation rate in a manner similar to that observed during rivalry (compare with Fig. 3). The major differences between normal viewing and binocular rivalry are: (i) the greater frequency of fluctuations during binocular rivalry and (ii) the shorter delay in the onset of fluctuations (which under rivalrous conditions begin to occur within a fraction of a second; refs. 14 and 15).

As a further control, we viewed the same stimulus (an orthogonal grid of red and blue lines) independently presented to each eye, superimposing congruent monocular stimulus patterns by divergent fusion (Fig. 4A). The results were not distinguishable from those observed in normal binocular viewing, indicating that the divergent superposition we used to elicit binocular rivalry in these experiments did not influence the results (Fig. 4B).

Concordant Fluctuation of Rivalrous and Nonrivalrous Stimuli

To further explore the relationship between binocular rivalry and normal viewing, we devised another set of stimuli in which the central part of the scene was binocularly rivalrous, whereas the surrounding region configured with the same stimulus elements was not (Fig. 5). The question asked was whether the fluctuation of stimulus sets in the rivalrous and nonrivalrous portions of the scene behaved independently or cooperatively in this circumstance. The result was clear: the rivalrous transitions typically occurred in synchrony with the transitions in the annular, nonrivalrous portion of the scene. Moreover, the fluctuation rate of the nonrivalrous portion of the stimulus was greater than when similar nonrivalrous stimuli were presented alone; in contrast, the fluctuation rate of the rivalrous portion was reduced (compare Figs. 4A and 5).

Implications

Why does the continued observation of such patterns in normal binocular view elicit fluctuations that sequentially emphasize different aspects of the stimulus? Were it not for the striking similarities of these perceptual fluctuations in normal viewing with those experienced during binocular rivalry, one might dismiss them as simply another peculiar illusion to be added to the long list of unexplained phenomena in vision. The fact, however, that the fluctuations are qualitatively indistinguishable from the experience of dichoptic rivalry (which readers can verify for themselves by studying the figures presented here) argues that competition among stimulus sets is a general feature of vision. Binocular rivalry appears to be a much enhanced experience of fluctuation among the elements of a pattern, elicited by the unusual circumstance of presenting the components independently to the two eyes (an uncommon experience during the normal viewing of objects within Panum's area). Because the two monocular streams are to a greater or lesser degree separated from one another in at least the early stages of visual processing (16), dichoptic presentation may simply make it easier to separate the competing sets.

The similar competition between stimulus elements in normal and rivalrous viewing suggests that the basis of this phenomenon in any presentation is the degree to which the visual system parses simple patterns into subsets that share one

