Assessing the generalizability of eye dominance across binocular rivalry, onset rivalry, and continuous flash suppression

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It is commonly assumed that one eye is dominant over the other eye. Eye dominance is most frequently determined by using the hole-in-the-card test. However, it is currently unclear whether eye dominance as determined by the hole-in-the-card test (so-called sighting eye dominance) generalizes to tasks involving interocular conflict (engaging sensory eye dominance). We therefore investigated whether sighting eye dominance is linked to sensory eye dominance in several frequently used paradigms that involve interocular conflict. Eye dominance was measured by the hole-in-the-card test, binocular rivalry, and breaking continuous flash suppression (b-CFS). Relationships between differences in eye dominance were assessed using Bayesian statistics. Strikingly, none of the three interocular conflict tasks yielded a difference in perceptual report between eyes when comparing the dominant eye with the nondominant eye as determined by the hole-in-the-card test. From this, we conclude that sighting eye dominance is different from sensory eye dominance. Interestingly, eye dominance of onset rivalry correlated with that of ongoing rivalry but not with that of b-CFS. Hence, we conclude that b-CFS reflects a different form of eye dominance than onset and ongoing rivalry. In sum, eye dominance seems to be a multifaceted phenomenon, which is differently expressed across interocular conflict paradigms. Finally, we highly discourage using tests measuring sighting eye dominance to determine the dominant eye in a subsequent experiment involving interocular conflict. Rather, we recommend that whenever experimental manipulations require a priori knowledge of eye dominance, eye dominance should be determined using pretrials of the same task that will be used in the main experiment.

Introduction

When viewing through a small aperture or when aiming to throw a dart, we generally experience a preference for using either our left or right eye. This preference for using one eye over the other is generally defined as "eye dominance." On a physiological level,

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Coren and Kaplan (1973) regarded (eye) dominance to be the result of any sort of physiological preeminence, priority, or preferential activity of one member of a bilateral pair of organs.

Researchers have used several methods to determine eye dominance. The different definitions of eye dominance that follow from these different methods of assessment can be classified into three behavioral categories: (a) sighting dominance (e.g., a dominant eye used for sighting when looking at a distant object through a hole); (b) dominance in visual functions inherent to spatial vision, such as acuity (Mapp, Ono, & Barbeito, 2003; Wade, 1998); and (c) sensory dominance (i.e., the eye yielding the longest or most prevalent percepts) during interocular conflict (Stanley, Forte, Carter, & Cavanagh, 2011; Yang, Blake, & McDonald, 2010). In the clinic, the dominant eye is usually determined by using the first method (the "hole-in-the-card test"). When an object is viewed with both eyes through an aperture placed at about an arm's-length distance, the retinal images of the eyes differ. Because of this perceptual difference, one eye dominates the other eye in order to see a single, coherent picture of the object. When the dominant eye is closed during the test, the percept of the object is suddenly displaced because the nondominant eye with the other retinal image becomes visible. A visual displacement after closing one eye is thus indicative of eye dominance in the hole-in-the-card test. The second method also reveals a clear bias toward one of the two eyes, both in terms of a consistent difference in far and near visual acuity between the eyes (Bausch and Lomb Orthorator, Rochester, NY). The third method relies on binocular rivalry: alternations of perception that arise when dissimilar images are presented to the same retinal location of both eyes. This method reveals that the image presented to one eye tends to consistently dominate perception over the image presented to the other eye (e.g., Blake & Logothetis, 2002). In addition, Wolfe (1983) reported that an initial fused image of the two monocular images will be quickly replaced by the perception of only one of the two images, a phenomenon called *onset rivalry*. Ongoing rivalry will start if the participant continues to view the images. As with the first two methods, a preference for recruiting one eye over the other can be observed with these phenomena: A stimulus presented to a specific eye can produce the most frequently reported percept during onset rivalry. Likewise, the stimulus presented to a specific eye can be the most dominant percept during ongoing rivalry (assessed by the frequency or duration of the dominant percept).

Recently, researchers started employing a novel experimental paradigm that is related to the phenomenon of binocular rivalry. Tsuchiya and Koch (2005) presented a static target to one eye and a dynamic mask to the other eye, causing perceptual suppression of the static stimulus (i.e., continuous flash suppression [CFS]). In a variation of this paradigm, researchers measured the time it took before a static target image was released from suppression and, thus, was perceived (breaking CFS, or b-CFS; Jiang, Costello, & He, 2007; Stein, Hebart, & Sterzer; Gayet, Van der Stigchel, & Paffen, 2014). In this paradigm, too, a consistent imbalance for one of the two eyes can be observed: on average, a target image presented to one eye is released from suppression earlier in time than the same target image presented to the other eye. The eye eliciting a shorter suppression duration is then labeled as the dominant eye.

In the current study, we aim to investigate to what extent different forms of sensory eye dominance (as engaged by interocular conflict) and sighting eye dominance (as measured by the hole-in-the-card test) are related. We are not the first to address this question: It is commonly assumed that eye dominance measured by different methods shares general properties. Valle-Inclán, Blano, Soto, and Leiros (2008), for example, reported a statistically significant correlation ($r = 0.375$) between the dominant sighting eye and dominance in onset rivalry. Yang et al. (2010) observed correlations between sighting eye dominance, acuity scores, and dominance durations during b-CFS. However, earlier studies were more cautious in generalizing across different methods for measuring eye dominance. For example, Coren and Kaplan (1973) found consistencies as well as inconsistencies across 13 different eye dominance tests. They therefore claimed that eye dominance is a multifaceted phenomenon and suggested that it is important to specify which type of dominance is being referred to. More recently, Mapp et al. (2003) reviewed studies measuring eye dominance and concluded that the sighting task is constrained by the fact that only one eye can be used and that the sighting dominant eye for this task reflects the ease or habit of using this eye for such viewing behavior tasks (Barbeito, 1981; Ono & Barbeito, 1982). It is important to note that even in the study by Yang et al. (2010), the correlations between preferred sighting eye dominance and eye dominance measured by b-CFS were weak, which suggests that eye dominance as measured by the different methods (preferred sighting eye test and b-CFS) could have similar but not necessarily identical underlying mechanisms.

