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Interocular conflict attracts attention

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When each of our two eyes is presented with a dissimilar image, the intriguing phenomenon of binocular rivalry occurs: Perception will start alternating between the images. Since Wheatstone's (1838) invention of the stereoscope, which initiated the scientific study of this fascinating phenomenon, it has been debated whether binocular rivalry is subject to attentional control[1] (for a review, see Paffen & Alais, 2011). In recent years, evidence has converged toward the view that attentional control over which of the images is dominant in perception is limited but possible (Chong, Tadin, & Blake, 2005; Lack, 1979; Meng & Tong, 2004; van Ee, van Dam, & Brouwer, 2005). What is more, it has become evident that object-based attention influences which of the two images is dominant first (Chong & Blake, 2006; Mitchell, Stoner, & Reynolds, 2004), while spatial attention modulates the temporal dynamics of the alternations (Ooi & He, 1999; Paffen & Van der Stigchel, 2010). Moreover, alternations in perception occur more frequently when more attentional resources are available for reporting them (Paffen, Alais, & Verstraten, 2006).

In contrast to the question of whether and how attention affects binocular rivalry, our aim was to investigate whether binocular rivalry is capable of *attracting* attention. Previous studies concerned with this issue have answered this question by investigating the degree to which interocular conflict (i.e., the situation leading to binocular rivalry) attracts attention during visual search (Paffen, Hooge, Benjamins, & Hogendoorn, 2011; Wolfe & Franzel, 1988). The results of the previous studies have been inconclusive. On the one hand, Wolfe and Franzel showed that search for interocular conflict was far from efficient: A rival target did not pop out when searching for it. On the other hand, Paffen et al. (2011) recently showed that participants searching for interocular conflict *can* approach efficient search behavior. Although the search in that study might not warrant the claim that interocular conflict pops out (search slopes were around 15 ms/item), the result is suggestive of the fact that binocular rivalry can attract attention.

The present study is motivated by the question of whether interocular conflict is able to attract attention in a situation in which observers do not explicitly know what they are looking for in stimuli depicting natural and man-made scenes. To investigate the attention-attracting potency of interocular conflict, we employed a change blindness paradigm (Rensink, O'Regan, & Clark, 1997; Simons & Levin, 1997) in which two scenes are presented sequentially with a blank screen in-between. The observer is required to detect the change from one view to the next. These scenes are presented continuously until the change is detected. Previous studies have shown that observers are generally quite poor in detecting such a change unless visual attention is allocated to the location of the change (Cavanaugh & Wurtz, 2004; Scholl, 2000). From this finding, it can be inferred that an increase in performance on change detection is related to a shift of attention to the location of the change. This also predicts that change blindness will be attenuated when the changed location contains an attention-grabbing feature.

In the present study, participants had to detect a change that could be (1) binocular, in which the same change occurred in a small region of two identical images presented to both eyes; (2) monocular, in which the change occurred in a small region of only one of the images (leading to interocular conflict); or

[1] For one example, the question was part of the dispute between Helmholtz (1909/1962) and Hering (1920/1964).

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(3) transparent, in which there was a transparent overlap of the changed and unchanged regions for each eye (see Fig. 1). The latter condition was included to assess whether superior change detection in the monocular condition could be due to normal fusion of both images, and not to interocular conflict. If detection of monocular changes is faster than detection of transparent changes, interocular conflict and not binocular fusion is the driving force underlying superior monocular change detection. We thus reasoned that if interocular conflict attracts attention, monocular changes (inducing interocular conflict) would be detected faster than both binocular and transparent changes.

Experiment 1

Method

A group of 10 observers, all naïve as to the purpose of the experiment, participated. All had normal or corrected-to-normal vision and were tested for accurate stereo vision (TNO test for stereoscopic vision).