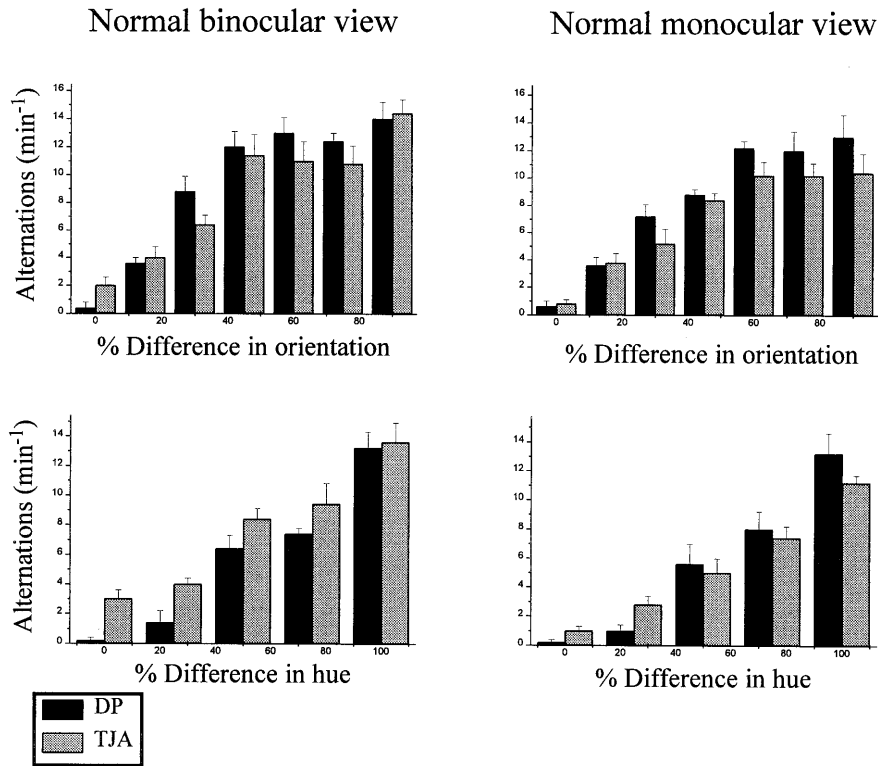


FIG. 2. Effects on the rate of line-set fluctuations elicited by varying the quality of the component elements of the stimulus in normal view. (Left) Results obtained during binocular viewing. (Right) Results with the left eye closed. (Upper) Effect of varying the angle between the two line-sets from 0 and 90°. (Lower) Effect of varying the spectral distinction between the two line-sets; 0% difference indicates that both sets of orthogonal lines were red and 100% difference indicates that one set of lines was red and the other blue, as in Fig. 1A.

or more salient features. For example, although the stimulus presented in Fig. 1A is at first seen as a grid of red and blue

lines when regarded in normal binocular view, visual attention is eventually drawn to one of the line-sets or the other at a rate

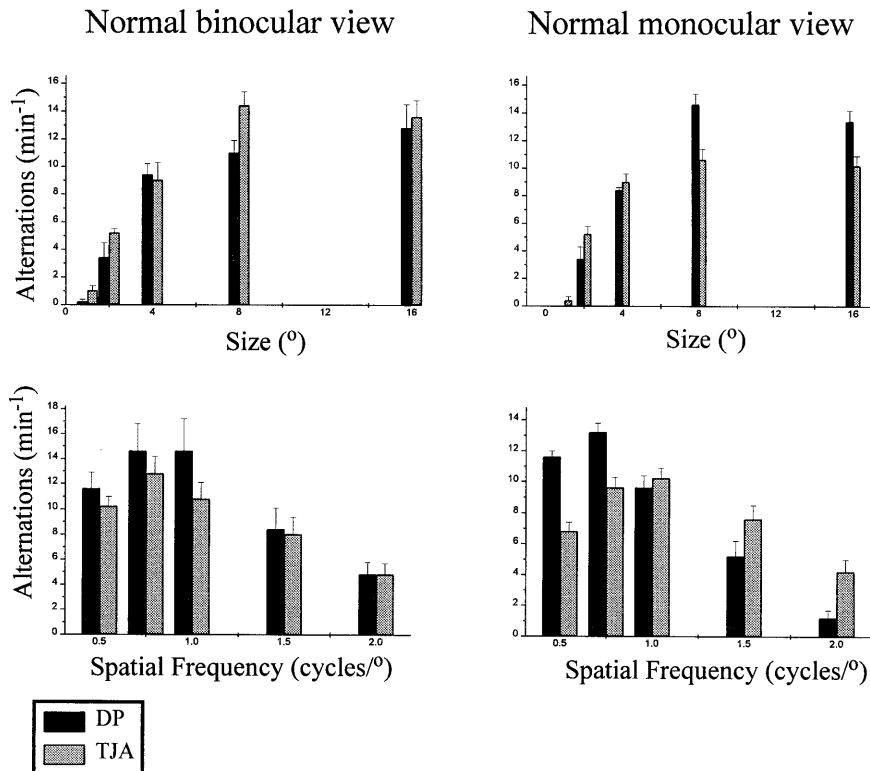


FIG. 3. Effects of varying some overall aspects of the stimulus sets in normal view. As in Fig. 2, Left shows the results obtained during binocular viewing and Right the results with the left eye closed. (Upper) Effect of changing the overall size of the stimulus from 1° to 16°. (Lower) Effect of changing the spatial frequency of the pattern from 0.5 to 2.0 cycles per degree.