Many have suggested that differences in the outcomes of paradigms inducing interocular conflict (onset rivalry, ongoing rivalry, and [b-]CFS) are also caused by factors other than eye dominance. Leat and Woodhouse (1984), for example, reported that the location of the stimuli on the retinae influences the dominance of onset and ongoing rivalry tasks differently. Also, strong and stable localized biases in perceptual dominance that vary across the visual field have been reported both within and between participants in onset rivalry tasks but not in ongoing rivalry tasks (Carter & Cavanagh, 2007; Stanley et al., 2011). Based on this, Stanley et al. (2011) concluded that the properties of onset rivalry differ significantly from those of ongoing binocular rivalry and may, in fact, be caused by distinct mechanisms. When comparing CFS and ongoing rivalry, Tsuchiya, Koch, Gilroy, and Blake (2006) reported that CFS not only is a stronger version of binocular rivalry but also is affected by the accumulated suppressive effects of multiple flashes, suggesting that CFS could be caused by mechanisms that are different from those involved in onset rivalry and ongoing rivalry.

In sum, only weak correlations have been observed between different methods for assessing eye dominance, and different variations of interocular conflict elicit varying perceptual experiences. Nonetheless, researchers still interchangeably use different methods for assessing eye dominance, relying on the tacit assumption that applying one method to assess eye dominance will reveal the same dominant eye as applying another method. Examples of these include studies measuring eye dominance with the preferred sighting eye test (Handa et al., 2004; Salomon, Lim, Herbelin, Hesselmann, & Blanke, 2013), onset rivalry (Valle-Inclán et al., 2008), ongoing rivalry (Hastorf & Myro, 1959; Washburn, Faison, & Scott, 1934), and b-CFS (Yang et al., 2010). A potentially more troublesome situation arises when researchers determine eye dominance using one method and then apply this information in a subsequent part of the experiment in which another method is used (e.g., to elicit b-CFS of the nondominant eye only). Examples of this include studies in which eye dominance is first established with the hole-in-the-card test, after which this information is used in a main experiment involving interocular conflict (e.g., Mastropasqua, Tse, & Turatto, 2015; Moors, Wagemans, & de-Wit, 2014; Yokoyama, Noguchi, & Kita, 2013). The question thus remains whether this approach is valid.

Using different methods to assess eye dominance is warranted only if the different methods produce the same outcome: One method should produce the same result as to which eye is dominant as any other method. To investigate whether different measures are correlated, we assessed eye dominance with four methods: the hole-in-the-card test, onset rivalry, ongoing rivalry, and b-CFS. Importantly, we kept the stimuli and procedure in the different methods as similar as possible, thereby allowing us to make a fair comparison between methods. We used two distinct approaches to assess the relationship between the different types of eye dominance. First, we tested whether eye dominance measured in the three tasks involving interocular conflict (onset rivalry, ongoing rivalry, and b-CFS) systematically differed between the observers' dominant eye and nondominant eye as measured by the hole-in-card test. Second, we tested to what extent eye dominance in the three tasks involving interocular competition was related to one another.

Method

Subjects

Sample size was determined online using an optional Bayesian stopping rule. We set out to test a minimum of 20 participants and until at least one of our tests resulted in a Bayes factor of 6 (in favor of either the null or the alternative hypothesis) or until we ran out of participants. Thirty-five subjects took part in the current study for a monetary reward after signing informed consent. Two subjects aborted the experiment before the end, and another two subjects did not follow instructions (i.e., they forgot which response to give) and were therefore excluded from the analyses. The ages of the remaining subjects ranged from 18 to 33 years old ($M = 24.2$, $SD = 3.24$, 19 women). All subjects reported having normal or corrected-to-normal vision and having no visual disorders or epilepsy.

Apparatus

The study was conducted on an Apple dual 2-GHz PowerPc G5 equipped with a linearized 22-in. LaCie Electron Blue IV CRT monitor (1,024 × 768 pixels; 100-Hz refresh rate) in a dark room. Stimulus presentation and response collection were created in MATLAB (R2009b; MathWorks, Natick, MA) using the PsychToolbox extension (Brainard, 1997; Pelli, 1997). A mirror stereoscope mounted on a chin rest was used to achieve dichoptic presentation. The viewing distance was 57 cm.

Stimuli and procedure

The subjects conducted four different tasks in the following order: b-CFS, onset rivalry, ongoing rivalry, and the hole-in-the-card test to determine eye dominances. Subjects could take a break between the tasks.

b-CFS

As explained in the Introduction, b-CFS consists of the presentation of a target image to one eye and a

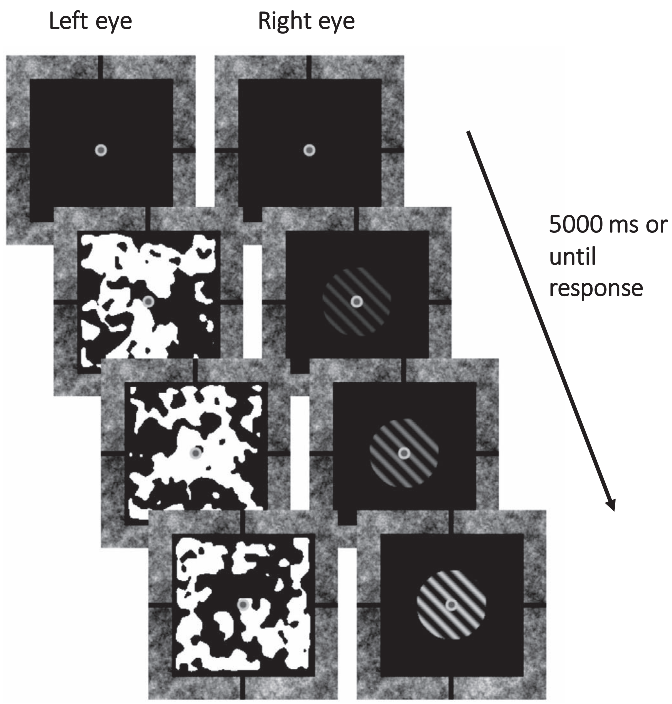

Figure 1. A schematic depiction of the sequence of events in a b-CFS trial. Subjects were instructed to keep gazing at the central gray dot and to indicate the orientation of the grating as fast and accurately as possible after it became visible.

