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A fresh look at interocular grouping during binocular rivalry

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Abstract

During binocular rivalry, observers sometimes perceive one complete visual object even though component features of that perceptually dominant object are distributed between the two eyes and are in rivalry against other, dissimilar features. This interocular grouping cannot be explained by models of rivalry in which one eye or the other is completely dominant at any given moment. But perhaps global interocular grouping is achieved by simultaneous local eye dominance, wherein portions of one eye's view and complementary portions of the other eye's view become dominant simultaneously. To test this possibility, we performed two experiments using relatively large, complex figures as rival targets. In one experiment we used an "eye-swap" technique to confirm that within given, local spatial regions of rivalry it was the region of an eye—not a given stimulus feature—that was usually dominant. In a second experiment, we measured dominance durations for multiple, local zones of rivalry and then created 1-min animations of a global "montage" in which dominance within local regions was governed by the distributions of dominance measured empirically. These animations included significant periods of time during which global interocular grouping was evident; observers viewed these animations intermixed with actual rivalry displays, and the resulting tracking data confirmed the similarity in global dominance of the two display types. Thus interocular grouping during rivalry does not rule out local, eye-based rivalry, although synergistic and top-down influences almost certainly provide additional force in the promotion of interocular grouping.
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1. Introduction

In 1996 Kovács and colleagues (Kovács, Papathomas, Yang, & Fehér, 1996) published an important, influential paper showing that pattern coherence strongly influences the spatio-temporal trajectory of binocular rivalry; a version of the kind of displays employed by Kovács et al. is shown in Fig. 1. Their compelling findings can be construed as evidence against "eye-based" accounts of binocular rivalry (Blake, 1989; Lehky, 1988; Matsuoka, 1984; Sugie, 1982), since observers sometimes experience a coherent spatial pattern even though the component parts of that pattern are distributed between the two eyes. This outcome, dubbed "interocular grouping" (IOG), would be

impossible, of course, if the two eyes themselves were competing for dominance during rivalry. [2]

In the present paper we have re-examined IOG during rivalry to determine whether global patterns of rivalry dominance among stimulus features distributed between the two eyes might arise owing to simultaneous dominance among local eye-based "zones" distributed between the eyes. The findings from two experiments indicate that global dominance may indeed be grounded in local, eye-based zones of rivalry and that salient periods of IOG can be achieved based on the simultaneous dominance of these local zones. From the outset it should be stressed that we are not questioning the existence of IOG or the involvement of cooperative, global processes in the promotion of IOG. Our intention

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[2] Actually, IOG had been described much earlier in the 20th century in a little-known paper by Diaz-Caneja (1928) that has recently been translated from its original French into English (Alais, O'Shea, Mesana-Alais, & Wilson, 2000). And several laboratories have also documented IOG using a variety of different kinds of rival targets (see review by Papathomas et al., in press).

Fig. 1. Dichoptic displays inducing binocular rivalry. (a) Conventional displays consisting of monocularly homogenous images. (b) Displays consisting of complementary, patchy images. Reproduced with permission from Kovács et al. (1996). An astute referee pointed out that the "monkey face" in fact looks more like a chimpanzee, and we cannot disagree. In their paper, however, the creators of this display, Kovács et al. (1996), refer to the animal as a "monkey" so we will respect their designation.

is simply to temper the implications of IOG for models of rivalry.

2. Experiment 1: eye-swapping

The rationale underlying this experiment is based on the eye-swap technique developed by Blake, Westendorf, and Overton (1980). To describe that technique in a nutshell, observers viewed a pair of rival figures and indicated by key-press when a given rival display (e.g., the monkey face) achieved exclusive dominance, the other figure (e.g., the jungle scene) being completely suppressed from visibility. Upon key-press, the two rival targets were exchanged, or "swapped", between the eyes, such that the dominant figure was re-routed to the eye that, just before the swap, was viewing the sup-

pressed figure, and vice versa. The swap was accomplished by smoothly reducing the contrast of both figures to zero and then smoothly returning them to their original contrast, to avoid abrupt transients that are known to disrupt rivalry (Walker & Powell, 1979). Also included were comparison trials on which the rival figures underwent exactly the same contrast change (decrease followed by increase) but were not exchanged between the eyes. Blake et al. found that observers nearly always continued seeing the same rival figure on "non-swap" trials but saw the previously suppressed stimulus on "swap" trials. This pattern of results implied that it was the region of an eye—not a particular stimulus figure—that was dominant at any given moment in rivalry.

