Pre-exposure to a stimulus can modulate initial perceptual dominance experienced in binocular rivalry with brief test stimuli (onset rivalry). This study investigated this modulating effect using both color and pattern stimuli. We confirmed separate contributions of eye- and feature-based suppressions and showed that their relative strength varied with temporal parameters. Eye-based suppression was stronger with a short test duration (10 ms) and shorter ISIs between the preceding and test stimuli. On the other hand, feature-based suppression grew with ISI and was more pronounced with a longer test duration (200 ms). We also investigated the nature of the modulating effect associated with feature-based suppression using chromatic gratings of high luminance contrast. Results revealed that different features of the preceding stimulus (i.e., color and orientation) exerted nearly independent effects on onset rivalry. However, different features shared their fate in competitive interactions for perceptual dominance; when one feature became dominant, the other also dominated. These findings suggest that competitive interactions for perceptual dominance and the modulation of these interactions are mediated at least partially by different mechanisms. Overall, the present findings are consistent with a theoretical view that initial dominance is established through competitive interactions at multiple levels of processing.

Keywords: binocular rivalry, flash suppression, onset rivalry, adaptation

had features that differed from either rivalrous stimulus. This indicates that the observed suppression depended on the eye to which the half-image was presented during rivalry (eye of presentation) and not on the particular stimulus features; this is termed eye-based suppression. However, subsequent studies using colored as well as patterned stimuli showed that a monocular preceding stimulus could suppress the half-image of rivalrous stimuli that contained the same features as the preceding stimulus regardless of the eye of presentation (Ikeda & Morotomi, 2000, 2002). This indicated feature-based suppression. Feature-based suppression emerged with longer test durations (e.g., 200 ms), although Wolfe (1984) mostly used much shorter duration (10 ms) and showed that the suppression simply decreased in magnitude with longer test duration when the test duration was varied. Ikeda and Morotomi (2000) also introduced a binocular condition in which a preceding stimulus was presented binocularly and found feature-based suppression. Recently, Brascamp, Knapen, Kanai, van Ee, and van den Berg (2007) demonstrated flash facilitation as well as suppression in this paradigm. Overall, previous findings suggest that pre-exposure to a stimulus can bias the resolution of subsequent rivalry in a systematic manner depending on various stimulus parameters.

The flash suppression paradigm can offer a useful method for probing visual mechanisms underlying rivalry resolution during the initial phase of binocular rivalry (“onset rivalry”; see also Brascamp et al., 2007; Carter & Cavanagh, 2007). This paradigm would be particularly important in view of recent accumulating findings suggesting that onset rivalry exhibits different properties from rivalry during sustained viewing (Carter & Cavanagh, 2007; Chong & Blake, 2006; Kamphuisen, van Wezel, & van Ee, 2007; Sheth & Pham, 2008; Song & Yao, 2009).

When using this paradigm to investigate visual mechanisms underlying onset rivalry, it is important to distinguish two different procedures that have been included in the name of flash suppression. In one procedure, a monocular preceding stimulus and the rivalrous dichoptic stimuli are separated by an interstimulus interval (ISI), while in another procedure rivalrous stimuli were presented immediately after the preceding stimulus. Both procedures were used in Wolfe (1984). However, the procedure without an ISI has been used in the majority of studies (e.g., Kreiman, Fried, & Koch, 2005; Leopold, Maier, Wilke, & Logothetis, 2005; Ooi & Loop, 1994), because it offers a very effective way to control the percept in a reliable manner. Nevertheless, the latter procedure may not be suitable for investigating onset rivalry. This is because what actually occurs in this procedure is that a novel stimulus is flashed to the other eye during monocular stimulation. The sudden onset of the novel stimulus produces a large transient signal in only one eye, which can immediately induce a dominance switch that favors the eye of presentation (Blake, Westendorf, & Fox, 1990; Walker & Powell, 1979). Consequently, observers see only the flashed stimulus. On this account, even when a preceding stimulus is presented binocularly, a large transient change occurring in only one eye may bias the dominance of rivalrous stimuli in an eye-based manner. Ikeda and Morotomi (2000, 2002) did not interleave an ISI between the preceding and rivalrous test stimuli in most of their experiments; thus, it is not clear to what degree their findings concerned about a resolution of onset rivalry.

The present study only deals with the procedure in which the preceding and rivalrous test stimuli are separated by an ISI. With this procedure, we can investigate how a preceding stimulus modulates which of two rivalrous stimuli will gain perceptual dominance first when two test stimuli are switched on simultaneously (Brascamp et al., 2007). For purposes of differentiation, we refer to this procedure as the “initial dominance modulation” (IDM) paradigm. The name “flash suppression” is much more suitable to a procedure that does not include an ISI.

The objectives of the present study were three-fold. The first objective was to investigate the nature of the modulating effects of the preceding stimulus in the IDM paradigm. Specifically, we investigated whether the type of suppression changes with manipulations of temporal parameters, such as the test duration and ISI, and determined stimulus conditions that could favor, respectively, eye- and feature-based suppression. The second objective was to explore possible differences between visual features in competitive interactions during onset rivalry. Previous studies have used stimuli differing in either color or pattern, but they have not thoroughly examined competitive interactions involving such stimulus features in comparable conditions. Thus, in Experiment 1, we compared the modulating effects found with color and pattern stimuli using the same stimulus sequences in the IDM paradigm.

A third objective was to extend the investigation of differences between visual features, with the aim of exploring how color and pattern are integrated during onset rivalry using chromatic gratings. As will be shown, feature-based suppression can be reliably observed in certain stimulus conditions in Experiment 1. We took advantage of this finding and investigated integration of color and pattern information in these conditions in Experiment 2. As previous studies had already demonstrated misbinding of color and orientation with rivalrous chromatic gratings (e.g., Holmes, Hancock, & Andrews, 2006; Hong & Shevell, 2006), the present study specifically investigated the integration of color and orientation in the modulating effect of the preceding stimulus on feature-based competition in the IDM paradigm.

**Experiment 1**

Experiment 1 investigated the nature of the modulating effects of a preceding stimulus using both color and
pattern stimuli in the initial dominance modulation (IDM) paradigm.

**Methods**

**Observers**

Four observers participated in Experiment 1. One was the first author of this article; others were naive regarding the purpose of the experiment. All observers had normal or corrected-to-normal visual acuity, good stereopsis, and normal color vision as assessed with Ishihara pseudo-isochromatic plates. All gave informed consent after thorough explanation of the procedures.