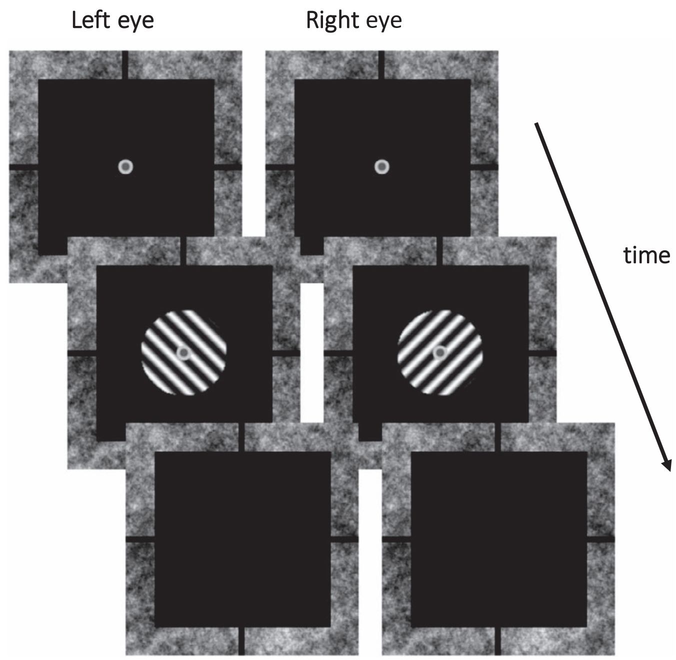

Figure 2. Stimuli used in the onset and ongoing rivalry experiments. The subjects were required to keep fixating at the center dot and to report the first orientation in the onset rivalry experiment and to continuously report the dominant orientation in the ongoing rivalry experiment.

dynamic mask to the other eye (Figure 1). We generated 50 different binary masks (0 and 27.3 cd/m^2 for the black and white parts, respectively) consisting of pink noise images filtered by a Gaussian low-pass filter ($\sigma = 3.2$; Gayet et al., 2014). We presented the masks for 100 ms each (10 Hz) in random order. For the targets, we used 45° oriented (counterclockwise (CCW) or clockwise (CW) from vertical) sinewave gratings with a diameter of 2° and spatial frequency of two cycles per degree. The presentation areas in both eyes were enclosed by an identical Brownian (i.e., $1/f^2$) noise frame with sides of 8° and a width of 1° to facilitate binocular fusion of the dichoptic images. We also presented gray dots sized 0.5° at the center of the visual field of both eyes to help subjects keep fixating.

After subjects had read the instructions and understood the task requirements, they performed an eye-alignment task in which stimulus position was calibrated for proper fusion. Subjects then performed eight practice trials, followed by 96 test trials. Subjects started each trial by pressing the space bar. The sequence of events of a single trial is shown in Figure 1, consisting of the presentation of a mask to one eye and the presentation of the target stimulus to the other eye. The Michelson luminance contrast of the target grating was linearly increased from 0% to almost full contrast (98%) within one second to ensure that the target was first suppressed by the mask and did not break through abruptly at the start of the trial. The subjects were instructed to keep fixating at the central gray dot and to respond to the target orientation by pressing a button as fast and accurately as possible (left arrow for CCW, right arrow for CW). Each trial lasted until a response was given or when 5 s without a response had passed. The trials were separated by an intertrial interval of 500 ms. The trials in which no response was given were recycled at the end of the task (i.e., performed again). The b-CFS task consisted of two blocks, each containing 48 trials. We counterbalanced the eye to which the stimuli were presented, and the trial order was randomized for each participant.

Onset rivalry

The stimuli and procedure of the onset rivalry experiment were similar to those of the b-CFS experiment. In this experiment, two target gratings (98% Michelson luminance contrast) with different orientations were presented dichoptically (see Figure 2). The subjects were instructed to report which orientation they perceived first by pressing either the left (CCW) or right (CW) arrow button. Each trial lasted for 5 s or until a response was given. Stimulus presentation was counterbalanced across eyes, and trials were separated by a five-second fixation interval (based on Leopold, Wilke, Maier, & Logothetis, 2002) to minimize potential history effects of previous percepts on subsequent percepts (Blakemore & Nachmias, 1971). After eight practice trials, the subjects finished a total of 80 trials, which were separated into two blocks. The trials in which no response was given were recycled.

Ongoing rivalry

The stimuli used in this experiment were identical to those used in the onset rivalry experiment, except for the duration of the target display (60 s instead of 5 s). The subjects were instructed to continuously indicate which orientation was the dominant percept by pressing and holding one of two arrow buttons (left arrow button for CCW; right arrow button for CW). The subjects performed 4 practice trials and 12 test trials.

Hole-in-the-card test

In this experiment, the dominant sighting eye was determined by using the hole-in-the-card test (Miles, 1929, 1930; Yang et al., 2010). The subject stretched both arms in front of the face and created a little triangular porthole with his or her thumbs and index fingers. Next, the subject was instructed to look at a small object fixed in the room through the center of the porthole with two eyes open. After this, the subject reported whether the object was still visible with one eye closed while keeping the hands and head static. When closing one eye (say the right) kept the object visible, the other eye (in this case the left) would be the dominant eye.

Analysis

After removing the data of subjects who failed to understand the instruction or finish all the tasks, the data of 31 subjects was analyzed. Performance on the b-CFS tasks was good: subjects reported the correct orientation in 98.06% (93.75% as the lowest) of the trials. To compare the data between different experiments, we calculated for each subject a so-called dominance index, reflecting perceptual dominance of one eye relative to the other:

- For the b-CFS task, the right eye's median reaction times (RTs) were divided by the sum of the two eyes' median RTs.
- For the onset rivalry task, the number of responses corresponding to the stimulus being presented to the left eye were divided by the total number of trials.
- For the ongoing rivalry task, the median durations of the left eye were divided by the sum of the two eyes' median durations.

The resulting ratios index the relative dominance of the right eye: A value smaller than 0.5 means that a stimulus presented to the right eye (a) broke suppression faster than one presented to the left eye in the b-CFS task, (b) was more often the first percept in the onset rivalry task, and (c) was perceived longer than that presented to the left eye in the ongoing rivalry task. In each case, a value smaller than 0.5 indicates that the dominance of the right eye is stronger than that of the left eye.