In the present experiment, we applied this eye-swap procedure to large, complex displays that, owing to

IOG, sometimes yielded perception of a coherent figure from component parts distributed between the two eyes. To simplify the observer's task, we made one modification in the eye-swap. As before, the observer initiated "swap" and "no-swap" sequences only when a given rival image was completely dominant. But, unlike with the earlier procedure, the observer, following the swap, monitored the dominant stimulus within a relatively small region of the overall display, which we term the region of interest (ROI). From the observer's report, we were able to infer whether the stimulus within the ROI following a swap corresponded to that predicted by stimulus rivalry or by eye rivalry.

2.1. Methods and procedures

2.1.1. Observers

Five observers (three naïve), 24–34 years old, all with normal or corrected-to-normal vision, volunteered their participation in this and the following psychophysical experiment. All aspects of this study were performed in a manner consistent with procedures authorized by the Vanderbilt University Institutional Review Board.

2.1.2. Displays

Rival patterns were displayed on the left and right halves of a 21-in. NEC monitor (1024 × 764 resolution; 100 Hz vertical refresh rate) controlled by MatLab in conjunction with the psychophysics toolbox (Brainard, 1997; Peli, 1997). Observers viewed these patterns, each $4° \times 6°$ in width and height, through a custom-designed mirror haploscope with the head stabilized by a chin and head rest. To create the various swap conditions, we generated four different dichoptic displays by modifying the "monkey" and "jungle scene" figures published by Kovács et al. (1996) in their study of IOG. Two of our displays ('MM-JJ' and 'JJ-MM' in Fig. 2a) consisted of conventional rival patterns in which an entire picture was presented to one eye ('whole' monkey face—"MM" and 'whole' jungle scene—"JJ"), and the other two displays ('MJ-JM' and 'JM-MJ' in Fig. 2a) consisted of montage-like patterns in which complementary portions of each figure were distributed between the two eyes ('patchy' hybrids of monkey face and jungle scene). Rectangles formed by thick (0.2°), alternating black and white lines framed the edges of the two rival patterns, thereby promoting and maintaining stable binocular eye alignment of these patterns.

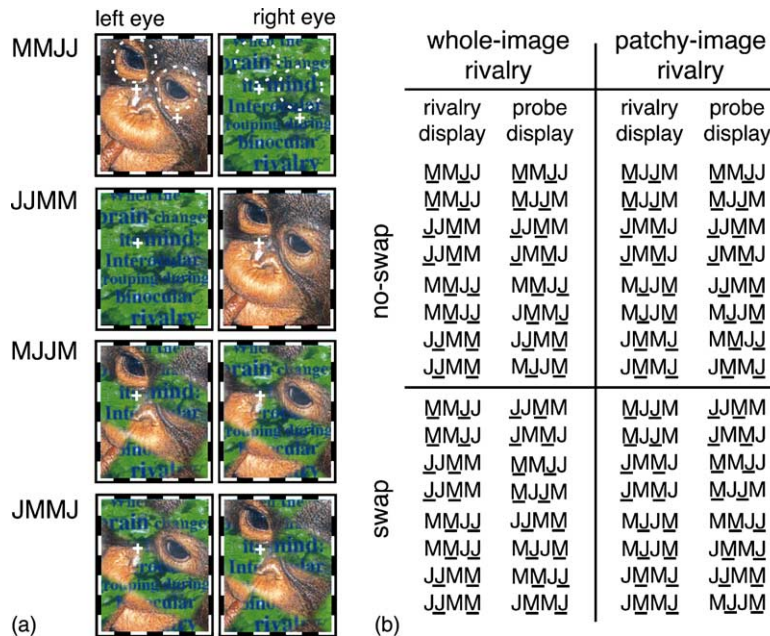|	left eye	right eye	whole-image rivalry		patchy-image rivalry	
			rivalry display	probe display	rivalry display	probe display
MMJJ			MMJJ	MMJJ	MJJM	MMJJ
			MMJJ	MJJM	MJJM	MJJM
JJMM			JJMM	JJMM	JMMJ	JJMM
			JJMM	JMMJ	JMMJ	JMMJ
MJJM		no-swap	MMJJ	MMJJ	MJJM	JJMM
			MMJJ	JMMJ	MJJM	MJJM
			JJMM	JJMM	JMMJ	MMJJ
JMMJ			JJMM	MJJM	JMMJ	JMMJ
			MMJJ	JJMM	MJJM	JJMM
			MMJJ	JMMJ	MJJM	JMMJ
			JJMM	MMJJ	JMMJ	MMJJ
			JJMM	MJJM	JMMJ	MJJM
		swap	MMJJ	JJMM	MJJM	MMJJ
			MMJJ	MJJM	MJJM	JMMJ
			JJMM	MMJJ	JMMJ	JJMM
			JJMM	JMMJ	JMMJ	MJJM