**Apparatus**

Figure 1 illustrates a haploscope used in this study, which consisted of three 17-inch color monitors. The images on the left and right monitors (M_{L} and M_{R}; EIZO, Flex Scan T566) were superimposed over that on the front monitor (M_{F}; Radius, PressView17SR), respectively, at the two beam splitters (BS) just in front of each of the observer’s eyes. The alignment was carried out by rotating movable bases on which M_{L} and M_{R} were placed and then by superimposing fixation patterns presented on M_{L} and M_{R} upon the same pattern on M_{F}, respectively. All monitors were placed at an optical distance of 57 cm from the eyes. The distance between the beam splitters was also adjusted to fit interpupillary distance for each observer. The observer’s head was stabilized by a chin and forehead rest. The adjustment of the equipment was carried out for each observer before each daily session.

The stimulus for the left and right eyes was presented on M_{L} and M_{R}, respectively. The M_{L} and M_{R} were controlled with two VSG 2/5 graphic cards with 15-bit color resolution (Cambridge Research Systems). The two monitors had a pixel resolution of 1024 × 768 and a frame rate of 100 Hz. Their refresh timing was synchronized using built-in functionality of VSG cards. Spectroradiometric calibration was performed on three phosphors of the two monitors with a Minolta CS-1000 spectroradiometer and an LS-100 luminance meter. M_{F} was controlled with a Radius board and had a pixel resolution of 1024 × 768 and a frame rate of 75 Hz. Its luminance was calibrated with the LS-100 luminance meter. The Psychophysics Toolbox extensions for Matlab were used in the phosphor calibrations and colorimetric calculations (Brainard, 1997; Pelli, 1997).

**Stimuli**

Both preceding and rivalrous test stimuli were 2° circular fields located at the center of a dark gray background field (x = 0.313, y = 0.329). The background subtended 10° × 10° and its luminance was 0.1 cd/m². The low-luminance background was chosen to strengthen suppressive effects (Brascamp et al., 2007).

In Experiment 1a (color experiment), test stimuli were composed of a red (x = 0.378, y = 0.298) and a green (x = 0.232, y = 0.368) disk, and their luminance was 4 cd/m². The color was chosen along T(L–M) directions in DKL color space (Derrington, Krauskopf, & Lennie, 1984). The color contrast was set to the highest contrast available for one color and the same value was also used for the other color. The preceding stimulus was either the same color disk as one of the test stimuli or a white disk (x = 0.313, y = 0.329) with a luminance of 4 cd/m², depending on preceding stimulus conditions.

In Experiment 1b (pattern experiment), test stimuli were composed of 2-cpd square-wave gratings oriented 45° clockwise (CW) or 45° counterclockwise (CCW) from vertical. The mean luminance and the Michelson contrast of the gratings were 4 cd/m² and 0.60, respectively. The preceding stimulus was either the same grating as one of the test stimuli or a vertical grating, which differed only in orientation from the test stimuli.

The fixation pattern presented on all three monitors comprised four white crosses. Each cross subtended 1.5° × 1.5° and was located at 2.7° away from the center of the background field in the left, right, upper, and lower directions. The fixation pattern was always presented during the experiment and observers were asked to look at the center of the pattern.

**Procedure and conditions**

At the beginning of each daily session, observers dark-adapted for at least 5 min and then pre-adapted to the dark gray background field for 2 min. On each trial within a session, a preceding stimulus was presented for 1000 ms to either one or both eyes, depending on preceding stimulus conditions. There was always an ISI of 20, 50, or 200 ms, which separated the offset of a preceding stimulus from the onset of a pair of test stimuli; the ISI corresponded to a blank field. Then, a test stimulus pair
was dichoptically presented, with one stimulus projected, respectively, to each of the two eyes for 10 or 200 ms. The stimulus sequence was the same for Experiments 1a and 1b. The temporal parameters were selected based on both the previous findings (Brascamp et al., 2007; Ikeda & Morotomi, 2000, 2002; Wolfe, 1984) and results from preliminary experiments. The 1000-ms preceding duration was used to obtain well-developed modulating effects but not to induce strong chromatic and pattern adaptations. Relatively short test durations were used to prevent observers from perceiving a switch in dominant percept during the test period.

For both Experiments 1a and 1b, four preceding stimulus conditions and one control condition were designed to investigate eye- and feature-based suppressive effects. The four conditions were ipsilateral, contralateral, different-feature, and binocular conditions. These are illustrated schematically in Figures 2 and 3. In the ipsilateral condition, the preceding stimulus was the same as one of the test stimuli and presented to the same eye as the test stimulus, whereas in the contralateral condition, the preceding stimulus was presented to one eye on the opposite side of the test stimulus. In the different-feature condition, a preceding stimulus, unlike either test

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**Figure 2.** Results of dominance rating with color stimuli (Experiment 1a). The top row shows stimuli and results in the ipsilateral and contralateral conditions, and the bottom row shows those in the different-feature and binocular conditions. (a, d) Illustration of stimulus sequences (and corresponding data symbols) used in the measurement. It should be noted that this is only a simplified version, i.e., during the actual measurements, the eye receiving each test stimulus was counterbalanced and an ISI was interleaved between the preceding and test stimuli. (b, c) Averaged (over observers) ratings in the ipsilateral and contralateral conditions as a function of ISI when the test duration was (b) 10 ms and (c) 200 ms, respectively. A rating value of −3 or +3 on the ordinate, respectively, denotes that a green or red test stimulus was exclusively perceived, as illustrated on the rightmost vertical axis. The dashed line in each graph shows the baseline rating in the control condition. Error bars denote the 95% confidence intervals for the mean. (e, f) Averaged ratings in the different-feature and binocular conditions as a function of ISI when the test duration was (e) 10 ms and (f) 200 ms, respectively. In (e), the leftmost data point of red circles is not shown, because observers reported that the test stimulus could not be reliably seen in this condition. Other aspects are the same as those in (b) and (c), respectively.
stimulus was presented to one eye. A white disk was used as the preceding stimulus in Experiment 1a, while a vertical grating was used in Experiment 1b. This condition allowed us to examine an eye-based effect because the monocular preceding stimulus did not correspond with either test stimulus. In the binocular condition, the preceding stimulus was the same as one of the test stimuli and presented binocularly. This condition allowed us to examine a feature-based effect because the binocular preceding stimulus did not specify either eye. Finally, in the control condition, only the test stimulus was presented using the same stimulus durations as in other stimulus conditions (i.e., a blank interval was presented instead of a preceding stimulus).