For our main statistical analyses, we conducted nondirectional Bayesian paired-sample *t* test or tests (standard Cauchy prior width of 0.707; JASP Team, 2017) and Bayesian pairwise correlations for support (standard Beta prior width of 1; JASP Team, 2017). This allows for providing statistical support for the alternative hypothesis (BF10 > 3), as well as for the null hypothesis (BF10 < 0.33; Dienes, 2014; Jeffreys, 1939/1961).

Results

Results of b-CFS

The results showed that one subject had an extremely dominant eye in the b-CFS task ($SD = 4.02$ from the mean dominance index, Mahalanobis distance of 11.23), which led us to exclude the subject from further analyses. Figure 3b illustrates the distribution of eye dominance across subjects for the three indices introduced above. When using the index for the b-CFS task, 66.67% subjects were categorized as having a right dominant eye and the rest (33.33%) as having a left dominant eye (Figure 3b). The finding that the right eye is dominant over the left eye in b-CFS is in line with a previous study (Yang et al., 2010).

The mean RT observed in the b-CFS task was 1.33 s ($SD = 0.68$). Subjects perceived the grating slightly faster in trials when it was presented to the right eye ($M = 1.30$ s; $SD = 0.72$) than when it was presented to the left eye ($M = 1.36$ s; $SD = 0.65$), but the evidence for this difference was statistically inconclusive (BF10 $= 0.55$).

Results of onset rivalry

The number of subjects categorized as having a right dominant eye (53.33%) was slightly greater than the number of subjects categorized as having a left dominant eye (46.67%; Figure 3c). A Bayesian *t* test

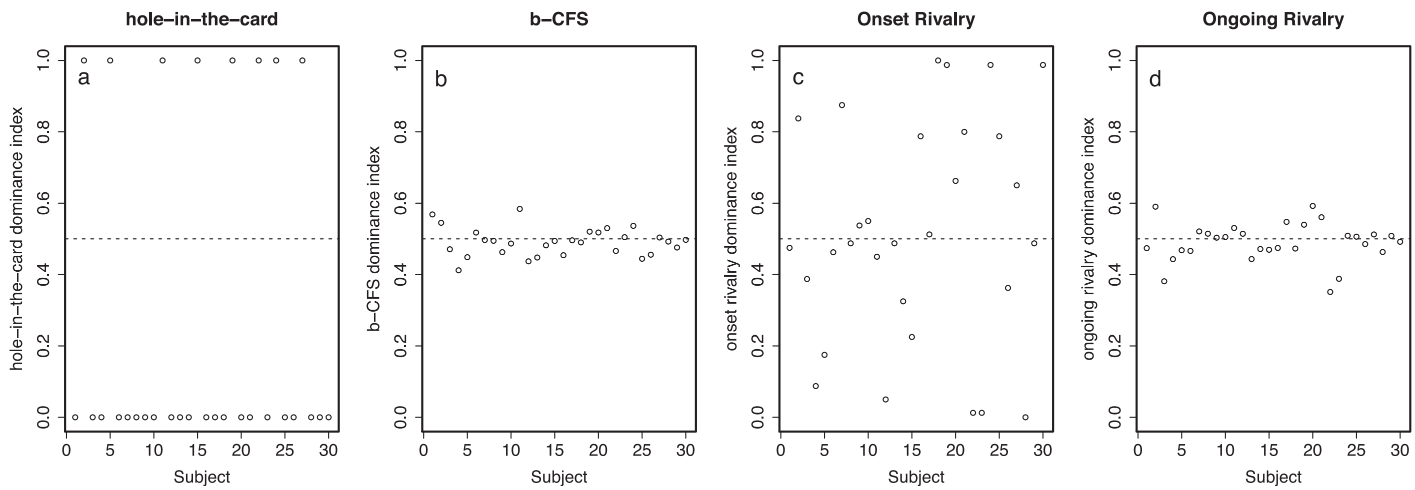

Figure 3. Eye dominance as measured by the hole-in-the-card test (0 stands for right eye dominant and 1 stands for left eye dominant), b-CFS (ratio between right-eye RT and the sum of left-eye RT and right-eye RT), onset rivalry (ratio between left-eye perceived trial number and all trial numbers), ongoing rivalry (ratio between left-eye duration and the sum of left-eye and right-eye durations). For all four plots, a dominance index smaller than 0.5 indicates right-eye dominance.

showed that the eye to which the stimulus was presented did not affect which grating was perceived (left eye perceived trial number: $M = 51.50\%$) or right eye (right eye perceived trial number: $M = 48.50\%$; BF10 = 0.20).

Results of ongoing rivalry

We measured the dominantly perceived grating durations by each eye as the dependent variable. The first and last reported dominance durations in each trial were excluded from the analyses to exclude truncated percepts. The results are presented in Figure 3d. Based on the index introduced above, we did not observe an eye dominance preference in ongoing rivalry because 50% of the subjects had longer left eye and 50% had longer right eye dominance durations. The Bayesian t test (BF10 = 0.3) provided support for the absence of a difference between left and right eye dominance durations (left eye, $M = 2.96$ s; right eye, $M = 3.12$ s).[1]

Results of hole-in-the-card test

In the hole-in-the-card test, more subjects used their right eye (73.33%) as their sighting eye, $\chi^2(1) = 6.53$, $p = 0.01$. To test whether the sighting eye dominance affected the dominance measurements in the three interocular conflict tasks, we compared the eye dominance indices within these interocular conflict tasks between the sighting dominant and sighting nondominant eye. The data provided support for the null hypothesis (i.e., no difference) for onset rivalry and ongoing rivalry but were inconclusive for b-CFS (b-CFS: BF10 = 1.89; onset rivalry: BF10 = 0.20; ongoing rivalry: BF10 = 0.26), which means that sighting eye dominance (as determined with the hole-in-the-card test) did not reliably predict eye dominance in the interocular conflict tasks (Figure 4).