(a)   (b)

Fig. 2. Stimuli used in Experiment 1. (a) Four different dichoptic displays were used as rivalry stimuli and probe stimuli. ROIs (denoted by white dotted circles, which were not shown in the experiment) were indicated by a binocularly viewed small, white fixation cross, which appeared at one of two locations (shown in the display in the first row) on a given trial. Each display was named by a string of four letters (shown in the upper left corner of each display), which represent images that appeared inside ROIs. 'M' represents a part of the monkey image whereas 'J' represents a part of the jungle image. The first letter corresponds to the left ROI of the left eye stimulus, the second to the right ROI of the left eye stimulus, the third to the left ROI of the right eye stimulus, and the fourth to the right ROI of the right eye stimulus. (b) There were four viewing conditions, which were determined by two factors: the type of rivalry display ('whole-image' vs. 'patchy-image') and the mode of rivalry–probe transition ('no-swap' vs. 'swap'). Eight different pairs of dichoptic displays were shown for each condition. Underlines indicate locations of ROIs. Note that underlined letters were not changed between rivalry displays and probe displays in the 'no-swap' condition whereas underlined letters were changed in the 'swap' condition.

For each observer and for each pair of rival patterns, the luminance contrast and the color contrast of the figures were adjusted to equate them as nearly as possible in terms of their relative predominance.

2.1.3. Procedure

Each trial in this experiment consisted of the following sequence of events. At the beginning of each trial, the observer viewed one of the four dichoptic displays (e.g., 'MM-JJ' in Fig. 2a) while fixating a small, white cross. On a given trial this fixation cross was located at one of two positions within both displays, with the position on a given trial located just below the ROI to be monitored on that trial. One of the ROIs corresponded to the spatial location occupied by the monkey's left eye and the other ROI corresponded to the spatial location occupied by the monkey's right eye (these two possible ROI positions are denoted by dotted circles in 'MM-JJ' in Fig. 2a). Note that only one ROI was monitored on a given trial and that the ROI was designated by the position of the fixation cross, not the presence of a dotted circle. We switched between the different ROI positions over trials to minimize adaptation and to avoid testing only one region of the display.

The observer carefully monitored the pattern of dominance between the two rival displays and pressed a key once a designated figure (the entire monkey display in one block of trials, the entire jungle scene in another block of trials) was completely dominant. This key-press triggered a "rivalry–probe transition" wherein the initial rivalry display was replaced by a probe display, itself also one of the four dichoptic display types (e.g., 'JJ-MM' in Fig. 2a). This probe transition was executed by gradually decreasing the contrast of the rivalry display to zero and then gradually increasing the contrast of the probe display to the contrast of the original display. The time courses of contrast increase and decrease followed sigmoidal functions with identical time constants ($1\sigma = 83.8$ ms) but opposite sign. Once at maximum contrast, the probe display remained at this value for 500 ms after which the two images comprising the probe disappeared. At this time, the observer pressed one of two computer keys to indicate which of two possible image components—the monkey eye or a patch of jungle scene—was dominant following the probe transition.

Depending on whether 'whole' or 'patchy' images were used in the 'rivalry' display and whether local dichoptic images inside the ROI were 'swapped' or 'not swapped' during the rivalry–probe transition, individual trials fell into one of the following four conditions (Fig. 2b): (1) 'whole-rivalry swap', (2) 'whole-rivalry no-swap', (3) 'patchy-rivalry swap' and (4) 'patchy-rivalry no-swap' (Fig. 2b). For example, suppose the observer started a given trial by viewing the 'whole' monkey image in the left eye and the 'whole' jungle image in the right eye ("MM-JJ"). Suppose further that the observer

