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Interactions between Binocular Rivalry and Gestalt Formation

Charles M.M. de Weert, Peter R. Snoeren and Arno Koning

Nijmegen Institute for Cognition and Information (NICI)
Radboud University Nijmegen
The Netherlands

Abstract

A question raised a long time ago in binocular rivalry research is whether the phenomenon of binocular rivalry is purely determined by local stimulus properties or that global stimulus properties also play a role. More specifically: do coherent features in a stimulus influence rivalrous behavior? After decades of underexposure of the subject, recently this question seemed to be answered in the affirmative. This paper presents additional evidence for an influence of coherent features. In an experiment in which aimed eye movements cannot bias conclusions it is demonstrated that Gestalt formation influences binocular rivalry positively, i.e., stronger Gestalts have longer total dominance times. New is that Gestalt formation appears to intervene in the states of dominance ("what"), not directly in the dominance intervals ("how long"). This evokes a conjecture about the nature of interactions between binocular rivalry and Gestalt formation. Gestalt formation seems to be fed by signals that are generated after binocular convergence and only leaves its mark on binocular rivalry by feedback to monocular channels.

Keywords: Binocular rivalry, Gestalt formation.

Interactions between Binocular Rivalry and Gestalt Formation

Binocular rivalry is the phenomenon that starts when two dichoptically presented images are incompatible. Instead of a stationary miscellany of both images, an alternation is seen with mosaic percepts at intervals. Notice that this description of binocular rivalry is formulated slightly more careful than usual. That is, binocular rivalry is not described as an alternation of half-images, but just as an alternation. The reason is that what is alternating is exactly the topic of this paper, and this is not necessarily an alternation of half-images.

As long as binocular rivalry research exists, there is ongoing debate about its driving force. Regarding this, there are two extreme points of view. Either, binocular rivalry is a low-level process that is concerned only with interocular competition and stimulus strengths (yielded by spatial frequency, and contrast among others) of the two-half-images (e.g., Levelt, 1968), or that binocular rivalry is a high-level process that is concerned with interocular grouping, attention and percepts (e.g., Helmholtz, 1924). There is plenty of evidence since Levelt (1968) that stimulus strength is indeed one of the driving forces of binocular rivalry. Currently, the evidence that higher visual areas should also play some role accumulates. This evidence originates from diverging properties of binocular rivalry and related phenomena. Each on its own might not serve as convincing evidence, but put together the global picture emerges that two forces, one that supports the low-level point of view and one that supports the high-level point of view, drive binocular rivalry.

Depth of Suppression

By the detection of shortly flashed test probes, Fox and Check (1972) showed that the depth of suppression for a stationary stimulus is constant during a single phase of suppression. Moreover, they also showed that the depth of suppression is independent to suppression duration. They concluded therefore that the magnitude of suppression and the duration of suppression cannot be accounted for by a single mechanism. Also by using the test probes paradigm, Norman, Norman, and Bilotta (2000) showed that an increased depth of suppression by motion-induced rivalry goes with a predominance of moving patterns. However, increasing the speed of motion does not further increase this suppression depth. Of course, this does not prove the existence of a role of high-level processes in binocular rivalry, but it does show that, next to a single low-level process, a second and independent mechanism is needed to explain the results.

Real-world occlusion escapes binocular rivalry

Shimojo and Nakayama (1990) demonstrated that real-world occlusion escapes binocular rivalry. Although they attributed this to an implementation of occlusion constraints early in the visual pathway where eye-of-origin information is still present, it at least shows that there is more than contour-rivalry and such. Their low-level explanation fits in the then going zeitgeist. It is, however, also possible that occlusion constraints are implemented well behind binocular convergence; that the escape of suppression takes place by feedback to monocular channels.

Interocular grouping

The strongest kind of evidence for a high-level contribution to binocular rivalry came from Kovács, Papathomas, Yang, and Feher (1996) who renewed the debate about the driving force of binocular rivalry by demonstrating that color-similar percepts rival as a whole, even after half-fields are intermingled. It was Diaz-Caneja (1928) who first reported interocular grouping, but not until recently has his demonstration of interocular grouping received the attention it deserved (Alais, O'Shea, Mesana-Alais & Wilson, 2000). In an experiment in which a monochromatic version of Diaz-Caneja's experiment was briefly quantified, Ngo, Miller, Liu, and Pettigrew (2000) showed, like Kovács et al. (1996), that a substantial part of the percepts consisted of interocular grouped percepts.

Objectives

The first objective of this study is to find corroborating psychophysical evidence for the hypothesis that Gestalt formation influences binocular rivalry. That is, whether binocular percepts with the stronger Gestalt will be seen longer and/or more often than percepts with the weaker Gestalt. This is measured by a dichoptically presented stimulus that consists of components that are suited to bring about rivalrous behavior and global components that are suited to form different Gestalts of shape.

In this respect, the stimulus does not differ essentially from most other stimuli that are used in traditional binocular rivalry research. Although the influence of coherence was not always the topic in such research, the dichoptically presented images often comprised both rivaling features as well as coherent features (e.g., dichoptically presented orthogonal gratings). A possible reason why an influence of coherence has not often been mentioned, or even contradicted, is that discerning between rivaling eyes and rivaling percepts was hardly possible, because both corresponded to the same eye and therefore produced an effect in the same direction.

Stimuli that are suitable to investigate the influence of coherent features on binocular rivalry differ from these stimuli by the fact that effects of coherent features cannot coincide with effects of rivalrous features. In general, this is accomplished by intermingling two half-images with coherent features (e.g., Kovács et al., 1996; Diaz-Caneja, 1928). Either coherent features will not show an effect and the rivalrous behavior can, for example, be explained by mutual inhibition of monocular cells, or, coherent features show an effect and the rivalrous behavior can only be explained by also including interocular grouping of coherent features. Different stimulus dimensions were investigated this way. For example, Kovács et al. (1996) intermingled two coherent patterns of color-similarity, and Diaz-Caneja (1928) intermingled two coherent patterns with form-similarity and color-similarity.

With respect to the experiment presented in this paper there is yet another difference. Either the number of obvious coherent patterns in the above-mentioned stimuli remained two after the interminglement of two half-images, or the measurements were done in a two-alternative-forced-choice paradigm. As a result, the stochastic properties of the series of percepts were not investigated. In contrast, the stimuli used in this paper consisted of four distinctive coherent patterns: two monocular shapes and two binocular shapes (see Figure 1). Using a four-alternative-forced-choice paradigm, this enabled us to investigate the second objective: how do binocular rivalry and Gestalt formation interact? It will be shown that Gestalt formation only intervenes in what dominates, not in how long it dominates (without being interrupted). This result could be another explanation why the influence of coherent features has not attracted attention for a long time. By measuring only two alternating percepts with coherent features, the influence of coherent features simply leaves no traces behind, neither in the domain of time, nor in the domain of states.