Correlations

Bayesian Pearson correlations between the hole-in-the-card test and the interocular conflict tasks and their corresponding Bayes factors are displayed in Table 1. The Bayes factors can be classified as statistically inconclusive for the correlation between b-CFS and the hole-in-the-card-test (BF = 1.26) and as evidence for the null hypotheses (no correlation) for the correlations between the hole-in-the-card test on one hand and onset (BF = 0.35) and ongoing rivalry (BF = 0.36) on the other. This conclusion is further illustrated by sequential analyses of Bayes factors for the correlations between b-CFS and the hole-in-the-card test (Figure 5a), onset rivalry and the hole-in-the-card test (Figure 5b), and between ongoing rivalry and the hole-in-the-card test (Figure 5c). These results provide evidence that sensory eye dominance, as measured with onset rivalry or ongoing rivalry, does not correlate with sighting eye dominance as measured with the hole-in-the-card test and that this absence of a correlation cannot be explained by a lack of experimental power. Furthermore, the results show that the correlation between b-CFS and the hole-in-the-card test is weak at most.

To explore whether different experimental paradigms that engender interocular conflict measure the same underlying factor (i.e., a generalized form of

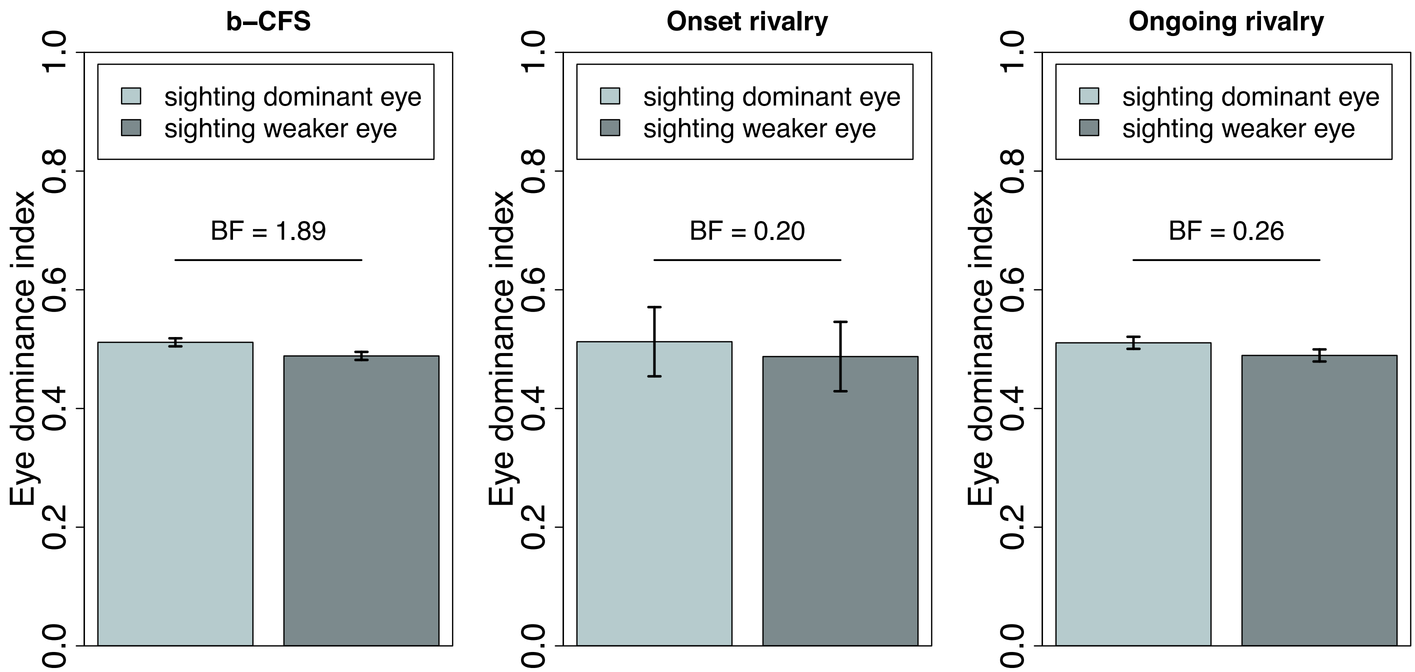

Figure 4. Sensory eye dominance index of b-CFS, onset rivalry, and ongoing rivalry separated for the dominant (light gray) and nondominant (dark gray) sighting eye. Error bars depict the standard error of the mean.

sensory eye dominance), we conducted correlations between the dominance indices obtained from the three tasks involving interocular conflict. We report Pearson's correlations here because the Shapiro-Wilk test suggested the eye dominance indices in the interocular conflict tasks were normally distributed (b-CFS: $p = 0.88$; onset rivalry: $p = 0.11$; ongoing rivalry: $p = 0.18$). As illustrated in Figure 6, the results showed a convincing positive correlation between onset rivalry dominance and ongoing rivalry dominance ($r = 0.57$, $BF10 = 29.0$). This indicates that approximately 30% of the variance in eye dominances is shared between ongoing and onset rivalry. The correlations between b-CFS dominance and onset rivalry dominance ($R = 0.36$, $BF10 = 1.6$) and between b-CFS dominance and ongoing rivalry dominance ($R = 0.41$, $BF10 = 2.5$) were of the expected direction but were statistically inconclusive.

To further investigate the robustness of these test results, we plotted the evolution of the Bayes factors after addition of each new subject. These plots confirm that there is no convincing correlation between b-CFS dominance and onset rivalry dominance (Figure 7a) but also suggest that the correlation between b-CFS dominance and ongoing rivalry dominance might eventually emerge with the addition of more participants (Figure 7b). Importantly, however, the evidence for a relation between sensory eye dominance as measured by these different experimental paradigms is clearly weaker than what would be expected if they were fully supported by a single generalized type of sensory eye dominance.

	b-CFS	Onset rivalry	Ongoing rivalry
Hole-in-the-card	0.33 (BF = 1.26)	0.05 (BF = 0.35)	0.07 (BF = 0.36)

Table 1. Correlations between the eye dominance index measured by the hole-in-the-card test and the three interocular conflict tasks.

Following these quantitative analyses, we also investigated to what extent the different eye dominance measures employed in this study yield qualitatively different classifications of eye dominance. To do so, we computed for each pair of interocular suppression tasks the percentage of matching classifications (i.e., both measures classify a participant as being left-eye or right-eye dominant) and of mismatching classifications (i.e., one measure classifies the participant as right-eye dominant whereas the other measure classifies the participant as left-eye dominant). Mismatching classification rates between pairs of methods ranged between 23.3% and 43.3%, with the most extreme example showing that only 56.7% of participants that were classified as left- or right-eye dominant with the hole-in-the-card test exhibited the same eye as dominant in the ongoing rivalry task (see Supplementary Tables S1–S6 for a full overview of classifications between pairs of tasks).