was instructed to report the perceived stimulus in the left ROI after the rivalry–probe transition ('MM-JJ' under the 'rivalry display' column under the 'whole-image rivalry' column in Fig. 2b). If the monkey image appeared in the ROI of the left eye and the jungle image in the ROI of the right eye as a probe display ('MM-JJ' or 'MJ-JM' under the probe display column under the 'whole-image rivalry' column in Fig. 2b), this trial was sorted into the 'whole-rivalry no-swap' condition since the dichoptic local images inside the ROI were not swapped between the two eyes. On the other hand, the trial would be sorted into 'whole-rivalry swap' condition if the probe display consisted of the jungle in the ROI of the left eye and the monkey face in the ROI of the right eye ('JJ-MM' or 'JM-MJ' under the probe display columns under the 'whole-image rivalry' column in Fig. 2b) since the dichoptic local images within the ROI were swapped between the two eyes. The same designations were applied to trials wherein the initial rivalry display comprised complementary, patchy images.

For each of the four conditions, there were eight different combinations of a rivalry display and a probe display, and these eight are listed in Fig. 2b. For each pair in this list, two different trials were generated depending on which global figure (monkey or jungle scene) was dominant when the observer initiated the rivalry–probe transition. As a result, each of the four conditions included 16 different trial types, each of which was repeated eight times per observer. This produced a total of 128 trials per condition for each observer. From trial to trial observers never knew which stimulus condition ("whole" vs. "patch"), which probe condition ("swap" vs. "no-swap") or which probe type ("whole" vs. "patch") was being tested, and these factors were randomized across trials. It should be noted that the smooth transients accompanying swap trials were also present on no-swap trials, in which case the image features within the ROI gradually disappeared and then reappeared within the same eye.

2.1.4. Predictions and results

The pattern of results was equivalent among observers, thus averaged data across observers are shown in Fig. 3. Percentage of trials in which a percept within the ROI changed during the probe transition period is plotted for each condition. Just as a reminder, image feature swaps only occurred when an entire image (e.g., monkey face) was dominant completely, regardless whether the components forming that image were presented to a single eye (conventional rivalry) or subdivided between the two eyes (IOG). We had observers monitor just a single ROI—not the entire display—merely to simplify the task.

For trials when the image features within the ROI did not change during the swap transition, observers continued to see the same image feature on the majority of
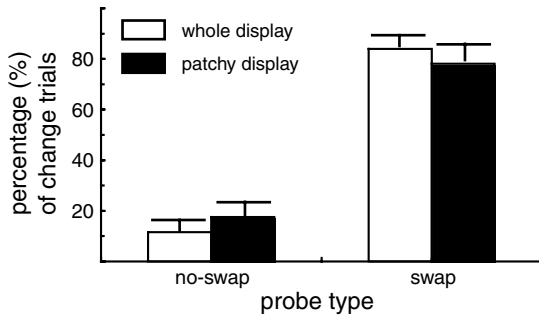
Fig. 3. Averaged data across observers from Experiment 1. Percentages of trials in which a percept within the ROI changed during probe transition period are plotted for each condition. White bars represent data from conditions wherein rivalry displays consisted of whole images and black bars represent data from conditions wherein rivalry displays consisted of patchy images. Error bars represent standard errors.

trials; this was true both for 'whole' image trials and 'patchy' image trials. Results from these conditions merely confirm that turning the displays off and then on again usually had no disruptive effect on the rivalry states of the two eyes/stimuli. [3] These results have no bearing on the role of "eye" and "stimulus" in IOG, but they do provide baselines for comparison of the results from the various 'swap' conditions, where the two hypotheses make very different predictions.

In the 'swap' conditions, a given stimulus is initially dominant throughout the entire visual display (e.g., the monkey face). If rivalry were based on the "stimulus" irrespective of the eye in which that stimulus—or its components—was imaged, observers should continue perceiving the same image even though that stimulus (or that component of the stimulus, in the case of IOG) is now being imaged in the other eye. "Eye rivalry", in contrast, predicts that, following the transition swap, observers should see the probe stimulus now being presented to the initially dominant eye, even though that stimulus was not dominant prior to the swap. As can be seen in Fig. 3, the pattern of results favors eye rivalry. Regardless whether the rivalry display consisted of 'whole' or 'patchy' images, observers were very likely to experience changes in the dominant stimulus (83.9% of trials in the 'whole-rivalry swap' condition and 78.1% in the 'patchy-rivalry swap' condition). The ratios of trials wherein a dominant image was changed in both of the 'swap' conditions were significantly higher than those in their corresponding 'non-swap' conditions ($p < 10^{-5}$ for both 'whole-rivalry' and 'patchy-rivalry' conditions,

one-tailed paired t-test). Results for the 'patchy-rivalry swap' condition are particularly relevant, for they imply that different regions of the two eyes are dominant simultaneously in different local zones when global IOG is experienced during binocular rivalry. IOG, in other words, is not necessarily evidence against a modified version of "eye rivalry" in which rivalry transpires within local zones.