Stimuli

The stimulus consists of rivalrous components and of components that are suited to form binocular or monocular Gestalts. For example, the stimulus in Figure 1.1BW shows rivalry because the left and right horizontal contrasts are incompatible (that much we know from the classical doctrine). In terms of stimulus strength, the most important determinant of rivalrous behavior are the opposite horizontal contrasts, which are present in all four stimulus conditions in Figure 1. The difference in stimulus strengths of the semi-cross and the semi-diamond is subordinate to this. Additionally, Figure 1.1BW consists of semi-diamonds and semi-crosses. When the stimulus is presented dichoptically, these semi-shapes are suited to form the Gestalts of a complete cross, a complete diamond (between-eye percepts), and of arrows (same-eye percepts). Two or more of these shapes will be observed during an experiment. The question is whether Gestalt formation can influence the rivalrous behavior, or vice versa, and how we can measure that influence.

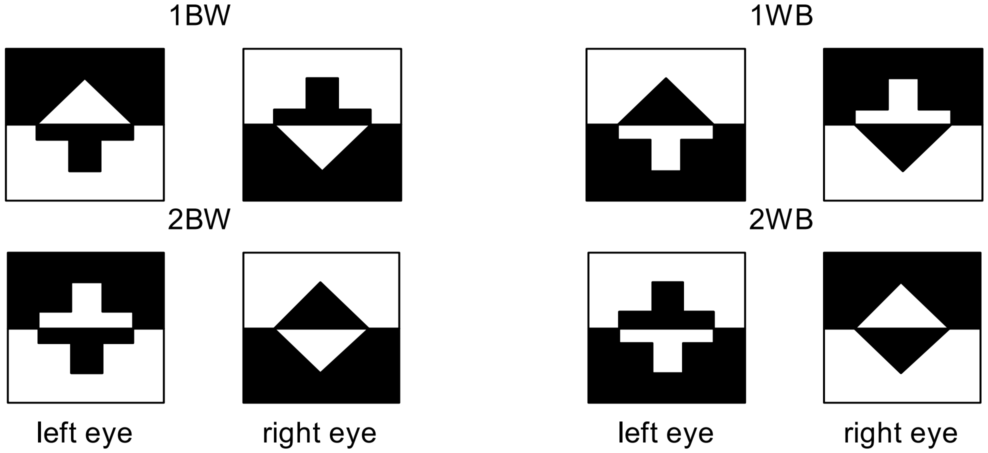

Figure 1. Schematic representation of the stimulus conditions. Condition 1 is formed by the upper two stimuli; Condition 2 is formed by the lower two stimuli.

If Gestalt formation of shape does not influence binocular rivalry, we would mainly expect complete alternations of the left and right half-image of the stimulus in Figure 1.1BW. If the hypothesis is true, that Gestalt formation does influence binocular rivalry, we also expect between-eye percepts (i.e., crosses and diamonds in this case).

An experiment solely based on this stimulus can cause some problems in the interpretation of data. If we indeed would observe between-eye percepts, we cannot simply conclude that the hypothesis should be accepted; and in case of the opposite, if we would mainly observe same-eye percepts, we should not be allowed to reject the hypothesis. The reasoning for this is based on two types of arguments. First, not a single stimulus, not even the disk ring stimulus by Levelt (1968), can guarantee that two half-images show complete alternations; neither when the hypothesis is true, nor when it is false. Hence, observing between-eye percepts does not automatically mean that Gestalt formation influences binocular rivalry. Second, there is a remote chance that the monocular shape-Gestalts (the arrows in Figure 1.1BW or the crosses and diamonds in Figure 1.2.BW) influence the alternation process exclusively. This makes it impossible to reject the hypothesis when only same-eye percepts are observed. To remove the ambiguity we added a second kind of stimulus condition in which we swapped the semi-shapes in the upper part of the stimulus (Figure 1.2BW). Now, the two above-mentioned alternative arguments cannot hold simultaneously for both stimulus conditions and we should conclude that Gestalt formation and binocular rivalry either interact or that they are independent mechanisms.

Up to now we only spoke about the Gestalt of shape, but the stimulus conditions in Figure 1 also contain another potential kind of Gestalt formation that could influence binocular rivalry, namely the Gestalt formation due to color-similarity. If the Gestalt of color-similarity influences binocular rivalry, then we expect that the homogeneous percepts black-black and white-white will dominate the inhomogeneous percepts black-white and white-black. In that case, the between-eye percepts would be favored. Only from the occurrence of a strong dominance of between-eye percepts in both stimulus conditions, we may conclude that the hypothesis can be accepted. To possibly increase evidence for the influence of color-similarity Gestalt, we added two more stimulus conditions (Figures 1.1WB and 1.2WB). These are simply black/white-reversed versions of the previously discussed stimuli. When, for example, the white-white percepts occur more often than the black-black percepts we will have stronger evidence when we perform the experiment with four stimulus conditions instead of two. In the next we remove the additional BW or WB, and simply speak of Conditions 1 and 2, when color reversed alternatives are not of interest.

It is a well-known fact that (aimed) eye movements can change the dynamics of binocular rivalry. Eye movements increase the alternation frequency of the left and right half-image and aimed eye movements can favor a specific half-image. It is however nearly impossible to favor a between-eye percept this way. Hence, when between-eye percepts occur more often than same-eye percepts this cannot be explained by (intentional or unintentional) aimed eye movements, and, mistakenly accepting the hypothesis of Gestalt influence because eye-movements biased the data is hardly possible then.

In broad outlines, one can recognize either one of the four qualitative response patterns in Table 1. This table only discerns same-eye percepts and between-eye percepts. As argued before, we do not expect large differences between stimulus strengths of semi-crosses and semi-diamonds, because the opposite horizontal contrasts that are present in all stimulus conditions dominate stimulus strength.

Nevertheless, suppose that the experimental results corresponds with the lower left panel of Table 1, but that this was mainly caused by long dominance times of crosses only, then such results can either be explained by a strong shape Gestalt of crosses or by a strong stimulus strength of crosses. Consequently, the experiment would not give a definite answer about the influence of Gestalt formation. This is why we will only be conclusive when both same-eye percepts predominate over between-eye percepts or when both same-eye percepts are predominated by between-eye percepts.