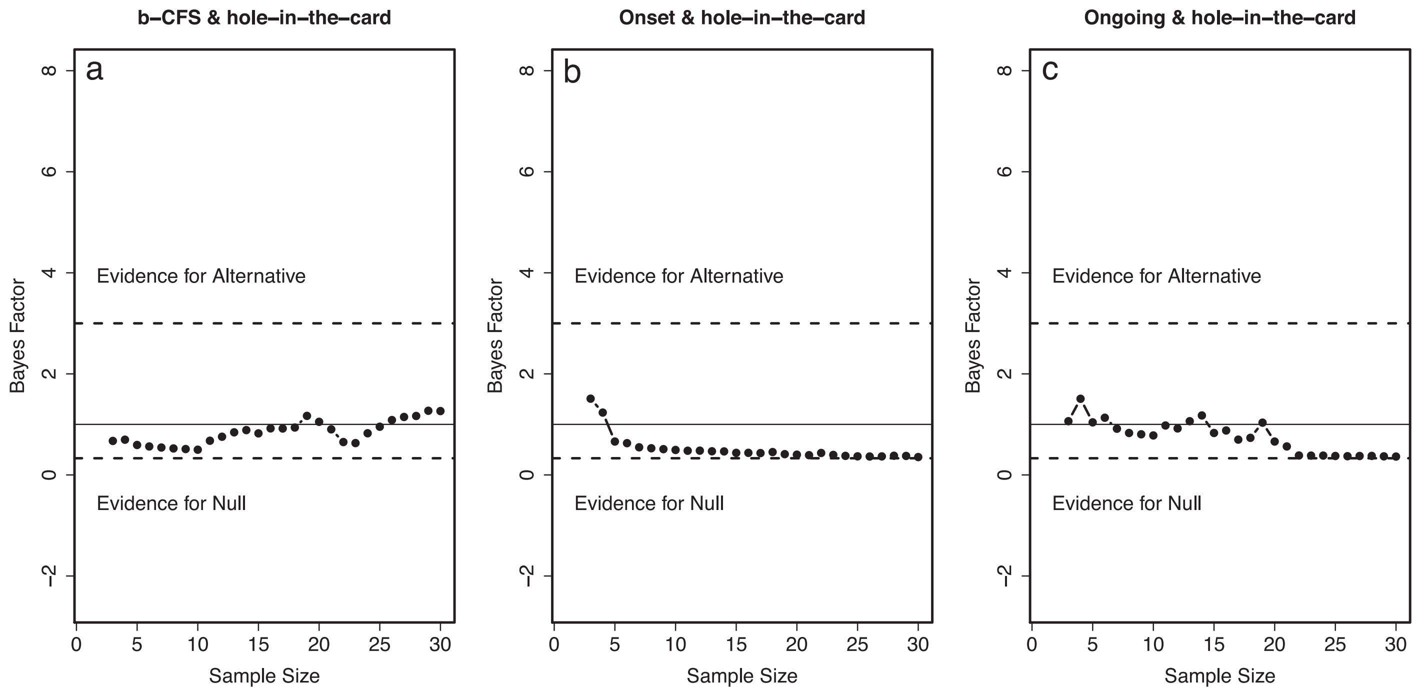

Figure 5. The sequential analyses of Bayes factors for correlations between sighting eye dominance and (a) b-CFS dominance, (b) onset rivalry dominance, and (c) ongoing rivalry dominance.

Effects of task order

We did not randomize the task order in the current study. Together with the fact that we used naïve observers, one could wonder whether practice effects might have influenced the results. To investigate this, we compared the dependent measures per eye for the first half of trials and second half of trials. Breakthrough times in b-CFS (left eye: BF = 0.23; right eye: BF = 0.23), number of percept onsets (left eye: BF = 0.32; right eye: BF = 0.32), and dominance durations in ongoing rivalry (left eye: BF = 0.25; right eye: BF = 0.21) did not differ between the first and second half of trials, implying that our measures were not affected by the effect of practice.