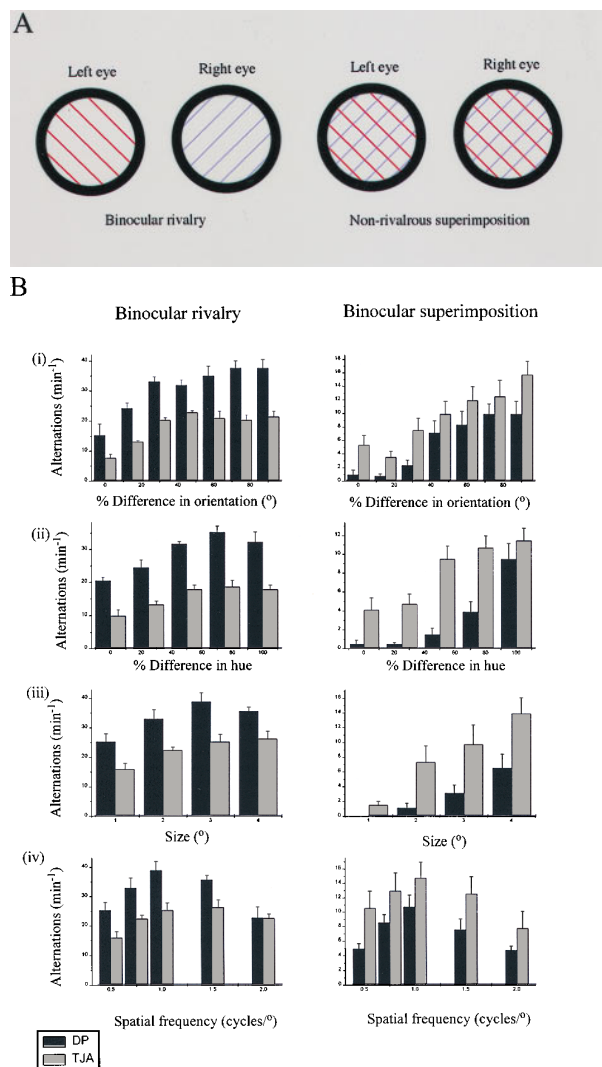


FIG. 4. Effect of varying the same parameters as in Figs. 2 and 3 with the stimuli presented in binocularly rivalrous view. The type of stimulus used is shown in *A*, the rivalrous stimulus pair being on the left and the nonrivalrous control on the right; the performance of the subjects is shown in *B*. For each of the parameters tested, the right and left eye stimuli were fused by divergent (or convergent) viewing, a technique that many readers will be familiar with from viewing autostereograms. When fused, the overall stimulus pattern is similar to that in Figs. 2 and 3; however, the two orthogonal stimulus components are now available to only one eye or the other. (i) Effect of varying the orientation of the two line-sets. (ii) Effect of varying their hue. (iii) Effect of varying the overall size of the stimulus. (iv) Effect of varying the spatial frequency of the stimulus. Although quantitatively greater, the influence on perception of changing these several parameters in binocularly rivalrous conditions is qualitatively the same as that observed during normal binocular or monocular presentation (compare with Figs. 2 and 3). Furthermore, the performance in the superimposition controls is not significantly different from that shown in Figs. 2 and 3.

that varies according to the degree of difference between them (see Fig. 2). This visual strategy appears to be much the same as that employed when observing incompatible monocular scenes (17) or ambiguous objects (18). When viewing more typical scenes, this strategy is not readily apparent, because we rarely look at the same scene for more than a fraction of a second (e.g., ref. 19), and because readily interpretable objects (rather than iterated patterns with potentially competing components) usually meet our gaze.

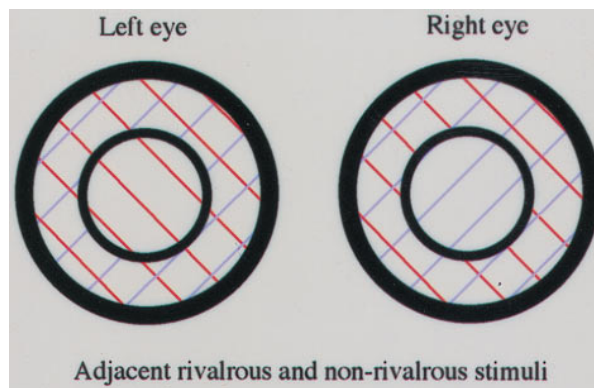


FIG. 5. Coordinated fluctuation of competing stimulus sets when rivalrous and nonrivalrous portions of a stimulus pattern are viewed simultaneously. Circular stimuli subtending 4° were superimposed by divergent fusion, as in Fig. 4. The center was rivalrous and the annulus nonrivalrous. The percentage of concordant fluctuations in the rivalrous and nonrivalrous portions of the stimulus was $84.2 \pm 2.4\%$ for DP and $78.2 \pm 2.7\%$ for TJA (values are the mean and standard error of 10 trials, each of which lasted 1 min).

Based on quite different evidence, others have also considered that the nature of binocular rivalry may have been misinterpreted (15, 17). The reconciliation we suggest is that retinal stimulation generates associations, rather than initiating the computation of an image. In most circumstances, the visual stimulus elicits an association that has a compelling interpretation. When, however, the stimulus elicits a less certain association (as with the patterned stimuli we have used here, or as occurs when the stimulus is an ambiguous figure or dichoptically rivalrous), then perception fluctuates between various possible associations in an ongoing effort to find a definite meaning. The purpose of such fluctuations in the face of uncertainty is presumably to interpret the visual scene with maximal efficiency.

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