Table 1. Possible qualitative results of Conditions 1 and 2 with respect to dominating between-eye percepts and dominating same-eye percepts. The rows present qualitative results of Condition 1 and the columns qualitative results of Condition 2. The table elements describe the preferred Gestalts that correspond to these two observations. If it is indeed the shape-Gestalt and not higher visual processes that influence binocular rivalry then we would rather expect that crosses and diamonds predominate than arrows, because arrows lack the vertical mirror symmetry of crosses and diamonds. However, if the opposite is observed then this does not alter the fact that the hypothesis should be accepted.

Conditions 1	Condition 2	
	Both same-eye percepts predominate over both between-eye percepts	Both between-eye percepts predominate over both same-eye percepts
Both same-eye percepts predominate over both between-eye percepts	no Gestalt	arrows are preferred
Both between-eye percepts predominate over both same-eye percepts	crosses and diamonds are preferred	color-similarity is preferred

EXPERIMENT

Subjects

Eight subjects performed the experiment. Subjects S1-S4 were well practiced in binocular rivalry experiments and were experienced in performing psychophysical tasks. Subjects S5-S8 were not practiced in binocular rivalry experiments. All subjects possessed normal or corrected to normal vision.

Stimuli

The stimuli, which are schematically depicted in Figure 1, were presented on a computer screen. With the help of a mirror system and a septum, the left half-image was projected on the left eye, and the right half-image on the right eye. Both half-images were presented in black-and-white on a gray background as in Figure 2.

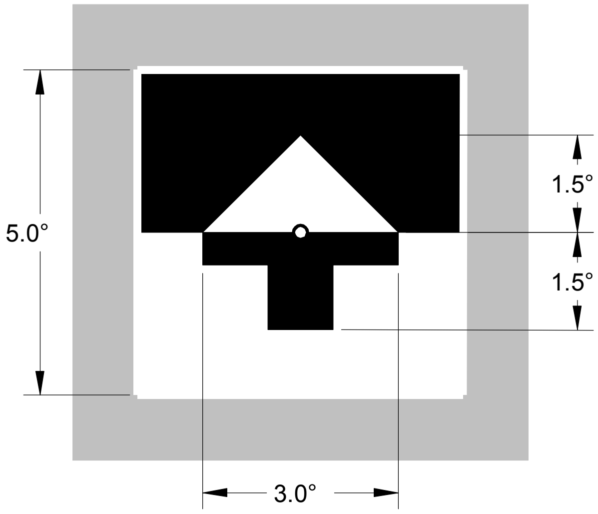

Figure 2. Dimensions of the stimulus. Only the stimulus dimensions of the left half-image of Figure 1.1BW are depicted. The right half-image is just the mirrored copy of this. Copying, inverting, and mirroring parts of this half-image give the other stimuli conditions. A white line on a gray background, which serves as a fusional component, outlines the half-images. A fixation dot is obtained by a white disk with a black outline.

Procedure

There are at least two possible ways of measuring the four states of dominance in a timing experiment. The first way, the wrong way as will be clear soon, is by measuring the four states in two separate two-state tasks. The second way, which we finally applied, is measuring the four states in one experiment. In a pilot experiment we applied both measuring methods, but we soon realized that the first method was not appropriate. We first measured the dominance times of crosses and diamonds and of the two arrows separately. To our surprise, we found that both fractions of occupied time summed to values of the order 1.2. One can conclude that instruction related processes truly biased the rivalrous process itself. However, the data can also be explained by a response bias that is independent on what is binocularly observed. These two explanations cannot be discerned and therefore we chose the method in which all four shapes are timed in a single task.

The four stimuli that are depicted in Figure 1 were presented in random order for periods of two minutes in a total of 20 to 30 sessions (different per subject). Subjects were instructed to register transitions between four shapes, that is, crosses, diamonds and two arrows, by pressing either one of the four buttons on the cursor key pad of a regular computer keyboard. The arrow up and arrow down buttons were the natural choice for the two arrow percepts, and the left and right button were used when a cross or diamond appeared. Furthermore, subjects were instructed to fixate on a small fixation dot that was presented at the exact middle of the cyclopean stimulus. Despite the fact that the task is slightly more difficult than in usual timing experiments with two alternating percepts, after some training all subjects reported that they could easily carry out the task.

Results

Usually one quantity is of major interest in binocular rivalry experiments, that is, the dominance times of the two eyes. As a consequence the order of dominance states is obviously not a quantity of interest, because the alternation pattern is much like {left, right, left, right,…}. In this experiment, we allowed four responses, which adds the order of dominance states as an other quantity of interest because the sequence of dominance states is not obvious anymore. Therefore, we investigated the sequences of dominance states, that is, whether successive dominance intervals are still independent, and whether dominance states (as events) depend on previous dominance states.

Main Results. The main results of accumulated data, that is, the order of successive dominance states is ignored, are depicted in Figures 3 and 4. Figure 3 shows the influence of the stimulus conditions on dominance intervals, and Figure 4 shows the influence of the stimulus conditions on dominance states. The rather large between-subject effects (both regarding mean dominance intervals and counts of dominance states) are concealed by normalizing the data points of the four responses. It is clear that differences of total dominance times are primarily determined by differences in the numbers of visits of dominance states and to a much lesser degree by differences in dominance intervals (the four dominance states are comparable as for duration, which is reflected by the fractions close to .25 in Figure 3). Subjects S1 through S3, and S6 through S8 show similar patterns of results. These subjects show mainly between-eye percepts in Condition 1 and mainly same-eye percepts in Conditions 2. Subjects S4 and S5 deviates substantially from this. In Condition 2 subjects S4 and S5 mainly reported between-eye percepts, while the results of Condition 1 are similar to those of the other subjects.

A marginal note is at place. Because the two between-eye percepts have comparable results in all cases and because the two same-eye percepts have comparable results, we conclude that the found differences are caused by Gestalt formation. (See also the discussion concerning Table 1.) Hence, while subjects S1-S3 and S6-S8 conform to shape, subjects S4 and S5 conform to color similarity. All eight subjects show an independence of black/white-reversals, even subjects S4 and S5, who showed a preference for color-similarity.