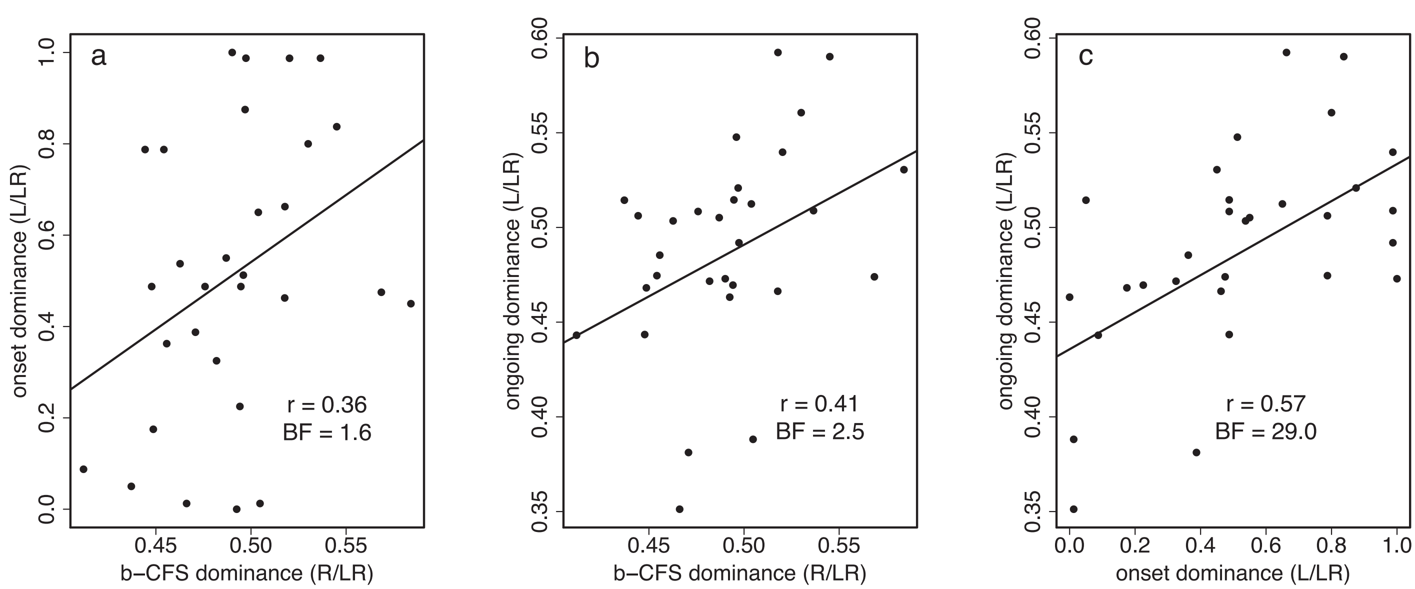

Figure 6. (a) The correlation between the b-CFS dominance index and the onset rivalry dominance index. (b) The correlation between the b-CFS dominance index and the ongoing rivalry dominance index. (c) The correlation between the onset rivalry dominance index and the ongoing rivalry dominance index.

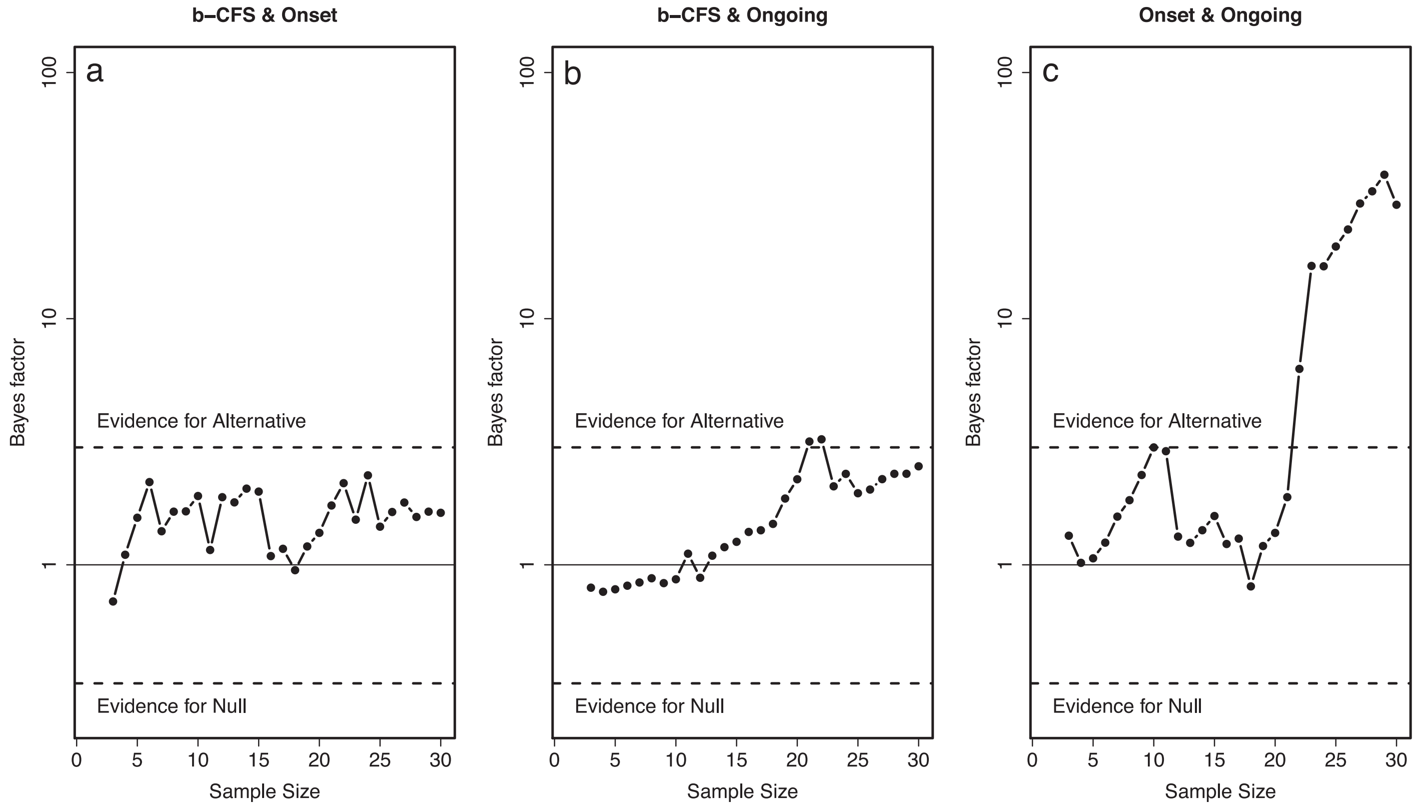

Figure 7. The sequential analyses of Bayes factors for the correlational analyses between (a) CFS dominance and onset rivalry dominance, (b) b-CFS dominance and ongoing dominance, and (c) onset rivalry dominance and ongoing rivalry dominance.

Effects of task requirements

In the ongoing rivalry task, the participants were required to continuously indicate the perceived dominant orientation. However, enduring interocular conflict typically also included phases in which neither one of the images was dominant in perception. Our final analysis was concerned with the question of whether these so-called mixed percepts or piecemeal rivalry confound our results. To evaluate the potential impact of piecemeal rivalry on our findings, we recalculated the dominance indices from a modified data set in which we treated 50% of the dominance durations as mixed percept (as could be expected for ongoing rivalry between stimuli with a diameter of 2°, based on O'Shea et al., 1997). Mixed percept time was not assigned to one of the eyes because we counterbalanced the rivalry inducers' orientation for both eyes, meaning that dominance durations for the left and right eye were equally reduced by 25% of the average dominance duration. This data transformation resulted in a new set of dominance indices for the ongoing rivalry task. Similar to the original results, the piecemeal-corrected dominance indices of ongoing rivalry did not correlate with the other interocular task indices (b-CFS: $r = 0.42$, BF $= 2.87$; onset rivalry: $r = 0.57$, BF $= 29.47$). These results show that mixed percepts did not confound our results.