The stimuli were presented using an Apple dual 2-GHz PowerPC G5 and a linearized LaCie Electron blue IV 22-in. monitor running at 75 Hz, using MATLAB and the PsychToolbox extensions. Dichoptic presentation was achieved using a

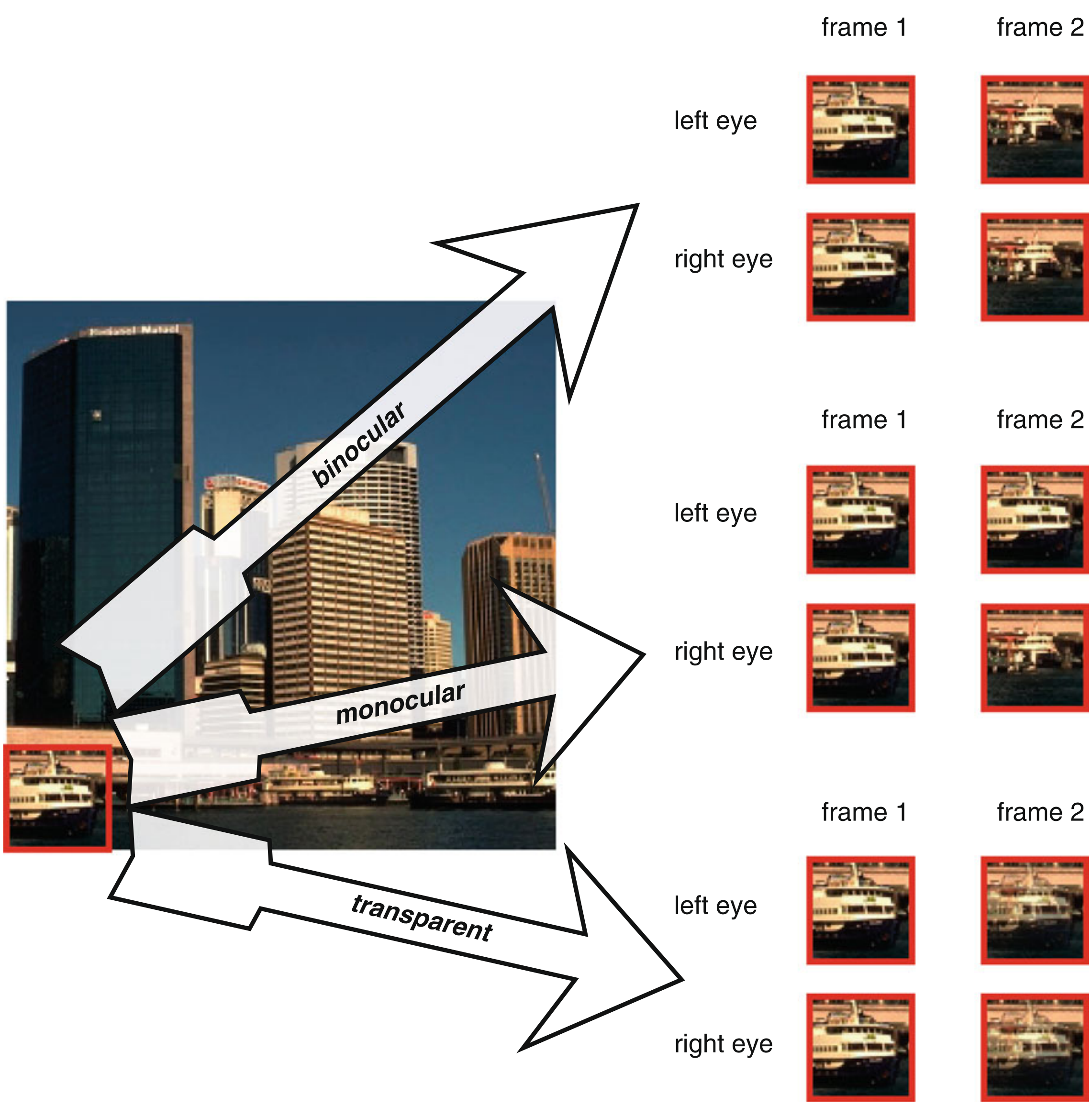

Fig. 1 Stimuli. Observers detected changes as quickly and accurately as possible in two images presented in alternation. The image on the left is an example of the images, presented in two frames to the left and the right eyes. In one of the two frames, a change occurred in a small area of the image (depicted by the red box for this particular image). The change could be (1) binocular, in which the change was presented to both eyes; (2) monocular, in which the change occurred in one image; or (3) transparent, in which there was a transparent overlap of the changed and unchanged regions in each image

mirror stereoscope. The length of the optical path (from the monitor via the mirrors to the observer's eyes) was 57 cm.