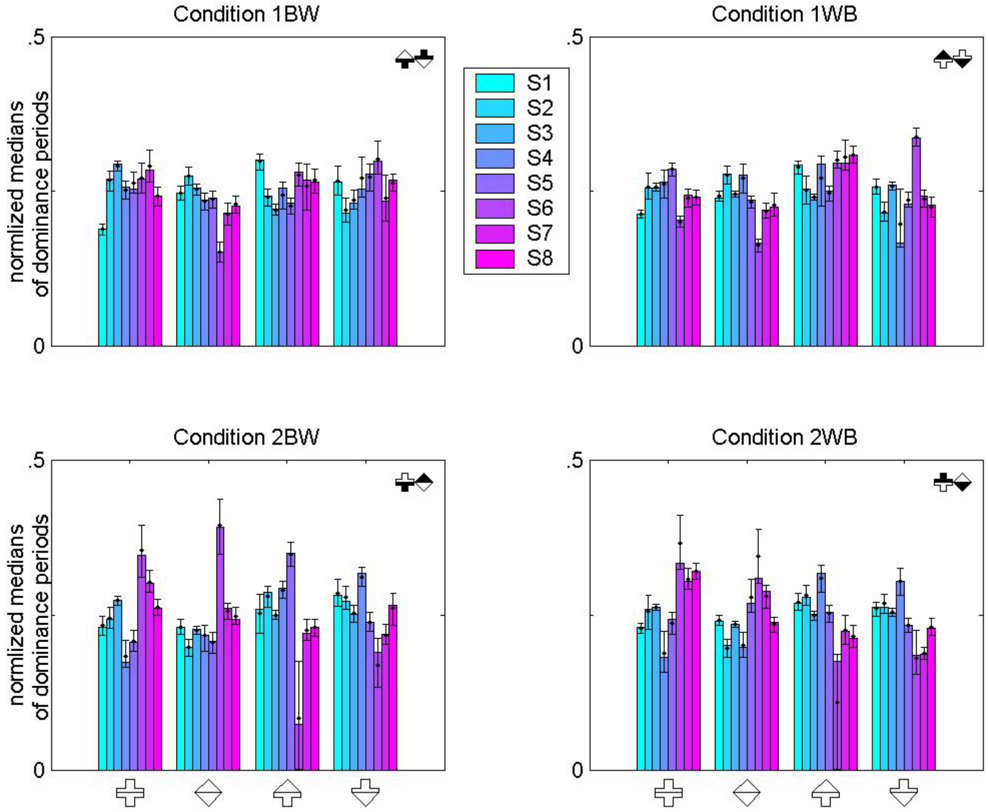

Figure 3. Medians of dominance intervals. Bars represent normalized medians of dominance intervals (medians md {t_resp} divided by sum {md {t_resp}, resp = cross, …, diamond}). 2,3 Results are depicted per condition (the four panels), per subject (S1 to S4), and per response (the four shapes at the bottom). The error bars represent the 68% confidence interval as obtained by a bootstrap procedure. Notice that between-eye percepts are associated with crosses and diamonds in Condition 1 and with arrows in Condition 2.

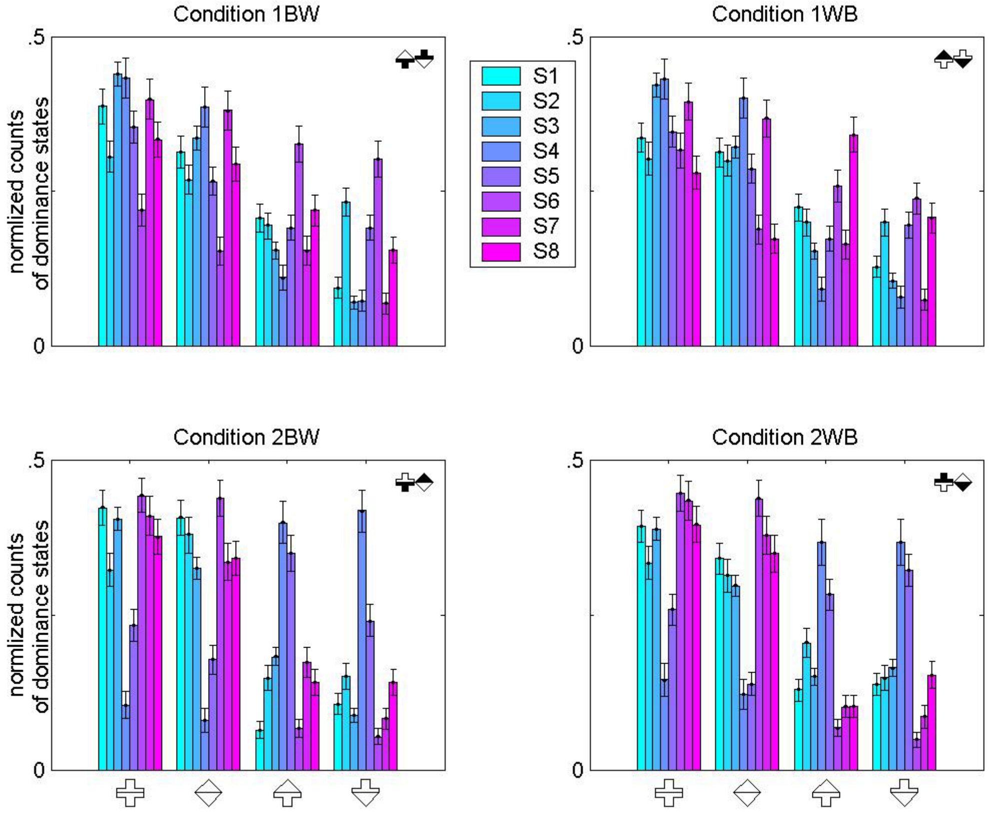

Figure 4. Dominance states. Bars represent normalized counts of dominance states per condition and subject. (For the rest the arrangement of results is the same as in Figure 3).

Successive dominance intervals and states

In the previous part we ignored the order of successive dominance states. Here we examine that order. The questions we ask are: 1) are successive dominance intervals still independent in spite of the influence of Gestalt formation; and, 2) are successive dominance states randomly ordered, or are there preferences for certain successive states. Except, of course, for the fact that no repeats occur in the sequence of dominance states.

Successive dominance intervals

To test independence of dominance intervals we first determined the values of the empirical cumulative probability density function (CDF) for each of the four dominance states (corresponding to the four shapes). By definition, these values are uniformly distributed over U=[0,1]. Independence means that the combined CDF of two successive periods is uniformly distributed over UxU. This is tested by counting the number of occurrences in an equally spaced two-dimensional grid with n^2 cells. If O_{ij} is the observed number in cell i,j and $E_{i,j}$ the expected number for independent intervals then $\text{sum}((O_{ij}-E_{ij})^2/E_{ij})$ is chi-square distributed if intervals are independent.