The observer’s task was to provide a dominance rating of the test stimuli. They had to rate how dominant a test stimulus was perceived using a 7-point rating scale. A rating value of −3 or +3 on the scale denoted that one stimulus was exclusively perceived. Rating scores for color stimuli were arbitrarily set to −3 for green and to +3 for red. For pattern stimuli, −3 was associated with CW and +3 with CCW. A rating value of 0 denoted that the two half-images contributed equally to the appearance of the test stimulus (i.e., fused or piecemeal perception). A baseline rating was defined as the rated value for the test stimulus in the control condition.

Experiments 1a and 1b were conducted in different sessions. The four preceding stimulus conditions along with the control condition were randomly interleaved within each session. Within a session, the duration of the test stimulus was fixed at either 10 or 200 ms, but the ISI varied randomly over trials. The eye of presentation for the test stimulus was switched in a counterbalanced manner to control ocular biases in all stimulus conditions, and the results were pooled over the different eye-of-presentation conditions. Each session was repeated twice on different days and each stimulus condition was tested 8 times in total for each observer.

**Single-flash experiment**

To differentiate the effects of the preceding stimulus specific to rivalrous stimuli from those observable with
monocular flashes as in forward masking effects, an additional single-flash experiment was conducted (see also Wolfe, 1984). In this experiment, following the preceding stimulus, only a half-image of rivalrous stimuli was presented as a test stimulus to the eye contralateral or ipsilateral to the preceding stimulus. The observer was asked to rate the visibility of the test stimulus with a 4-point scale. A rating value of 3 denoted that the test stimulus was seen as clearly as when it was presented alone, and a value of zero meant that the test stimulus could not be seen. Intermediate visibility was rated with an intermediate value. Three observers who had also participated in Experiments 1a and 1b participated in this experiment. Other aspects of the additional experiment were similar to those in Experiments 1a and 1b.

Results

Figures 2 and 3 show the results with color (Experiment 1a) and pattern stimuli (Experiment 1b), respectively, averaged across different observers. In the results of dominance rating, the dashed line shows that the baseline rating of the control condition was close to zero, which means that observers usually reported rivalrous percepts (or fused percepts as well for the shorter test stimulus) when the test stimulus was presented alone. When a preceding stimulus was presented, suppressive effects were found, biasing perceptual dominance of the test stimulus. The nature of the suppression varied with the preceding stimulus condition and depended on the duration of the test stimulus in both color and pattern experiments.

Results of the color experiment (Experiment 1a)

In Experiment 1a, the results in the ipsilateral and contralateral conditions showed that, when the test duration was 10 ms (Figure 2b), observers rated that the contralateral test stimulus was perceived to be dominant, regardless of the color of the preceding stimulus. For example, when either a green or red preceding stimulus was presented to the left eye (green triangles or red squares), the rating values were positive, which indicates that the test stimulus presented to the right eye (i.e., red; see also Figure 2a) became dominant. Alternatively, when the preceding stimulus was presented to the right eye (green squares or red triangles), the dominant stimulus was the one presented to the left eye (i.e., green). Therefore, this effect can be classified as eye-based. When the test duration was 200 ms (Figure 2c), the observer’s rating indicated that the dominant stimulus was the one with a different color from the preceding stimulus. When the preceding stimulus was green (green triangles and green squares), the rating values were positive, which means that the red stimulus was dominant in both ipsilateral and contralateral conditions. Alternatively, when the preceding stimulus was red (red triangles and red squares), the green stimulus became dominant. Thus, the effect can be described as feature-based. The magnitudes of both eye- and feature-based effects were larger when the ISI was short, as shown by the results that the confidence intervals at shorter ISIs did not overlap the rating value in the control condition (dashed line).

Eye- and feature-based suppressive effects were also found in the different-feature and binocular conditions (Figures 2e and 2f). In the different-feature condition (inverted triangles and diamonds), observers rated that the test stimulus contralateral to the preceding stimulus was dominant. Thus, the results illustrate an eye-based suppressive effect. This effect was strong when the test duration was short (Figure 2e). By contrast, in the binocular condition (green and red circles), observers reported the test stimulus as having a different feature from the preceding stimulus. The latter illustrates a feature-based suppressive effect.

Results of the pattern experiment (Experiment 1b)

Similar results were found with pattern stimuli as shown in Figure 3. When the test duration was 10 ms, strong eye-based suppressive effects were observed in the ipsilateral and contralateral conditions (Figure 3b) as well as in the different-feature condition (Figure 3e). The observer’s rating indicated that the contralateral test stimulus became dominant, regardless of the orientation of the preceding stimulus. By contrast, feature-based suppressive effects were stronger when the test duration was 200 ms in the ipsilateral and contralateral conditions (Figure 3c) as well as in the binocular condition (Figures 3e and 3f).

Magnitude of eye- and feature-based effects

To assess the temporal properties of eye- and feature-based suppressive effects, the magnitude of each effect was estimated with two methods: one using the results in the ipsilateral and contralateral conditions and the other using those in the different-feature and binocular conditions. The first method utilizes the fact that in the ipsilateral condition eye- and feature-based effects phenomenally suppress the same half-image of rivalrous test stimuli, whereas they suppress a different one in the contralateral condition. In other words, eye- and feature-based suppressive effects are in the same direction in the ipsilateral condition but in the opposite direction in the contralateral condition. Thus, for example, for the results with the shorter test duration, adding the rating values in the ipsilateral condition (e.g., green triangles in Figures 2b and 3b) to those in the contralateral condition (green squares in the same figures) and then dividing by 2 could cancel out the eye-based effect and provide a rough
estimate for the magnitude of the feature-based effect. Using a similar rationale, subtracting the rating values in the contralateral condition from those in the ipsilateral condition and then dividing by 2 could provide an estimate for the magnitude of the eye-based effect. A similar analysis could be applied for the results with the longer test duration (Figures 2c and 3c). Results of these analyses were shown with circle symbols in Figure 4. The second method to estimate the magnitude of each suppressive effect simply averages the absolute values of the ratings obtained with different preceding features in the different-feature or binocular condition (Figures 2e, 2f, 3e, and 3f). Results of these analyses were shown with square symbols in Figure 4. We conducted a two-way repeated measures analysis of variance (ANOVA) with test duration (10 and 200 ms) and ISI as the within-subject variables separately on the results derived with different methods for color and pattern stimuli. One result was