3. Experiment 2: simulated IOG

If we are to conclude that global IOG is dynamically assembled from signals arising in local, eye-based zones of dominance, the onus is on us to explain how this perceptual state can arise given the seemingly low probability of the appropriate zones being dominant all at the same time. Indeed, it was this kind of statistical improbability that led Kovács et al. to focus on stimulus-based coherence, not eye of origin, as a basis for IOG. They assumed that the incidence of global IOG should be very low even for a relatively small number of local "eye-based" patches whose individual states of dominance are independent of one another; their reasoning was based on the standard formula for independence for two equally likely, mutually exclusive states. However, this formulation treats the decision process associated with dominance judgments as binary in nature, thereby potentially oversimplifying the complex dynamics characteristic of these kinds of relatively large rival figures. To illustrate what we mean, observe the alternations in rivalry associated with the rival patterns in Fig. 1a and b. With the IOG display in particular, one must adopt some criterion for "global dominance" and this criterion must take into account the ever-changing spatio-temporal appearance created by these kinds of figures. Moreover, a low probability of conjoint, global predominance also assumes that the probability of either stimulus interpretation at each, given location is roughly equal (such that the formula $1/2^n$ applies). Inequality between the two complementary alternatives will increase the expected incidence of IOG.

Rather than try to compute the likelihood of IOG using probability values and the independence theorem, we instead felt it worthwhile to estimate empirically the incidence of global dominance when viewing dynamic displays in which local regions are forced to fluctuate in appearance independently of one another. Toward that end we have: (1) measured the distributions of rivalry dominance associated with local zones of rivalry, (2) used those distributions to create a video sequence simulating the global appearance of the monkey/jungle scene generated on the assumption of local, independent zones of rivalry, and (3) had observers view and track

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[3] Those few trials where rivalry state did change following the stimulus transition could be attributable to errors made by observers (e.g., triggering the probe transition at an inappropriate time or blinking eye during probe transition), to residual transients that were not fully eliminated in our swapping procedure or to occasional brief dominance periods that produced state changes based on chance alone.

periods of global dominance portrayed by those simulations. These three steps and the results from them are described next.

3.1. Methods, procedures and results

3.1.1. Step 1: dominance durations for local rivalry

The aim here was to derive distributions of dominance durations associated with local rivalry occurring within several individual, restricted regions of the visual field. The rival figures used to generate each of these distributions consisted of circular patches drawn from corresponding regions of the monkey figure and the jungle figure (see Fig. 4a). So, for example, observers fixated the small, binocularly presented cross and tracked successive periods of dominance between two relatively small, spatially local rival images. This procedure was repeated for two pairs of rival patches, with one pair imaged at the point of fixation (region '1' in Fig. 4a) and the other pair imaged 1.67° away from the fixation (e.g., region '2' in Fig. 4a). Each tracking period lasted 1-min and was repeated 12 times for each pair of rival patterns for each observer. The diameter of the circular patches was 1.34° visual angle for the foveal patch and 2° for the parafoveal patch. For both pairs of

rival patches, the edges of the patches were blurred with a spatial gaussian.

For each of five observers, these measurements produced two pairs of distributions of dominance durations, one pair for foveal stimulation and the other for parafoveal stimulation. One member of each pair corresponded to a patch from the "monkey" image and the other to a patch from the "jungle" image (representative distributions are shown in Fig. 4b). Consistent with previous findings (Fox & Herrmann, 1967; Levelt, 1965), the resulting frequency distributions generally resembled a gamma distribution, although we did not perform goodness of fit tests to confirm this point.