Table 2 shows the results of the tests of independence of dominance intervals for each subject and stimulus condition separately. Notice that for most individual cases there is no evidence for dependence of successive dominance intervals. Six cases (two of which for subject S4) show a significant dependence on the .05 level, while we expect at most one Type I error. Although these six cases are significant, the effects are minute. Because of this as well as the fact that response bias and, to a lesser degree, erroneous responses probably also play a role in the experiment we conclude that dominance intervals are in general independent.

Table 2. Test of independence of dominance intervals. For each subject and stimulus a chi-square test is performed to test the independence of successive dominance intervals. It is tested whether two CDF-values that correspond to two successive dominance intervals are uniformly spaced over UxU. Comparing counted pairs in a ten-by-ten grid with the expected counts does this. ($df = (n-1)^2 = 81$). See text for more details.

Subject	Condition				
S1	1BW	χ^2 (81, N=	316) =	81,	p = .5
	1WB	χ^2 (81, N=	379) =	77,	p = .6
	2BW	χ^2 (81, N=	306) =	66,	p = .9
	2WB	χ^2 (81, N=	373) =	68,	p = .8
S2	1BW	χ^2 (81, N=	346) =	66,	p = .9
	1WB	χ^2 (81, N=	316) =	77,	p = .6
	2BW	χ^2 (81, N=	293) =	82,	p = .4
	2WB	χ^2 (81, N=	298) =	92,	p = .2
S3	1BW	χ^2 (81, N=	623) =	84,	p = .4
	1WB	χ^2 (81, N=	665) =	89,	p = .3
	2BW	χ^2 (81, N=	691) =	100,	p = .06
	2WB	χ^2 (81, N=	707) =	75,	p = .7
S4	1BW	χ^2 (81, N=	232) =	96,	p = .1
	1WB	χ^2 (81, N=	226) =	118,	p < .05
	2BW	χ^2 (81, N=	200) =	109,	p < .05
	2WB	χ^2 (81, N=	169) =	84,	p = .4
S5	1BW	χ^2 (81, N=	357) =	103,	p = .051
	1WB	χ^2 (81, N=	359) =	95,	p = .1
	2BW	χ^2 (81, N=	270) =	82,	p = .4
	2WB	χ^2 (81, N=	328) =	78,	p = .6
S6	1BW	χ^2 (81, N=	250) =	79,	p = .5
	1WB	χ^2 (81, N=	278) =	82,	p = .4
	2BW	χ^2 (81, N=	296) =	105,	p < .05
	2WB	χ^2 (81, N=	305) =	92,	p = .2
S7	1BW	χ^2 (81, N=	229) =	92,	p = .2
	1WB	χ^2 (81, N=	251) =	94,	p = .15
	2BW	χ^2 (81, N=	249) =	82,	p = .5
	2WB	χ^2 (81, N=	252) =	117,	p < .05
S8	1BW	χ^2 (81, N=	274) =	91,	p = .2
	1WB	χ^2 (81, N=	274) =	75,	p = .7
	2BW	χ^2 (81, N=	285) =	94,	p = .1
	2WB	χ^2 (81, N=	276) =	81,	p = .5

Successive Dominance States

As a bonus of allowing more than two responses in this experiment, we are able to examine the randomness of the sequences of dominance states. First, the (in)dependence of two successive states is examined.

Two successive dominance states are, of course, dependent because repeats of the same state were not allowed in the experiment. If $O_{A,B}$ is the number of occurrences of two successive dominance states A and B (with A,B belong2 {cross, diamond, arrow up, arrow down}), this means that the diagonal of the 4x4 matrix O consists of zeros. However, can the sequence be viewed as a random permutation of dominance states with removed repeats, or is the dependence of the last dominance state stronger? To test this we actually consider a process that generates a random sequence of states, after which repeats are removed (taking care that the remaining frequency distribution of separate states match the observed distribution). This results in a symmetric matrix of expected counts E. If differences between O and E cannot be explained by chance, then the dependence of successive states is not only explained by the dictated task (no repeats), but also by the underlying mechanism that produces the sequence states (binocular rivalry).

If the only dependence of O is that no repeats may occur then $\mathrm{Sum}\{(O_{A,B} - E_{A,B})^2 / E_{A,B}, A,B=\{\text{cross},\ldots,\text{arrow down}\}\}$ is approximately chi-square distributed with $df = (m-1)^2 - m$ and $m=4$ states. In fact, what we are testing is whether a sequence of states has first order Markov properties.

The results of the analysis are given in Table 3. The analysis is done over combined data of black/white-reversed conditions. After separate analyses, we concluded that both have similar properties, but that the numbers of observations were sometimes too small for the chi-square approximation to be valid. From Table 3 it is clear that sequences of dominance states have strong first order Markov properties.

Table 3. First order properties. Chi-square test of first order Markov properties. The table gives the probabilities that χ^2 is larger than the observed χ^2 if the underlying process would be of order zero. See text on how the test is performed.

Subject	Condition	1st order	
S1	1	χ^2 (5, N= 695) = 62.55	p < .001
	2	χ^2 (5, N= 679) = 31.53	p < .001
S2	1	χ^2 (5, N= 662) = 95.32	p < .001
	2	χ^2 (5, N= 591) = 60.98	p < .001
S3	1	χ^2 (5, N= 1,288) = 81.68	p < .001
	2	χ^2 (5, N= 1,398) = 241.49	p < .001
S4	1	χ^2 (5, N= 458) = 43.39	p < .001
	2	χ^2 (5, N= 370) = 87.06	p < .001
S5	1	χ^2 (5, N= 716) = 83.74	p < .001
	2	χ^2 (5, N= 598) = 72.85	p < .001
S6	1	χ^2 (5, N= 528) = 17.33	p < .01
	2	χ^2 (5, N= 601) = 1067.20	p < .001
S7	1	χ^2 (5, N= 480) = 44.46	p < .001
	2	χ^2 (5, N= 501) = 127.00	p < .001
S8	1	χ^2 (5, N= 548) = 131.36	p < .001
	2	χ^2 (5, N= 561) = 177.28	p < .001

Other related properties that are interesting to examine are conditional probabilities (see Figure 5 and Figure 6), for example, the probability that a diamond will be reported at n+1 in the chain of events, given the fact that a cross was reported at n.