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**Figure 4.** Magnitude of eye- and feature-based suppressive effects as a function of ISI. The top row shows the magnitudes of suppressive effects derived from the results with color stimuli (Experiment 1a), and the bottom row shows those derived with pattern stimuli (Experiment 1b). The magnitude of each suppressive effect was assessed with two different methods using the rating values shown in Figures 2 and 3. The first method used the rating values obtained in the ipsilateral and contralateral conditions. An estimate for the magnitude of the eye-based effect ($C$) was derived by subtracting the rating values in the contralateral condition (e.g., $\triangle$ for the green preceding stimulus in Figure 2) from those in the ipsilateral condition (in the same figure), dividing by 2, and then averaging the values obtained with different preceding stimuli. Thus, $C = [(\bigtriangleup - \bigtriangleup)/2 + (\bigtriangleup - \bigtriangleup)/2]/2$. Similarly, an estimate for the magnitude of the feature-based effect ($\bigcirc$) was calculated with $\bigcirc = [(\bigtriangleup + \bigtriangleup)/2 + (\bigtriangleup + \bigtriangleup)/2]/2$. The second method for assessing the magnitude of the suppressive effect used the rating values in the different-feature and binocular conditions. An estimate for the magnitude of the eye-based effect ($\square$) was derived by averaging the absolute values of the ratings obtained with different preceding stimuli in the different-feature condition, i.e., $\square = (|\bigtriangleup| + |\bigtriangleup|)/2$. Similarly, an estimate for the magnitude of the feature-based effect ($\bigtriangledown$) was calculated with $\bigtriangledown = (|\bigtriangleup| + |\bigtriangleup|)/2$. Error bars denote the 95% confidence intervals for the mean across different observers. In (a), the leftmost data point of purple squares is not shown (see Figure 2e).
excluded from the analysis because of missing data (the estimates of the feature-based effect for color stimuli based on the results in the binocular condition, i.e., the ones shown with purple squares in Figures 4a and 4b).

In general, the results with two different methods were consistent with each other and the magnitudes of each effect found with color and pattern stimuli changed in a similar manner with temporal parameters of the stimulus. The magnitude of the eye-based effect (blue symbols) was larger with the shorter test stimulus than with the longer stimulus (Figures 4a and 4c; the results of the ANOVA showed that the main effects of test duration were significant for color ($F(1, 3) = 113.3$, $ps < 0.01$) and for pattern stimuli ($F(1, 3) = 21.3$, $ps < 0.05$)). Moreover, the magnitude of the eye-based effect was largest when ISI was short (in post-hoc analysis with significant interactions between test duration and ISI ($F(2, 6) > 8.34$, $ps < 0.05$), the simple main effects of ISI were significant for the shorter test stimulus ($F(2, 12) > 42.8$, $ps < 0.01$) and multiple comparisons with Ryan’s procedure ($a = 0.05$) indicated significantly larger effects at short ISIs). The eye-based effect was small when the test duration was 200 ms (Figures 4b and 4d), and the effect of ISI was not statistically significant for color stimuli (the simple main effect of ISI; $F(2, 12) < 1.2$) or marginally significant for pattern stimuli ($F(2, 12) > 3.1$, $ps < 0.10$). The absolute magnitude of the eye-based effect appears slightly different with color and pattern stimuli, which reflected larger differences in the rating values with pattern stimuli between the ipsilateral and contralateral conditions (see Figure 3).

By contrast, the magnitude of the feature-based effect (solid purple symbols) for the test duration of 10 ms grew gradually as ISI increased (Figures 4a and 4c; the results of the ANOVA showed significant interactions between test duration and ISI ($F(2, 6) > 11.0$, $ps < 0.01$). Post-hoc analysis showed significant simple main effects of ISI with the shorter test stimulus ($F(2, 12) > 8.41$, $ps < 0.01$) and multiple comparisons with Ryan’s procedure ($a = 0.05$) indicated larger effects at longer ISIs). When the test duration was longer (Figures 4b and 4d), the magnitude was largest shortly after the preceding stimulus and decreased slightly with the ISI (for color stimuli, the simple main effect of ISI for the longer test duration was significant ($F(2, 12) = 6.53$, $p < 0.05$), and for pattern stimuli, the effect was significant for one type of estimate (purple circles; $F(2, 12) = 8.87$, $p < 0.01$) but not for the other (purple squares; $F(2, 12) = 1.54$, n.s.).

**Single-flash experiment**

The modulating effect of a preceding stimulus on monocular test stimuli was investigated in a single-flash experiment. The results with the test duration of 10 ms were shown in Figure 5. We conducted a three-way ANOVA with eye of presentation (ipsilateral and contralateral), preceding feature (same, opposite (or orthogonal), and different), and ISI as the within-subject variables on the results with color and pattern stimuli. The results indicated that all of the main effects and interactions were significant ($ps < 0.05$) for both color and pattern stimuli. As very little effect of the preceding stimulus was found in the contralateral condition, a significant effect generally indicates the visibility reduction in the ipsilateral condition.

The main points of the results can be summarized as follows: First, a preceding stimulus reduced the visibility of the ipsilateral stimulus (Figures 5b and 5f) but not of the contralateral stimulus (Figures 5d and 5h; the main effect of eye of presentation was significant; $F(1, 2) = 33.94$, $p < 0.05$ for color stimuli and $F(1, 2) = 21.12$, $p < 0.05$ for pattern stimuli). Second, the visibility reduction was selective to the stimulus feature as well as the eye of presentation (the interaction was significant; $F(2, 4) = 19.92$, $p < 0.05$ for color stimuli and $F(2, 4) = 64.75$, $p < 0.01$ for pattern stimuli). Post-hoc analysis for color stimuli showed that the visibility reduction was found in the ipsilateral condition regardless of the preceding color (Figure 5b; the simple main effects of eye of presentation were significant; $F(1, 6) > 9.07$, $ps < 0.05$), but the magnitude of reduction was the largest with the same preceding color and the smallest with the different preceding color (Ryan’s procedure, $a = 0.05$, $MSE = 0.06$). Post-hoc analysis for pattern stimuli showed that the visibility reduction was found only with the same preceding orientation in the ipsilateral condition (Figure 5f; the simple main effect of eye of presentation was significant only with the same preceding orientation; $F(1, 6) = 104.14$, $p < 0.01$). Additionally, the visibility reduction for single flashes appears to occur over a narrower time window; the effect completely disappeared when the ISI was 200 ms.