Discussion

This study was conducted to investigate whether the hole-in-the-card test, onset rivalry, ongoing rivalry, and b-CFS tasks indicate similar biases in eye dominance. In line with previous studies (Weinman & Cooke, 1982; Yang et al., 2010), we evaluated eye dominance by calculating the relative eye dominance indices between the eyes, which allowed us to assess imbalances in binocular strength quantitatively. We observed no consistent effect of sighting eye dominance on eye dominance in the three interocular conflict tasks. Specifically, using Bayesian statistics allowed us to establish that perceptual reports in the two rivalry tasks did not differ between the dominant and nondominant eye, as measured by the hole-in-the-card test, and that RT for b-CFS was weakly dependent on the dominant eye. This suggests that preferred sighting eye dominance is a different type of eye dominance than that which is measured through interocular conflict. We did observe a statistically significant correlation between onset and ongoing rivalry eye dominance indices, suggesting that imbalances in perceptual onset frequency and dominance durations between the eyes are affected by a shared mechanism for these two tasks specifically.

Although previous studies reported positive relations between eye dominance measurements, especially those that depend on similar experimental paradigms (Valle-Inclán et al., 2008; Yang et al., 2010), differences across paradigms have been observed as well (Barbeito, 1981; Coren & Kaplan, 1973; Ono & Barbeito, 1982; also see review by Stanley et al., 2011). More specifically, eye dominance in interocular conflict does not correlate well with eye dominance in spatial vision tasks nor with preferred sighting dominance as assessed with the hole-in-the-card test. Our results concur with these findings.

Surprisingly, Yang et al. (2010) did report a relationship between the eye dominance determined by b-CFS and the hole-in-the-card test and concluded that b-CFS can be used as an efficient, reliable, and quantitative sensory eye dominance measurement. This is in contrast to our observations, which show no convincing relationship between preferred sighting eye dominance and b-CFS eye dominance. Neither did b-CFS eye dominance correlate convincingly with eye dominance assessed in the other two interocular conflict paradigms. It is currently unclear why we have found different results, and we can only speculate that it may be related to the design of the stimuli, which was different from that of Yang et al. (2010). Nonetheless, Tsuchiya et al. (2006) have already hinted at the possibility that CFS relies upon a different suppression mechanism than binocular rivalry, which could explain why eye dominance as measured with b-CFS was not correlated to eye dominance as measured with the other rivalry tasks (Yang & Blake, 2012). It is therefore tempting to suggest that b-CFS measures a different form of eye dominance than onset or ongoing rivalry.

The positive relationship in eye dominance between onset and ongoing rivalry concurs with previous studies (Dieter, Sy, & Blake, 2016; Leat & Woodhouse, 1984). For example, Leat and Woodhouse (1984) observed strong correlations in eye dominance between onset and ongoing rivalry. It is important to note, however, that there are other factors, such as eye movements, stimulus location, and stimulus characteristics, that can alter and attenuate biases in eye dominance (Dieter, Sy, & Blake, 2016; Dieter et al., 2017; Kalisvaart, Rampersad, & Goossens, 2011; for review, see Stanley et al., 2011). For example, Dieter et al. (2017) explored individuals' ongoing rivalry biases for eye and color within the visual field and observed idiosyncratic patterns of biases for both eye and color within the visual field. The origin of a perceptual dominance wave during nonexclusive rivalry might also be sensitive to such spatial anisotropies in eye dominance (Paffen, Naber, & Verstraten, 2008). In addition, it would be interesting to assess whether the timing and the speed at which perceptual dominance switches between the eyes (Genç, Bergmann, Singer, & Kohler, 2013; Genç et al., 2011; Knapen, van Ee, & Blake, 2007; Lee, Blake, & Heeger, 2005; Naber, Carter, & Verstraten, 2009; Wilson, Blake, & Lee, 2001) are affected by eye dominance. The above observations prevent us from generalizing our findings and concluding that onset and ongoing rivalry share a singular mechanism underlying eye dominance. Before this can be concluded, more work needs to be conducted to map out all the factors that influence eye dominance.

With regard to the neural substrates of eye dominance, one theory prevails in the literature. The visual brain area V1 is commonly assumed to be the neural locus of differences in eye dominance. The striate cortex consists of columns that receive only monocular input. The idea is that the dominant eye is represented by more interconnected and larger monocular columns. Evidence for this comes from a study by Le Vay, Wiesel, and Hubel (1980), who sutured one eye of the newborn macaque monkey. After a few weeks, the monocular columns in the striate cortex (V1) for the closed eye shrunk and were distributed more fragmented. Sengpiel, Blakemore, and Harrad (1995) suggested that perceptual dominance might also involve intracortical inhibition between adjacent ocular dominance columns. Indeed, human neuroimaging and psychophysical studies (for review, see Tong, Meng, & Blake, 2006) also indicate that neural sites that retain eye-selective information are responsible for binocular rivalry. Lastly, amblyopia, a condition in which one eye has weaker eye dominance, is most likely caused by size differences in ocular dominance columns (Goodyear, Nicolle, Humphrey, & Menon, 2000; Wong, 2012). Our results suggest that variable measurements assess different types of eye dominance, despite the potential involvement of a general mechanism underlying interocular suppression.

We conclude that ocular dominance is a multifaceted phenomenon and that in our search for the function and etiology of ocular dominance, we must first specify which type of dominance is referred to (Coren & Kaplan, 1973). This exploration highlights the importance of considering the factor of eye imbalance strength when drawing inferences about the perceptual processing of images in different paradigms. We suggest researchers choose appropriate tests to measure the eye dominance or dominant eye. Specifically, whenever experimental manipulations require a priori knowledge about eye dominance, pretrials of the task at interest (i.e., as used in the main experiment) should be used to determine eye dominance.

Keywords: eye dominance, *hole-in-the-card test*, *interocular conflict*, *onset rivalry*, *ongoing rivalry*, *b-CFS*

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Footnote

[1] In the ongoing rivalry task, mixed percepts were not recorded. To assess whether such mixed percepts affected our results, we ran a control experiment in which 10 new participants (5 women) reported not only exclusive percepts but also mixed percepts during ongoing rivalry. The results show that participants reported mixed percepts for only a limited proportion of the time (mean proportion: 12.83%; $SD = 10\%$). After removing the mixed percepts, and in line with our original findings, the median phase duration did not differ between the dominant and the weak eye (as measured by the hole-in-the-card test), BF10 = 0.41.

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