We used a set of 48 images of natural and man-made scenes (Nijboer, Kanai, de Haan, & van der Smagt, 2008; see Fig. 1 for an example), 10 × 10 deg in dimensions, which were presented in random order on a gray background with a luminance of 27.9 cd/m^2. A change occurred at a small location of one of the images or in both images.

In each viewing condition, observers viewed two distal stimuli presented at two overlapping retinal locations. Apart from the small region where a change occurred, the images were identical for the left and right eyes, leading to binocular fusion. The nature of the change was varied in three viewing conditions (Fig. 1): (1) binocular change, in which the change occurred in each image; (2) monocular change, in which the change occurred in one of the two images; and (3) transparent change, in which there was a transparent overlap of the changed and unchanged regions in each image. An image for the transparent condition was created by dividing the sum of the RGB intensities of the changed and unchanged images by two. Each observer saw each image only once, so that 16 images were used for each of the three viewing conditions. The selection of 16 images for each viewing condition was random for each observer. The observers were instructed to fixate the fixation cross and to initiate a trial by pressing the spacebar. Two frames, one without and one with the change, were presented in alternation. Each frame was presented for 240 ms, with an 80-ms blank interstimulus interval. Thus, a complete cycle took (240 + 80)*2, or 640 ms. This timing was identical to that of Rensink, O'Regan, and Clark (1997). During presentation of the frames, observers were allowed to move their eyes. The frames without and with a change were presented in alternation until an observer pressed the down arrow key, which was used to indicate that a change had been detected. Next, observers were asked to describe the nature of the change.

Results

The results of Experiment 1 are displayed in Fig. 2. Transparent changes were detected more slowly than binocular changes [$t(9) = 2.6$, $p < .05$], which in turn were detected more slowly than monocular changes [$t(9) = 4.0$, $p < .02$]. The lowest accuracy for our observers was 87%, and the rest performed even better. These results show that change blindness was highest for transparent changes, lower for binocular changes, and lowest for monocular changes.

Discussion

The results of Experiment 1 show that a change in an image is found faster when the change is presented to one eye only. This suggests that interocular conflict is able to attract visual attention within images toward salient changes that remain unnoticed for longer without the conflict.

What aspect of a monocular change could be responsible for its attention-attracting property? To answer this question, it is informative to discuss the phenomenology of the percept that interocular conflict produces. The most described property is binocular rivalry, which refers to spontaneous alternations in perception (for an overview of the properties of this phenomenon, see Blake & Logothetis, 2002). However, it is known that during the first ~200 ms of dichoptic stimulation, observers perceive the images as being fused, rather than in a phase of perceptual dominance or transition (Liu, Tyler, & Schor, 1992; Wolfe, 1983). This fusion, however, is abnormal in the sense that observers can easily discriminate between dissimilar, fused gratings and those that are optically fused (Blake, Yu, & Westendorp, 1991). Only after this first phase of abnormal fusion will alternations in perception typically arise (Liu et al., 1992; Wolfe, 1983). As the stimulus presentation used in Experiment 1 falls within the regime of abnormal fusion, Experiment 2 was designed to evaluate the degree to which interocular conflict is able to attract attention when its presentation duration is long enough to overcome abnormal fusion.

Experiment 2

Method

A group of 10 observers (all different from those participating in Exp. 1), who were naïve as to the purpose of the experiment, participated. All had normal or corrected-to-normal vision and were tested for accurate stereo vision (TNO test for stereoscopic vision).

The apparatus used was the same as in Experiment 1, whereas the stimulus and procedure were slightly different. Again, three basic viewing conditions—monocular, binocular, and transparent changes—were used. In contrast to Experiment 1, each stimulus frame was now on for either 240 or 507 ms. To keep the cycle durations of the presentations equal, the stimulus frame was off for 360 or 93 ms, respectively, for the shorter and longer frame durations. We chose to keep total cycle durations identical so that the minimal reaction times would not differ. The duration of one cycle of each condition added up to 1,200 ms. As in Experiment 1, each observer viewed 16 images for each viewing condition (monocular, binocular, and transparent, with two different durations for each condition). Due to the increased number of conditions as compared to Experiment 1, we doubled the number of images depicting natural and man-made scenes to 96. All other aspects of the experiment were the same as in Experiment 1.