For completeness, we also conducted a similar experiment with the test duration of 200 ms, but all observers reported little, if any, change in the visibility of the test stimulus (the results are not shown for brevity).

**Discussion**

The results of Experiment 1 demonstrated that the relative strength of eye- and feature-based suppressive effects varied with temporal parameters such as the test duration and ISI in the IDM paradigm. This was true for the results with both color and pattern stimuli. These results also identified those stimulus conditions that favor each of the two types of suppressive effect.

As evident in both the ipsilateral and contralateral conditions as well as in the different-feature condition, eye-based suppression was observed when rivalrous stimuli were presented with a brief duration shortly after a preceding stimulus. These findings suggest that transient changes are critical to produce the eye-based suppression.
This outcome was quite similar for color and pattern stimuli, which is consistent with the hypothesis that the eye-based effect is relatively independent of specific visual features. On the other hand, feature-based suppression exhibited a relatively slow-developing profile over time. It usually took tens of milliseconds to grow when the test duration was short. However, when the test duration was long, feature-based suppression was observed shortly after the offset of the preceding stimulus and it persisted over several hundred milliseconds. These tendencies of feature-based suppression occur with preceding stimuli presented both monocularly and binocularly.

The present results indicating that different types of suppressive effect were found, respectively, with short and long test durations may seem to contradict findings of Wolfe (1984) who concluded that test duration is not an important factor in suppression. This was largely because he found that the suppressive effects of the preceding stimulus simply decreased in magnitude as test duration increased. We believe that this apparent discrepancy arose...
because Wolfe only used the stimulus condition, which corresponds to our ipsilateral condition. As already mentioned, both eye- and feature-based suppressive effects are predicted to modulate rivalry resolution in the same way in the ipsilateral condition. Thus, it is important to test both ipsilateral and contralateral conditions for establishing the type of suppression with a monocular preceding stimulus.

The test duration of 10 ms used in this study is very short for rivalry studies, and in fact, it has been demonstrated that briefly flashed dichoptic pattern stimuli do not produce binocular rivalry but are perceived to be fused, the phenomenon called “false fusion” (Wolfe, 1983). We confirmed this when rivalrous test stimuli of 10-ms duration were presented alone under the control condition particularly with pattern stimuli, although with color stimuli piecemeal percept was frequently observed and false fusion (i.e., color mixture) was rare. False fusion implies that it takes time for the rivalry mechanism to be activated. However, as also shown in previous studies (e.g., Wolfe, 1984), when rivalry mechanisms are already biased by pre-exposing one of the rivalrous stimuli as in the IDM paradigm, dominance of one rivalrous stimulus over another can be experienced even with brief stimuli. Moreover, a more recent study demonstrated that false fusion can be discriminated from genuine binocular fusion and thus suggested that the existence of dissimilar dichoptic stimuli is registered in binocular visual system even with brief presentation (Blake, Yang, & Westendorf, 1991).

The present finding that the predominant type of suppression changes depending on test duration may raise a question that the observers may have experienced a temporal change of dominant percept during the presentation of a long test stimulus; the observers may have perceived one stimulus first due to an eye-based effect but then the other due to a feature-based effect. However, the change in percept was rarely observed. Rather, a steady percept, which could be piecemeal, was generally observed for the whole presentation time. It is possible that the temporal change in relative contribution of different types of suppression was manifested as a change in relative dominance of one image over the other in temporally steady piecemeal percept. Similar observations have been known for false fusion (e.g., Song & Yao, 2009; Wolfe, 1983). Although false fusion occurs when a pair of rivalrous gratings is briefly presented, piecemeal rivalry or even exclusive dominance of one grating can be perceived when presented for a longer duration. The percept for flashed rivalrous stimuli seems to be determined after temporal integration over a narrow time window.

The present finding that eye-based suppression was prominent just after the offset of the preceding stimulus with the shorter test duration raised a possibility that it was caused by eye-specific effects such as forward masking. We reasoned that, if that is the case, similar suppressive effects can be observed even in the absence of interocular competition. However, the single-flash experiment revealed that visibility reduction due to masking was selective to the stimulus feature as well as to the eye of presentation (Figure 5). Moreover, the degree of feature selectivity was much stronger with pattern stimuli than with color stimuli (Figure 5) in contrast to the results of eye-based suppression (Figure 4). Thus, the masking effect exhibited several different properties from the eye-based suppression. The visual mechanisms underlying eye- and feature-based suppressions will be further discussed in the General discussion section.

It is noteworthy that feature-based suppression was consistently found with both color and pattern stimuli when we used a binocular preceding stimulus and relatively long test stimuli. We found similar results when we used achromatic white and black disks as the preceding and test stimuli (results are not shown for brevity). This consistency suggests a good opportunity to investigate feature-based competition in onset rivalry. Taking advantage of this finding, Experiment 2 investigated how color information is integrated with pattern information during onset rivalry.

## Experiment 2

Recently, Holmes et al. (2006) concluded that pattern rivalry can occur independently of color rivalry by demonstrating a misbinding of color and orientation. Specifically, they used achromatic gratings superimposed on a uniform colored patch and showed that when rivalrous stimuli, differing in both color and orientation, were presented dichoptically immediately after a binocular preceding stimulus, observers sometimes saw a chromatic stimulus with the color from one half-image and the orientation from the other.

Experiment 2 also asked whether feature-based suppression in the IDM paradigm occurs separately for color and orientation. However, extending the previous studies, we differentiate two aspects of the question. One aspect is how competitive interactions for perceptual dominance are resolved in terms of selectivity to feature combination. Here, it is asked whether, when one feature of the test stimulus (e.g., color) becomes dominant, the other (orientation) also becomes dominant. Holmes et al. (2006) mainly focused on this aspect of the question.

The second aspect is how the modulating effect of a preceding stimulus works in terms of selectivity to feature combination. Here, a main question is whether the preceding stimulus can only have an effect if both color and orientation are the same as those of the test stimulus or whether the preceding color exerts a suppressive effect independently of the preceding orientation (or vice versa). To address this question, we used rivalrous test stimuli
composed of chromatic gratings in which only color or orientation was rivalrous; the other feature was the same in both half-images of the test stimuli (e.g., a green clockwise (CW) vs. a green counterclockwise (CCW) grating). We then assessed whether the magnitude of the suppressive effect varied as a function of the particular combination of color and orientation in the preceding stimulus. If the preceding color and orientation separately affect onset rivalry, then only that feature of the preceding stimulus that was relevant to binocular rivalry should determine the magnitude of the modulating effect. In other words, given a green CW vs. a green CCW test grating, on trials with a red CW preceding stimulus, the modulating effects should have the same magnitude as observed on other trials with a green CW preceding stimulus. We tested this prediction in Experiment 2.