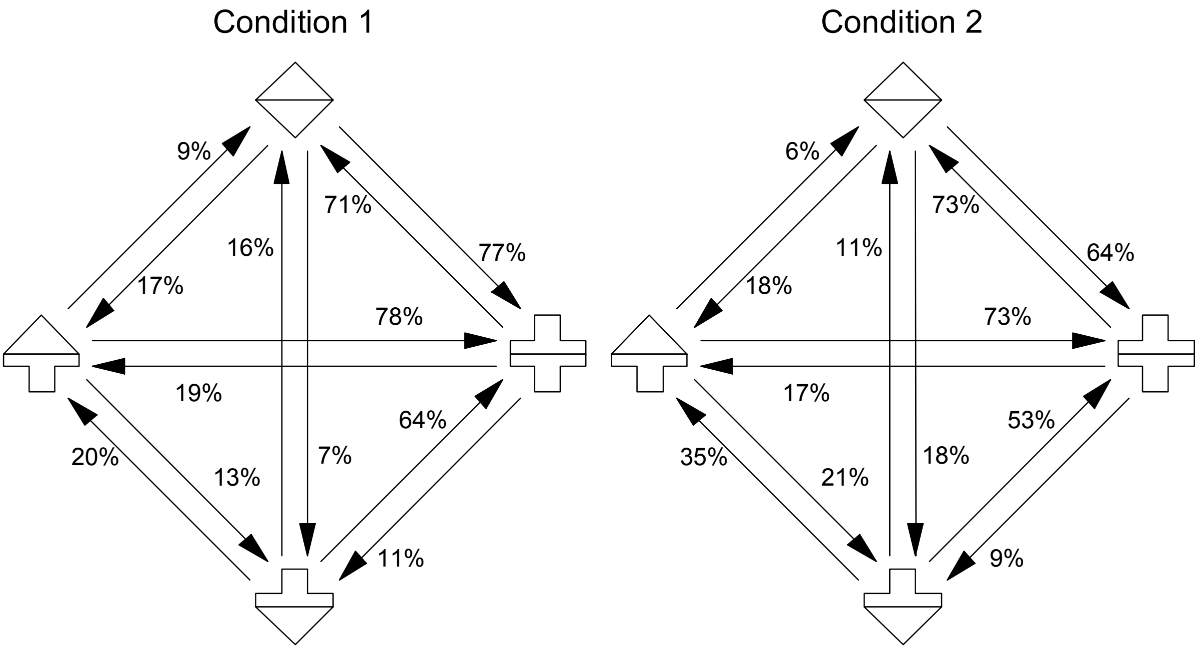

Figure 5. The conditional probabilities for subject S3. The black/white-reversed conditions are again combined.

For example, for subject S3, the fraction of diamonds reported at n+1 when a cross was reported at n is 71% in Condition 1 and 73% in Condition 2 (see Figure 5). Qualitatively, the most evident pattern is that of an alternation of crosses and diamonds that starts with a cross. Sometimes arrows are observed, but there is a relatively large chance that subsequently a cross will be observed. Though for Subject S3 this pattern is most obvious, in some degree the same kind of pattern can be observed for the other subjects in Condition 1, with the exception of S6 who showed a deviating pattern that indicated black-black and white-white transitions. Furthermore, subjects S1-S3 and S6-S8 also show this pattern in Condition 2. However, as can be expected from Figure 4, subjects S4 and S5 show a substantially deviating pattern in Condition 2 as can be seen in the right panel of Figure 6.

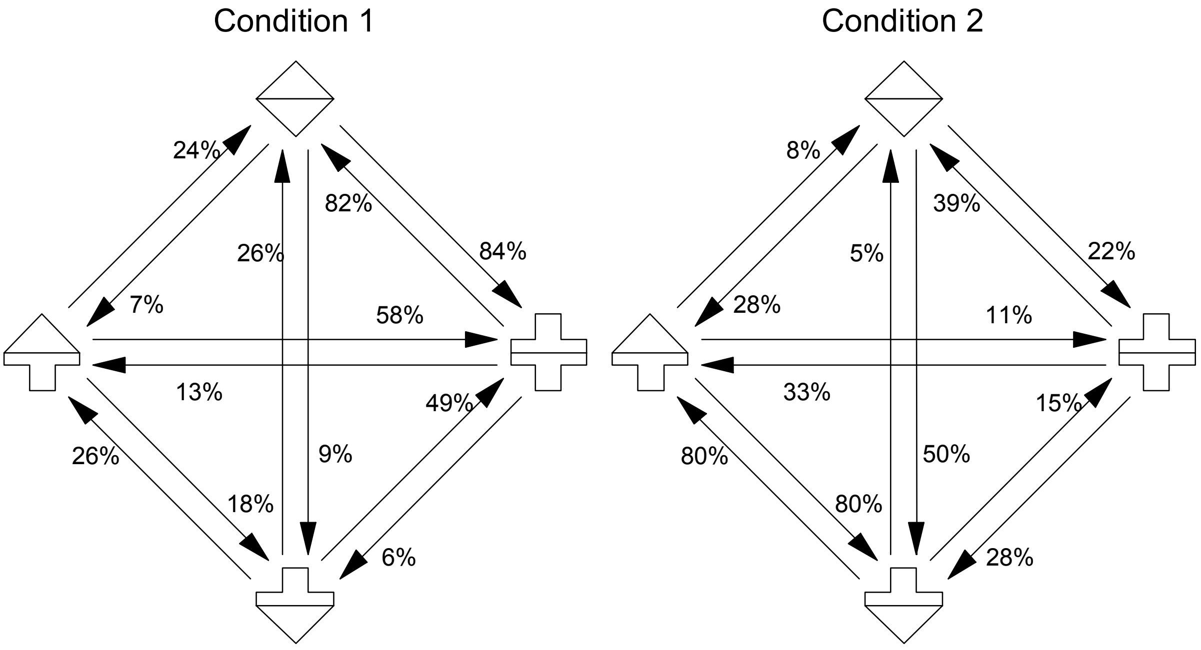

Figure 6. The conditional probabilities for subject S4. The black/white-reversed conditions are again combined.

While subject Subjects S1-S3 and S6-S8 stuck with the crosses and diamonds in both conditions, Subjects S4 and S5 stuck with the black-black and white-white transitions in Condition 2.