3.1.2. Step 2: creation of dynamic montages simulating rivalry

For each of the five observers, we created 1-min animations comprising a montage of monkey and jungle scene fragments that changed over time in a manner dictated by the dominance durations measured in Step 1; each montage comprised a series of individual images viewed by both eyes (i.e., not dichoptically). This was accomplished in the following manner (upper portion of Fig. 4c). First, we segmented the display into six, circularly shaped virtual regions, which remained constant
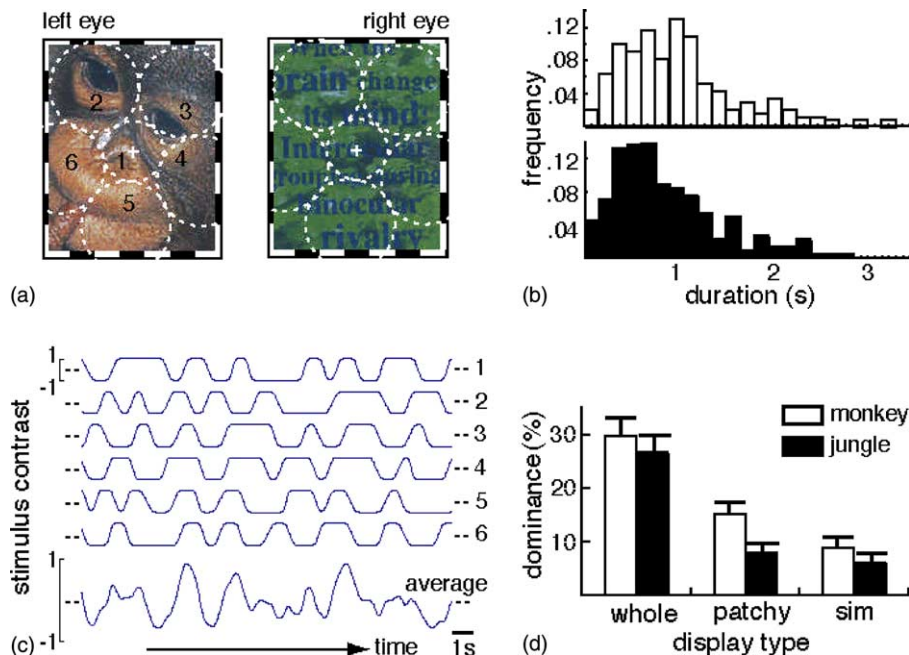

Fig. 4. Stimuli and results for Experiment 2. (a) The display were segmented into six, circularly shaped virtual regions around the fixation cross. The radius was 0.67 for the region at the fixation ('1') and 1° for the other regions ('2'–'6'). (b) Histograms of dominance durations are shown for the monkey (top), jungle (bottom) percepts in local zone '2' (see (a)). Results are averaged across observers. (c) Each of the top six graphs shows an example of fluctuations of image contrast over time for patches of rival images within each local region of the display in the hybrid animation. A value '1' means that the contrast of a patch of monkey face is its original value while the contrast of a patch of jungle scene is zero, and vice versa for a value '−1'. The graph at the bottom shows fluctuations of the mean contrast averaged across the six local regions. (d) Percentages of dominance are plotted against each viewing condition. White bars indicate percentages of time when the monkey face was perceived predominantly whereas black bars indicate percentages of time when the jungle scene was perceived.

in shape and position throughout all frames of the animation. Next, we placed in each of the six segments a patch of jungle scene or a patch of monkey face, randomly determining with equal probability which image patch would go in each position of the initial frames of the animation. That image fragment then remained present at that location for a duration determined by randomly sampling (with replacement) a duration from the frequency distribution associated with that image fragment. That sampled duration, of course, corresponded to an empirically determined duration of dominance for a patch of equivalent size. This sampling (with replacement) of a dominance duration was performed for each of the six virtual regions defining the entire display. Those durations then determined the duration that a given image fragment (e.g., patch of jungle scene) remained visible at a given region of the animation. At the conclusion of that animation duration, that "dominant" image fragment (e.g., jungle patch) was replaced by the complementary fragment (e.g., monkey patch) and duration of visibility for that new dominant fragment was determined by a random draw from the dominance distribution for that image fragment.

Thus over time, each of the six individual image fragments within the dynamic montage was changing at a rate dictated by randomly sampled dominance durations for that fragment. To more closely mimic the actual appearance of binocular rivalry, the transitions from one image to the other were made smoothly, not abruptly, by ramping down the contrast of one image while simultaneously ramping up the contrast of the other. Durations of individual transitions were also determined based on sampled transition durations in a manner similar to the way dominance durations were determined (the mean transition duration was around 500 ms). In addition, the boundaries among the six virtual zones were spatially blended to eliminate sharp edges. We did not attempt to simulate the wave-like spatial spread of dominance that one often experiences during state transitions in rivalry (Wilson, Blake, & Lee, 2001).