Methods

To favor feature-based suppression, the preceding stimulus was binocularly presented, and test duration and ISI were fixed to 200 ms and 20 ms, respectively. All other aspects of the methods (including observers) were the same as those in Experiment 1, with the following exceptions.

Stimuli

Test stimuli were a pair of rivalrous chromatic gratings differing in only color or orientation. Each of the test stimuli was a 2-cpd green/dark gray or red/dark gray square-wave grating and oriented 45° clockwise (CW) or 45° counterclockwise (CCW) from vertical. As a preceding stimulus, an achromatic grating or a colored disk was also used depending on preceding stimulus conditions. The red, green, and achromatic colors had the same chromaticity coordinates as those in Experiment 1. The mean luminance of the gratings was 4 cd/m² and the Michelson contrast was 0.60.

Procedure and conditions

Experiments 2a and 2b concerned orientation rivalry and color rivalry, respectively. In Experiment 2a (orientation rivalry experiment), the test stimulus comprised rivalrous chromatic gratings with the same color but different orientations (a green CW vs. a green CCW grating, or a red CW vs. a red CCW grating). The binocular preceding stimulus had the same orientation as one of the test stimuli, and the preceding color was manipulated in three conditions: the same-color, different-color, and achromatic-grating conditions. In the same-color condition, the preceding color was the same as the test color (e.g., a green CW or a green CCW grating, when green test stimuli were used; see also exemplar stimulus sequences shown in Figure 6). In the different-color condition, the preceding color was different from the test color (e.g., a red CW or a red CCW grating). In the achromatic-grating condition, the preceding stimulus was an achromatic grating (an achromatic CW or CCW grating).

In Experiment 2b (color rivalry experiment), the test stimulus comprised rivalrous chromatic gratings having the same orientation but different colors (a green CW vs. a red CW grating, or a green CCW vs. a red CCW grating). The preceding stimulus had the same color as one of the test stimuli, but the preceding spatial pattern was manipulated in three conditions: the same-orientation, different-orientation, and color-disk conditions. In the same-orientation condition, the preceding orientation was the same as the test orientation (e.g., a green CW or a red CW grating, when CW test gratings were used). In the different-orientation condition, the preceding orientation was different from the test orientation (e.g., a green CCW or a red CCW grating). In the color-disk condition, the preceding stimulus was a homogeneous color disk (a green or a red disk). Both Experiments 2a and 2b also included the control condition in which only the test stimulus was presented using the same stimulus sequence as in other conditions.

The observer’s task was dominance rating (similar to that of Experiment 1). The four preceding stimulus conditions and control condition were randomly interleaved within each session. Each session was repeated four times in 2 days and each condition was tested 16 times in total for each observer.

Results

Results of Experiments 2a and 2b are shown in Figure 6. Dominance ratings are plotted as a function of conditions that were comparable in the two experiments. The analysis of the confidence interval indicated that in both experiments feature-based suppression occurred. Furthermore, generally these effects were selective to that stimulus feature that was rivalrous in test gratings.

In Experiment 2a (orientation rivalry experiment), suppressive effects of the preceding stimulus were orientation-based. The observer’s rating indicated that the test stimulus with an orientation that differed from the preceding orientation became dominant regardless of the combination of color and orientation in the preceding stimulus (Figure 6a). When the preceding orientation was CW, observers rated that the CCW grating was dominant in all preceding stimulus conditions. On the other hand, when the preceding orientation was CCW, observers rated that the CW grating was dominant. To evaluate the magnitudes of the suppressive effect across the four conditions, a one-way ANOVA was conducted after the absolute magnitudes of the effect were averaged across different preceding stimuli in the same preceding
The results showed that the magnitude did not change with different preceding stimulus conditions ($F(2, 6) = 0.326$, n.s.). Thus, the differential effect of the preceding color was not found in the orientation rivalry experiment.

Similarly in Experiment 2b (color rivalry experiment), suppressive effects of the preceding stimulus were color-based. The test stimulus having a color that differed from the preceding stimulus was rated dominant in all preceding stimulus conditions (Figure 6b). However, in contrast to the results in the orientation rivalry experiment, the magnitude of the suppressive effects changed with the preceding stimulus conditions ($F(2, 6) = 5.735, p < 0.05$). Post-hoc comparisons revealed that a significant difference was found only between the same- and different-orientation conditions (Ryan’s procedure, $a = 0.05, MSE = 0.21$). Thus, which stimulus became dominant was mainly determined by the preceding color, but slight influence of the preceding orientation was also found in the color rivalry experiment.

Figure 6. Results of dominance rating in Experiment 2. The bars show mean ratings averaged across different observers in each preceding stimulus condition. Error bars show the 95% confidence intervals for the mean. Diamond symbols connected with a dashed line denote the baseline rating in the control condition. The color and line orientation of the bar correspond to those of the test stimulus, as shown in a simplified stimulus sequence in each preceding stimulus condition illustrated below the horizontal axis. (a) Experiment 2a (orientation rivalry experiment). Positive rating values indicate that a CCW grating was dominant in rivalry, while negative values mean that a CW grating was dominant. The results were averaged across red and green test gratings, but only green examples are shown below the horizontal axis for the purpose of illustration. (b) Experiment 2b (color rivalry experiment). Positive rating values indicate that a red grating was dominant in rivalry, while negative values mean that a green grating was dominant. The results were averaged across CW and CCW test gratings, but only CW examples are shown.
Experiment 2 revealed that exposure to different features of a preceding stimulus modulated onset rivalry in a manner that showed near independence of the two features examined (i.e., color and orientation; Figure 6). The findings that onset rivalry can be modulated in both eye- and feature-based manners are consistent with a theoretical view that onset rivalry is resolved through competitive interactions at multiple processing levels.