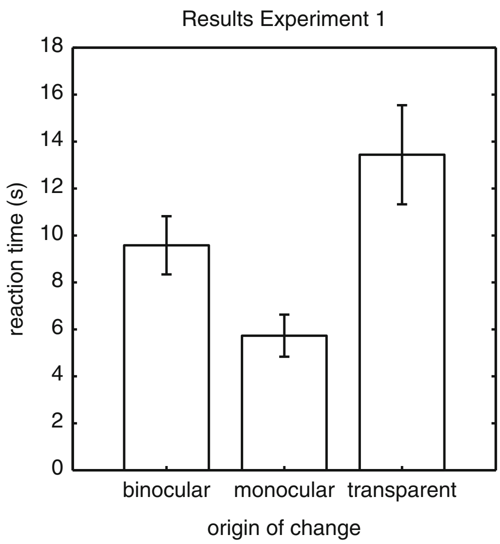

Fig. 2 Reaction times for accurately detected changes in Experiment 1. Change detection was slowest in the transparent condition, faster in the binocular condition, and fastest in the monocular condition. Error bars represent 1 *SEM*

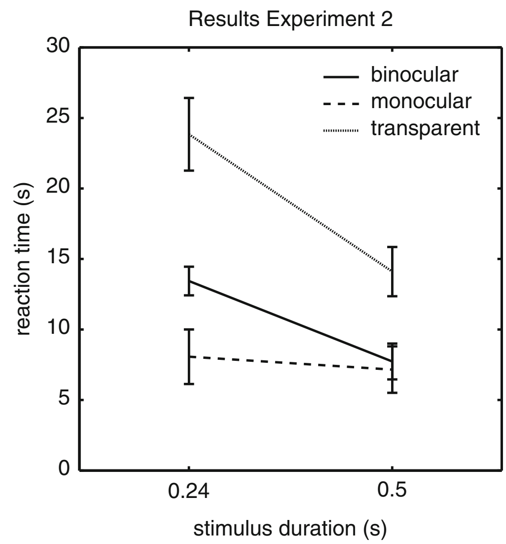

Fig. 3 Reaction times for accurately detected changes in Experiment 2. The results for the short stimulus duration are similar to those of Experiment 1. When the stimulus duration was longer, the benefit for the monocular condition disappeared. Error bars represent 1 *SEM*

Results

The results of Experiment 2 are displayed in Fig. 3. To evaluate the effects of viewing condition (monocular, binocular, or transparent) and stimulus duration (240 or 507 ms), we performed a 3 (mode of presentation) × 2 (duration) repeated measures ANOVA. We found main effects of viewing condition [$F(2, 18) = 33.3$, $p < .0001$] and stimulus duration [$F(1, 9) = 12.2$, $p = .007$], and a significant interaction between them [$F(2, 18) = 3.9$, $p = .04$].

To gain better insight into the results, we performed several post-hoc analyses. First, and replicating the main result of Experiment 1, monocular changes were detected faster than binocular and transparent changes when the stimulus duration (240 ms) was similar to that of Experiment 1 [monocular faster than binocular, $t(9) = 3.5$, $p = .02$; monocular faster than transparent, $t(9) = 6.2$, $p < .0005$].

However, the results for the longer stimulus duration were different. Although change detection was still slower for the transparent condition than for the monocular condition [$t(9) = 3.9$, $p = .02$], detection times for the binocular and monocular conditions were not significantly different [$t(9) = 0.6$, $p = .9$]. These results are related to the fact that change detection became faster for the binocular [$t(9) = 3.0$, $p = .04$] and transparent [$t(9) = 3.3$, $p = .03$] conditions when the stimulus duration increased from 240 to 507 ms. In the monocular condition, however, no such decrease in change detection time was observed [$t(9) = 1.0$, $p = .7$].[2] Note that the latter observation is the cause of the interaction found in the ANOVA.