Multiple rivalry "montages" were made for each observer, using that individual's dominance distributions. Examples of the resulting animations can be seen by navigating to:

http://www.psy.vanderbilt.edu/faculty/blake/rivalry/ IOG/IOG.html.

3.1.3. Step 3: incidence of global dominance in dynamic montages

Simple inspection of the resulting animations reveals occasional, striking periods of time during which one sees primarily the monkey face or the jungle scene. Indeed, the animation does a remarkably good job of simulating rivalry observed with IOG displays, especially considering that the six dynamic image fragments are generated independently. Of course, the montage's appearance will vary dependent on the size and distribution of the virtual zones, but the values we selected are not unreasonable given our knowledge of the sizes of spatial zones of rivalry measured empirically (Blake, O'Shea, & Mueller, 1992).

To more directly compare the fluctuations in global dominance in these montages with those experienced during actual binocular rivalry, we had observers track periods of monkey face and jungle scene dominance under three conditions: (1) conventional, whole-image rivalry, in which one eye viewed the monkey face and the other eye viewed the jungle scene (e.g., MM-JJ), (2) interocular "patchy images" in which each eye received complementary portions of the monkey and jungle scenes (e.g., JM-MJ), and (3) simulated rivalry in which both eyes viewed a single montage animation created from the dominance distributions for that observer. Individual tracking periods lasted 1 min and were repeated eight times for each condition and for each observer. The three conditions were randomly intermixed during a testing session, such that an observer could not anticipate which condition was being tested at any given time. A single set of instructions pertained to all tracking periods: depress one key when the monkey face was predominantly visible and another key when the jungle scene was predominantly visible. Observers were free to adopt their own criterion for "predominantly visible" but they were required to apply that same criterion in all three conditions.

Results from these measurements for each of the three conditions are shown in Fig. 4d, which plots the average percentage of time observers reported predominance of the jungle scene, predominance of the monkey face and, by inference, the percentage of time observers experienced mixed dominance. Here it can be seen that the "whole" images (e.g., 'MM-JJ') produced the highest incidence of global predominance, wherein one image or the other was visible predominantly. The incidence of global dominance was reduced under the interocular "patch" condition (e.g., 'JM-MJ'), consistent with the earlier findings by Kovács et al. (1996). This reduction in global dominance implies that grouping of image components distributed between the eyes is not as strong as the grouping promoted when coherent features are all imaged in the same eye. Of particular relevance for our purposes is the incidence of global dominance with the montage animation: observers predominantly saw the monkey face or the jungle scene 15% of the total viewing time, a value much larger than chance alone would predict ($100\% \times 0.5^6$). These results thus reinforce the subjective impressions one obtains when viewing these montages.

How can a simulation based on multiple, independent samples create a perceptual experience where the

incidence of coherent predominance far outstrips what one would expect based on the classic independence formulation? We analyzed several of these simulated montages by plotting on a frame-by-frame basis the weighted sum of image pixels associated with the monkey face and the jungle scene; an example of one of those plots is given in the lower part of Fig. 4c. This curve can be construed as the fluctuation over time in the "strength" of evidence favoring one of two alternative interpretations. Because this evidence varies smoothly and continuously, an observer forced to utilize this evidence to make a binary judgment must establish some criterion value that must be exceeded before declaring predominance of one figure or the other. Where that criterion is placed, of course, will determine the cumulative incidence of "predominance" over the entire viewing period. This way of conceptualizing the display and the task makes it easier to see how observers could produce the data shown in Fig. 4d. For that matter, we believe this conceptualization applies with equal force to the case of genuine binocular rivalry where transitions in dominance are characteristically piecemeal, wave-like and unpredictable. In the case of genuine rivalry, of course, we cannot objectively quantify the "strength" of evidence over time, but the observer is still faced with the challenge of making binary judgments about perceptual events that vary in a highly non-binary fashion.