**Visual mechanisms underlying eye-based suppression**

The results of Experiment 1 revealed that an eye-based suppression exhibits a transient nature. This finding raised a possibility that visual masking contributes to the eye-based suppressive effects. Several recent studies suggested that visual masking and at least some aspects of binocular rivalry are mediated by the same inhibitory mechanisms (e.g., Baker & Graf, 2009; Tsuchiya, Koch, Gilroy, & Blake, 2006; van Boxtel, van Ee, & Erkelens, 2007). Among others, Tsuchiya et al. (2006) investigated the depth of suppression in flash suppression, binocular rivalry, and continuous flash suppression. They discussed the contribution of visual mechanisms that have been proposed to account for forward and backward visual masking (Macknik & Livingstone, 1998; Macknik & Martinez-Conde, 2004, 2007; Macknik, Martinez-Conde, & Heglund, 2000). These masking studies argued that transient bursts of neural discharges at the onset and offset of a stimulus are particularly important for visibility of the stimulus. Moreover, the suppression generated by a masking stimulus is the strongest also at the onset and offset. Thus, when the onset response and after discharge to the masking stimulus spatially and temporally overlap those responses to a target stimulus, the visibility of the target can be much reduced.

This type of mechanism mediating visual masking may be partially responsible for the eye-based suppression observed in this study. In fact, it can account for the temporal properties of the eye-based suppression quite well. However, it is unlikely to be the only cause as the results of the single-flash experiment revealed several properties of the masking effects inconsistent with those of the eye-based suppression, such as feature-selective visibility reduction in the masking effects (Figure 5). Additionally, we confirmed in our preliminary experiments that the duration of the preceding stimulus should be longer than several hundred milliseconds for suppressive effects to occur (see also Brascamp et al., 2007; Wolfe, 1984). This result is not consistent with the masking explanation, because masking effects can occur with a much shorter mask duration (e.g., Macknik et al., 2000). Wolfe (1984) discussed that long duration is required for the preceding stimulus to establish perceptual dominance. Overall, the present results suggest that visual mechanisms mediating interocular competition contribute
to the eye-based suppression. A recent neurophysiological study, which used a flash suppression paradigm, demonstrated stronger response suppression in V1 neurons with rivalrous test stimuli than with a monocular half-image of the stimuli, although these neurons also exhibited orientation tuning (Keliris, Logothetis, & Tolias, 2010). It will be interesting to see how V1 neurons respond to a brief stimulus in the IDM paradigm.

**Visual mechanisms underlying feature-based suppression**

In contrast to eye-based suppression, feature-based suppression exhibited a relatively slow-developing nature (Figure 4). Moreover, we confirmed in an additional experiment (not reported here) that feature-based suppression occurred even when the preceding stimulus was ramped off and then the test stimuli of long duration was ramped on. In other words, the presence of a transient change is not necessary to elicit feature-based suppression. These temporal properties of feature-based suppression were similar for color and pattern stimuli, although there was a possible difference in feature-based suppression with the shorter test duration (solid purple squares in Figures 4a and 4c). Bartels and Logothetis (2010) also demonstrated that a suppressive contribution of stimulus-based processes to rivalry develops gradually with dominance duration of the initial percept.

The present results showed that feature-based effects prevail with a relatively long test duration. This is generally consistent with recent evidence suggesting that visual processes mediating onset rivalry (initial selection of dominance for rivalrous stimuli) are different from those responsible for sustained rivalry (alternations of perceptual dominance during sustained viewing; Carter & Cavanagh, 2007; Chong & Blake, 2006; Kamphuisen et al., 2007; Sheth & Pham, 2008; Song & Yao, 2009). Particularly, onset rivalry appears to be governed largely by feature competition. Previous studies showed that onset bias is determined independently of eye of presentation (Carter & Cavanagh, 2007) and that exogenous and endogenous attention can influence initial dominance (Chong & Blake, 2006; Mitchell, Stoner, & Reynolds, 2004) and attentional modulation of initial dominance does not depend on eye of presentation (Kamphuisen et al., 2007). The present study provided additional evidence for larger contribution of feature competition in onset rivalry.

Because the IDM paradigm involves pre-exposure to a stimulus, we hypothesize that neural adaptation or fatigue mediates feature-based suppression. Neural adaptation has been generally believed to underlie perceptual alternation during sustained binocular rivalry, i.e., neural activity caused by the dominant stimulus weakens over time and eventually yields to activity of the suppressed stimulus, thus provoking a perceptual switch (e.g., Laing & Chow, 2002; Lehky, 1988; Wilson, 2003). Additionally, recent studies provided supporting evidence for the contribution of neural adaptation to binocular rivalry (e.g., Alais, Cass, O’Shea, & Blake, 2010; Kang & Blake, 2010). In the IDM paradigm, pre-viewing a preceding stimulus presumably produces neural adaptation in visual processes coding that stimulus feature and then reduces the likelihood that the feature becomes perceptually dominant during subsequent onset rivalry. This account by adaptation is also consistent with the above-mentioned finding that the duration of the preceding stimulus should be longer than several hundred milliseconds for suppressive effects to occur. Moreover, this account may be related to the hypothesis that neural processes at higher cortical stages contribute to feature-based suppression. Neurophysiological studies showed that perception-related modulations of neural activity at higher cortical stages are much larger than those at early stages such as V1 (e.g., Blake & Logothetis, 2002; Keliris et al., 2010; Leopold & Logothetis, 1996; Logothetis, 1998). Stronger modulation with perception at higher stages may be correlated with larger feature-based influence of neural adaptation.

An important finding regarding the putative contribution of neural adaptation was that the preceding stimulus physically identical to one of the test stimuli did not necessarily produce the largest suppressive effect (Figure 6). Rather, the stimulus feature relevant to rivalry competition almost exclusively exerted the suppressive effect. Thus, if neural adaptation mediates feature-based suppression, it would occur in visual processes that code each stimulus feature separately, not in the ones coding the stimulus in a manner more directly associated with the presented image. Furthermore, clear feature-based suppression in the contralateral condition (Figures 2 and 3) indicated that the visual processes should be driven binocularly. These findings also appear to be consistent with the contribution of higher cortical processes.

**Visual mechanisms mediating competition for perceptual dominance and those modulating the competition**

In addition to eye- and feature-based effects on onset rivalry, other findings are also consistent with a theoretical view that initial dominance of rivalry is established through interactions at multiple levels of processing. As already discussed, Experiment 2 suggested that color and orientation of the preceding stimulus almost independently modulate onset rivalry. However, it is also suggested that competitive interactions for perceptual dominance of the test stimulus are resolved in a selective manner to a combination of color and orientation under the present condition (Appendix A). These findings make it difficult to assume that a single common mechanism mediates both...
competitive interactions for perceptual dominance and the modulation of these interactions due to exposure to the preceding stimulus. The present findings can be understood if we hypothesize the involvement of two different mechanisms. That is, on the one hand, onset rivalry for chromatic gratings of high luminance contrast was resolved through competitive interactions between visual processes that code a particular combination of color and orientation in the test stimulus. On the other hand, exposure to a preceding stimulus produced neural adaptation in binocular feature-related processes, which exhibited selectivity to separate, not combined, stimulus features as discussed in the previous section. This neural adaptation presumably biased competitive interactions for perceptual dominance and worked to favor the alternate stimulus features.