DISCUSSION

Corroborating Evidence for Interactions

The experiment supplies corroborating evidence that binocular rivalry is not solely determined by local stimulus properties; Gestalt formation is also of influence. The perceptible influence of Gestalt formation only intervenes in which state dominates, not directly in how long this state dominates. This conclusion is based on strong evidence that successive dominance states are dependent, but little or no evidence that successive dominance intervals are dependent. Six out of the eight subjects show a dependence on shape Gestalt, the remaining two subjects shows a dependence of color-similarity Gestalt. In both cases the strongest Gestalts have the most occurrences (at least, when a criterion of simplicity is used to judge what is strong and what is not). For the subjects who show a dependence of shape Gestalt, crosses and diamonds are reported more often than arrows. This might be explained by the horizontal symmetry in crosses and diamonds that is lacking in arrows. For the other two subjects, who showed a dependence of color-similarity Gestalt, the homogeneous color transitions (the black-black and white-white transitions) were reported more often than the inhomogeneous ones (the black-white and white-black transitions).

There is no indication of a mixed influence of shape Gestalt and color-similarity Gestalt. In that case one would expect a strong effect in Condition 1, because both kinds of Gestalt formation favor between-eye percepts, and a weak effect in Condition 2, because the color-similarity Gestalt favors between-eye percepts and the shape Gestalt favors same-eye-percepts. This means that the differences in Figures 4.1BW and 4.1WB would be more distinctive than in Figures 4.2BW and 4.2WB, and there is no evidence for that.

Successive Dominance Intervals and States

Analyzing the course of dominance states over time we found that dominance states are highly dependent of what happened before. The most redundant pattern of events is that of a sequence that starts with a cross and subsequently alternates between crosses and diamonds. Subject S6 did not show this pattern in Condition 1, but did show this pattern in Condition 2. Subjects S4 and S5 both showed the pattern of alternating crosses and diamonds in Condition 1, but a clear pattern of alternating arrows in Condition 2. In contrast to dominance states, dominance intervals are independent of the history of events. This is true for all eight subjects, all conditions, and all reported dominance states. It seems that the clear influence of Gestalt formation on dominance states is lacking for dominance intervals.

Nature of Interactions

To introduce a speculative model of what has happened during the experiment we first describe the following phenomenon. The idea behind it was inspired by the fact that Gestalt formation seems to set in only then when a choice needs to be made for the next dominance state, and furthermore, that this coincides with the intermediate time between two states of full dominance in which composites are seen.

We observed what happened when composites were simulated in a movie. We simply constructed frames of a movie by slowly varying F in (1- F) x left image + F x right image with half-images of Figure 1. Of course, this does not agree with the real appearance of composites, but it is close enough for the point we want to make. Because of this controlled environment, we are able to lengthen a phase of ‘composites’ to an arbitrary long time and observe what happens for the Gestalt formation. Figure 7 shows a few frames of movies we observed.

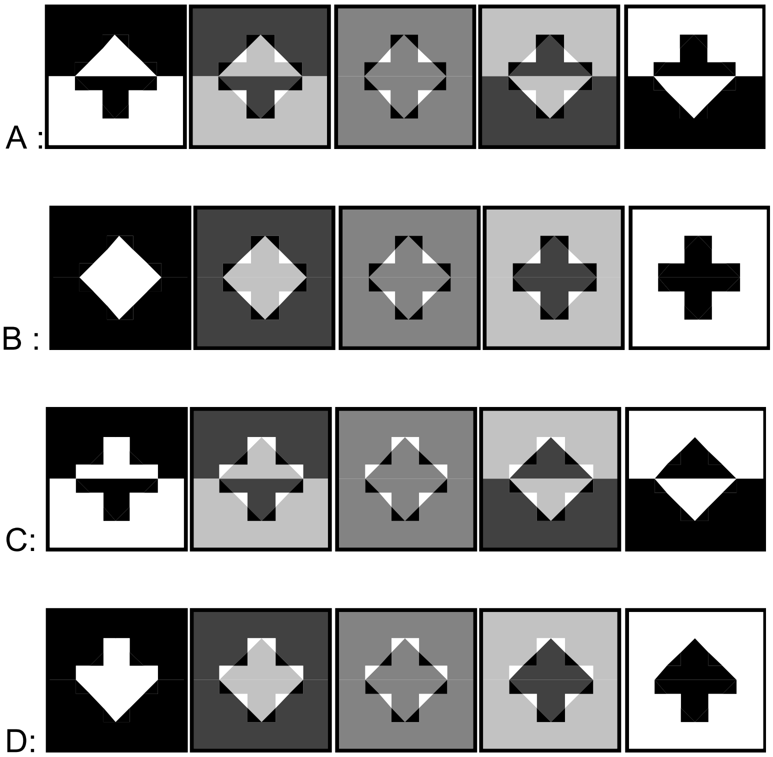

Figure 7. Panel A shows a few frames of a movie that simulates the composites during a transitions between full dominance states in Condition 1BW for same-eye percepts. Similarly, Panel B represents the movie for between-eye percepts in Condition 1BW, and Panels C and D show respectively the movies between same-eye and between-eye percepts in Condition 2BW. Typically, we observed the successive percepts in a cycle of 'composites' that was lengthened to the order of seconds. The frames shown here are (1-F) x left image + F x right image for respectively F = 0, ¼, ½, ¾, and 1 (from left to right). F was gradually changed from zero to one during the movie.

Condition 1

When watching the movie that corresponds to Figure 7.A (same-eye percepts of Condition 1BW) one respectively sees the arrow (‘full dominance’), a cross, a diamond, a cross again, and finally the opposite arrow (‘full dominance’). When the movie is played in reverse (Figure 7.A from right to left) then the pattern of observations is also reversed. When looking at the movie that corresponds to Figure 7.B (between-eye percepts of Condition 1BW), one only sees crosses and diamonds. Of course, these observations describe what mostly happens; sometimes the patterns of observations are different. The same is true for the black/white-reversed Condition 1WB. Most often the perceived pattern starts with a cross. The data, as well as these observations, suggest that a complete reversal of a percept (cross → diamond, or arrow up → arrow down) can be interrupted by an intermediate Gestalt. For example, when an arrow in Condition 1BW starts to switch to the other arrow, the intermediate Gestalt formation of the cross (or the diamond) might interrupt a full alternation. That is, the same-eye percept of an arrow switches to the between-eye percept of a cross. After that, the alternation of between-eye percepts can continue quite undisturbed, because the movie in Figure 7.B hardly showed intermediate arrows. Notice that this agrees with the conditional probabilities shown for Subjects S3 and S4 in Figures 5 and 6.