Discussion

The results of Experiment 2 show that when the stimulus duration is increased, change detection improves for binocular and transparent changes, thereby attenuating change blindness. However, in the case of monocular changes, no such improvement is observed. The decrease of reaction times for the two former conditions can easily be explained by the fact that the prolonged duration that the stimulus was present gave observers more time to inspect the stimulus, thus allowing more time to detect the change. But why were reaction times for the longer stimulus duration not faster than those for the short duration in the monocular viewing condition? We suggest two possible reasons for this. First, reaction times were already quite short for the short presentation duration, as compared to the binocular and transparent conditions, leaving minimal room for improvement. Second, and more importantly, we discussed that abnormal fusion only occurs within the first ~200 ms of dichoptic presentation. When the stimulus is present for longer, abnormal fusion still occurs at the beginning of presentation. The additional time that the stimulus is present, during which abnormal fusion has presumably ended, does not contribute to better or worse change detection. This suggests that interocular conflict attracts attention only during the first phase of presentation, and that abnormal fusion is the cause of this. We further discuss this issue in the General Discussion.

[2] Due to the many comparisons, we corrected *p* values according to the method of Bonferroni.

Note that reaction times for the stimulus duration of 240 ms were slower than those for the same duration in Experiment 1. However, as compared to Experiment 1, in which the stimulus was off for 80 ms, the stimulus was off for 360 ms in this particular condition of Experiment 2. The increase in reaction times with increasing time that the stimulus is off is in line with Rensink, O'Regan, and Clark (1997), who observed the same dependency of reaction times on the duration that the stimulus is off.

General discussion

The present study shows that change blindness is attenuated when the change is monocular: When both eyes view identical images, a change is detected faster when it occurs in only one of the images, as compared to when it occurs in both images. Moreover, in two experiments, we showed that superior detection for monocular changes is due to the conflict and not to a mixture (i.e., fusion) of the two half-images. These results show that interocular conflict is able to attract visual attention toward salient changes in images that remain largely unnoticed without the conflict. The attention-grabbing property of interocular conflict that we report here is in agreement with the finding that search for interocular conflict can be near-efficient and can produce a search asymmetry (i.e., search for interocular conflict among nonconflict distractors is faster than vice versa; Paffen et al., 2011). The present results extend these findings by showing that interocular conflict can facilitate change detection, much like exogenous cues, which are known to direct attention toward the location of the change (Cavanaugh & Wurtz, 2004; Scholl, 2000).

The results of Experiment 2 show that the detection of monocular changes does not improve when the phase during which the stimulus is present is increased. We suggest that this is due to the fact that interocular conflict attracts attention during the first phase of presentation, during which time the stimulus is abnormally fused (Liu et al., 1992; Wolfe, 1983). There is no extra gain from presenting the stimulus longer: When abnormal fusion has ended, the attention-attracting property of abnormal fusion has also ended.

Interestingly, the amount of abnormal fusion *decreases* with *increasing* contrast of the rival images (Liu et al., 1992). Paffen et al. (2011) showed that this observation explains why visual search for interocular conflict can be either fast (Paffen et al., 2011) or slow (Wolfe & Franzel, 1988): When the contrast of the rivaling images is high, the amount of abnormal fusion is low, and search for it is slow; when contrast is low, abnormal fusion is stronger, and search is faster. To evaluate the amount of abnormal fusion in our set of images, we calculated the root-mean square (RMS) contrast of the regions in the images that were conflicting. The RMS contrast of the conflicting regions used in Experiment 1 was 17% (*SD* 6%), which is considerably lower than the maximum RMS contrast possible (50%). Thus, since the contrast of the conflicting regions in the images was low, the images provided the conditions for abnormal fusion to occur. We therefore propose that abnormal fusion of dissimilar images is the source of the attention-grabbing capacity of interocular conflict shown here.

We further suggest that our results point to a bottom-up saliency map in V1 (Li, 2002; Zhaoping, 2008). According to this idea, saliency in an image is constructed by graded responses of V1 cells tuned to such basic features as contrast and color (Li, 2002). Since interocular conflict originates from conflict between monocular information gathered from the two eyes, and since V1 is known to be the last station where many cells are monocular (Hubel & Livingstone, 1987; Hubel & Wiesel, 1968), we suggest that the ability of interocular conflict to attract attention arises at the level of V1.

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