There are ample precedents for assuming that rivalry resolution is modulated by additional processes. For example, modulating effects have been commonly assumed in the hybrid model of binocular rivalry in a form that competitive interactions at one level can be modulated by activity at other, higher, levels through feedback (e.g., Freeman, 2005; Tong et al., 2006; Wilson, 2003). Moreover, it has been recently argued that low-level processes initiate and regulate binocular rivalry, whereas high-level processes, which cannot initiate rivalry, can nonetheless modulate it through feedback, once rivalry is initiated (Alais & Melcher, 2007; Carlson & He, 2004; Watson, Pearson, & Clifford, 2004). Although most of the studies invoke feedback to account for the modulating effects, other types of modulating interaction remain possible if multiple loci of competition receive a modulating influence from other loci in the distributed processing of binocular rivalry. Whether through feedback or not, the present results suggested that feature-based competition can be modulated by visual processes that are distinct in terms of selectivity to feature combination.

**Initial dominance modulation paradigm as a tool to investigate onset rivalry**

Finally, we underscore that the IDM paradigm can be a valuable tool to investigate the nature of feature-based competitions and possible interactions between eye- and feature-based competitions underlying onset rivalry. This paradigm allows us to control the percept at the onset of dichoptic rivalrous stimulation in a predictable manner and can be extended for use with various stimulus features and their combinations. In some situations, this paradigm may be more preferable than the one presenting a new stimulus to the other eye during monocular stimulation, because stronger contributions of feature-based effects could be found in the IDM paradigm. As previously pointed out (e.g., He, Carlson, & Chen, 2005), in the study of binocular rivalry relatively little attention has been paid to the possibility that distinct visual processes may mediate different stimulus features and thereby contribute differentially to rivalry resolution. By elucidating the nature of feature-related processing underlying onset rivalry, the IDM paradigm can open a path to the effective investigation of this and related issues.

### Appendix A

**Selectivity to color–orientation combination in competitive interactions for initial perceptual dominance**

An additional experiment investigated whether initial dominance for chromatic gratings that were rivalrous both in color and orientation was determined separately for color and pattern rivalries. All methodological aspects of this experiment were identical to those of Experiment 2 with the following exceptions. Test stimuli were a pair of rivalrous chromatic gratings differing in both color and orientation (i.e., a green CW vs. a red CCW grating, or another combination). We designed four experimental conditions in addition to a control condition. They were same-combination, different-combination, color-disk, and achromatic-grating conditions. In the same-combination condition, the preceding stimulus was identical to one of the test stimuli (e.g., a green CW or a red CCW grating), whereas in the different-combination condition, the color–orientation combination in the preceding stimulus was different from that in the test stimuli (e.g., a green CW or a red CCW grating). In the achromatic-grating condition, the preceding stimulus was an achromatic grating that had the same properties other than chromatic contrast as one of the test stimuli (a CW or a CCW grating). Again, the observer’s task was dominance rating. Observers were also asked to report any percept different from either of the test stimuli, if they saw it during observation.

Figure A1 shows mean ratings for the four experimental conditions relative to the baseline rating in the control condition (dashed line). The results showed that the magnitude of the suppressive effects varied depending on the preceding stimulus conditions ($F(3, 9) = 8.960, p < 0.01$). Post-hoc comparisons showed significant differences between the same- and different-combination conditions and between the same-combination and achromatic-grating conditions (Ryan’s procedure, $\alpha = 0.05, MSE = 0.20$). The results of ANOVA and the analysis of the confidence intervals indicated that feature-based
suppression was found in all preceding conditions except for the different-combination condition. Additionally, perceptual misbinding of color and orientation was never reported in any condition during the experiment.

Little feature-based suppression and no misbinding found in the different-combination condition suggest that competitive interactions for perceptual dominance of the present rivalrous chromatic gratings were resolved in a selective manner to a combination of color and pattern. If they were resolved separately for color and pattern, a green CCW preceding stimulus, for example, should have phenomenally suppressed green color in a green CW test grating and CCW orientation in a red CCW test grating, and thus, the dominant percept would be a red CW grating (misbinding). Clear suppressive effects in the color-disk and achromatic-grating conditions are consistent with the results of Experiment 2 in that the color and orientation of a preceding stimulus separately modulated onset rivalry. The preceding stimulus composed of only color or orientation in one of rivalrous chromatic gratings still phenomenally suppressed the test stimulus with the same color or orientation. Moreover, color and orientation in the percept were bound in the same way as one of the rivalrous chromatic gratings. Thus, the results in these conditions are also consistent with the belief that color and orientation rivalries were resolved in a combined fashion.

Although the present result of no misbinding between color and orientation can be prevented by increasing luminance contrast of rivalrous chromatic gratings during sustained viewing. We conducted similar experiments with equiluminant chromatic gratings in the IDM paradigm and actually found misbinding between color and orientation (Abe, Kimura, & Goryo, 2007).

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Corresponding author: Eiji Kimura.
Email: kimura@L.chiba-u.ac.jp.
Address: Department of Psychology, Faculty of Letters, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi, Chiba 263-8522, Japan.

References


Figure A1. Results of dominance rating in an additional experiment in which the test stimuli were rivalrous in both color and orientation. The preceding stimulus conditions tested were the same-combination, different-combination, color-disk, and achromatic-grating conditions. Simplified stimulus sequences are illustrated below the horizontal axis. Positive rating values indicate that a red CCW grating was dominant in rivalry, while negative values mean that a green CW grating was dominant. Other aspects are similar to those in Figure 6.

Figure A1: Results of dominance rating in an additional experiment in which the test stimuli were rivalrous in both color and orientation. The preceding stimulus conditions tested were the same-combination, different-combination, color-disk, and achromatic-grating conditions. Simplified stimulus sequences are illustrated below the horizontal axis. Positive rating values indicate that a red CCW grating was dominant in rivalry, while negative values mean that a green CW grating was dominant. Other aspects are similar to those in Figure 6.


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