These simulation results, then, complement the results from Experiment 1, further underscoring the possible role of eye-based zones in IOG. To be sure, we do not mean to imply that independent, eye-based zones are completely responsible for global dominance under conditions of IOG during rivalry. On the contrary, we know that rivalry dominance is sensitive to global, contextual effects, with the dominance of a given region of a rival target dependent on the perceptual status of neighboring regions—the evidence for this kind of dependence is overwhelming (Alais & Blake, 1999; Fukuda & Blake, 1992; Logothetis, 1998; Ooi & He, 2003; Sobel & Blake, 2002; Suzuki & Grabowecky, 2002; Whittle, Bloor, & Pocock, 1968). Still, the present results hopefully will serve to demonstrate that the existence of IOG, contrary to the conclusion reached by some investigators, does *not* necessarily rule out an involvement of "eye" information in the rivalry process. We are proposing, in other words, that the pattern of dominance during a given moment of rivalry comprises local eye-based zones of dominance which are subject to global grouping forces (e.g., good continuation) that operate regardless of the "eye zone" from which the interacting features arise. In this regard, it is noteworthy that evidence for some involvement of "eye" zones has been reported by Papathomas et al. (in press), and we believe that our conclusions are consonant with theirs.

4. Conclusion

It is natural to assume that rivalry involves competition between conflicting stimulus interpretations, not competition between the two eyes. After all, we are completely unaware which eye is currently dominant during rivalry. Instead when viewing rival figures, we see that one stimulus or the other is currently dominant (or that bits and pieces of both stimuli are jointly visible in the case of piecemeal rivalry). So, phenomenology encourages us to believe that the battleground on which rivalry plays out in our mind's eye is one defined by alternative stimulus interpretations. Yet based on several converging lines of evidence—including the results reported here—we remain convinced that these stimulus interpretations are being assembled in ways that take into account the given regions of an eye that are dominant. What are our reasons for this view?

For one thing, large changes in a rival figure may go completely unnoticed for several seconds when those changes are made during suppression phases of rivalry (e.g., Blake, Yu, Lokey, & Norman, 1998). This nonselective loss of visual sensitivity implies that suppression is rather general and not tailored to just a single stimulus interpretation. For another, we know that exchanging the dominant and suppressed stimuli between the eyes reliably reverses the stimulus that one experiences in rivalry (Blake et al., 1980). This result, which is replicated in Experiment 1, implies that a given region of the eye—not a given stimulus—dominates at any given time. Now it is true that people do experience slow alternations in dominance even when the two eyes' views are rapidly and repetitively exchanged during an extended viewing period (Logothetis, Leopold, & Sheinberg, 1996). However, this form of rivalry, while certainly not eye-based, is dependent on the presence of rapid, abrupt eye exchanges accompanied by even more rapid flicker-induced transients (Lee & Blake, 1999). It may well be that these stimulus conditions override the neural events underlying conventional rivalry, revealing in the process a high-level form of rivalry (Wilson, 2003).

In this paper, we have presented evidence showing that IOG is not necessarily inconsistent with accounts of rivalry in which "eye" plays an important role. At the same time, we wish to reiterate that the phrase "eye" rivalry is not meant to refer to complete dominance of one eye or the other. The incidence of piecemeal rivalry with conventional rival figures strongly argues against competition at the level of the entire eye. Rather, we believe the most parsimonious account of all the data is one in which overall dominance consists of patches, or zones, of dominance collated within and between the two eyes. Moreover, we fully endorse the idea that synergistic interactions among these putative zones serve to reinforce coherent patterns of stimulus dominance,

along the lines proposed by Kovács et al. (1996). Nor do we quarrel with the idea that rivalry dynamics can be guided by "high-level" influences operating beyond the level of eye-based zones, influences based on expectations, attention, stimulus coherence and behavioral demands (Kovács et al., 1996; Leopold & Logothetis, 1999; Leopold, Wilke, Maier, & Logothetis, 2002). After all, vision during dominance phases of rivalry is equivalent to vision under non-rival conditions, so all of the myriad forces shaping ordinary vision can come into play during dominance phases of rivalry. We remain convinced, however, that these forces, along with those mediating visual grouping, only operate on stimulus features that have achieved dominance, a point discussed in greater detail elsewhere (Sobel & Blake, 2002). Image features suppressed from conscious awareness during rivalry do not participate in perceptual processing except, perhaps, at the most rudimentary level (e.g., creation of low-level adaptation aftereffects). This way of thinking about rivalry is broadly consistent with the emerging idea that rivalry is the culmination of neural events distributed within the visual processing hierarchy (Blake, 2001; Blake & Logothetis, 2002; Freeman, Nguyen, & Alais, in press; Ooi & He, 2003). Our particular version of this view of rivalry, however, places paramount importance on neural dynamics early in the visual hierarchy, dynamics that gate competing signals based on the eye receiving those signals and not just the perceptual interpretation conveyed by those signals.

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