Condition 2

Figures 7.C and 7.D show some movie frames of same-eye and between-eye alternations of Condition 2BW, respectively. Although most subjects (except S5 and S6) still mostly saw crosses and diamond, the arrows played a more prominent role than in Condition 1. In contrast, Subjects S4 and S5 primarily saw arrows. Analogously to Figures 7.A and 7.B this is in accordance with the first order Markov properties of the data of Condition 2.

If this is indeed the way in which binocular rivalry and Gestalt formation interact, this would mean that binocular rivalry supplies input to Gestalt formation after binocular convergence (see Figure 8). During full dominance, only one Gestalt is possible because the other possible Gestalts are rendered invisible by rivalrous suppression. Only on the threshold between full dominance states, when composites cause ambiguous figures, are other Gestalts also possible. During this period of indecision Gestalt formation leaves its mark on binocular rivalry by imposing either one of the possible Gestalts. Because dominance intervals seemed to be insensitive to the particular dominance state there is no gradation of this feedback signal. That is, the strength of the Gestalt influence on binocular rivalry is the same for all Gestalts.

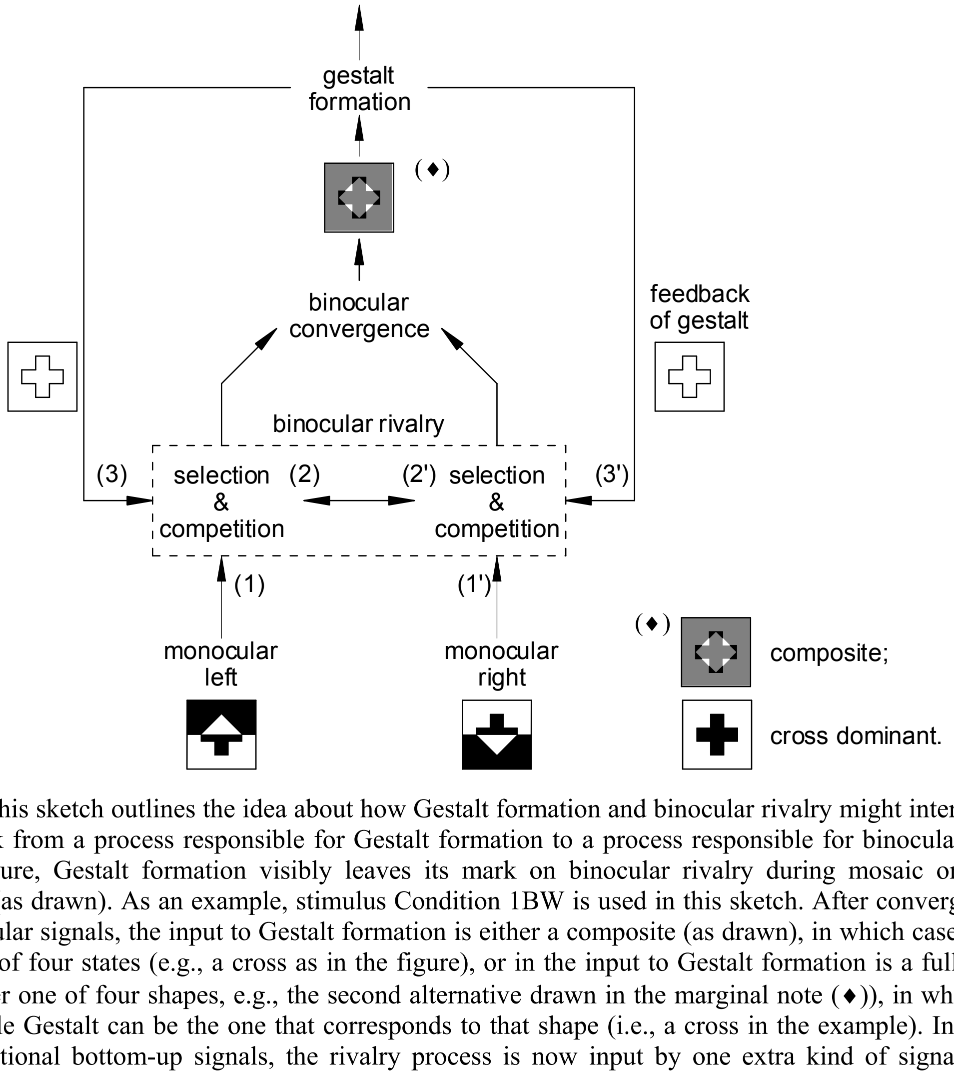

Figure 8. This sketch outlines the idea about how Gestalt formation and binocular rivalry might interact, namely by feedback from a process responsible for Gestalt formation to a process responsible for binocular rivalry. In this conjecture, Gestalt formation visibly leaves its mark on binocular rivalry during mosaic or composite perception (as drawn). As an example, stimulus Condition 1BW is used in this sketch. After convergence of the two monocular signals, the input to Gestalt formation is either a composite (as drawn), in which case the Gestalt can be one of four states (e.g., a cross as in the figure), or in the input to Gestalt formation is a fully dominant shape (either one of four shapes, e.g., the second alternative drawn in the marginal note (♦)), in which case the only possible Gestalt can be the one that corresponds to that shape (i.e., a cross in the example). Instead of the two conventional bottom-up signals, the rivalry process is now input by one extra kind of signal, namely a Gestalt signal. The rivalrous process is now a competition/selection of three kinds of forces; both monocular channels enter a competition/selection of their own inputs (labeled by 1 and 1') with contralateral signals (2 and 2') and Gestalt feedback (3 and 3'). The processes that take place within the dotted binocular rivalry rectangle are the most important part of the conjecture, but also the most unclear. As a result, there are too many possible escapes to explain other apparent high-level interactions with binocular rivalry.

Figure 8 shows that there are three kinds of signals that compete; two from both eyes and one from Gestalt formation. It is highly unclear how this works. A problem is that the dominance intervals seem to be unaffected by the Gestalt. One way to understand this is that the rivalry process is highly vulnerable for other signals than monocular signals when it finds itself in a state of indecision (i.e., in a state of composites), while the conventional rivalry process mainly takes over in case of full dominance and suppression.

Our data show that transitions of percepts simultaneously take place over the whole visual field, that is, between-eye percepts mainly switch to other between-eye percepts and same-eye percepts mainly switch to other same-eye percepts, which is an indication that interocular competition takes place.

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