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Bilateral attentional advantage on elementary visual tasks

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ABSTRACT

We examined interactions between and within the left and right visual hemifields using elementary visual tasks. Each trial required identifying a letter at fixation and then either discriminating the orientation of (experiment 1) or detecting (experiment 2) peripheral Gabor targets. On half the trials Gabor distracters were presented between the Gabor targets, and were either restricted to one lateral hemifield (unilateral condition) or presented across the left and right hemifields (bilateral condition). Orientation discrimination and detection each exhibited bilateral superiority only when distracters were present. The results confirm bilateral superiority in attentional selection, even on these most elementary visual tasks.

1. Introduction

Our visual system has its limits. In principle, the visual system's limits could be uniform within and across the left and right hemifields. This study was conducted to determine the extent to which two elementary visual tasks – discrimination and detection – depend on whether stimuli are positioned in one versus two lateral hemifields. We use the term 'unilateral' to describe stimulation restricted entirely to the left hemifield or entirely to the right hemifield, and the term 'bilateral' to describe stimulation distributed across the left and right hemifields.

Previous research on various relatively high-level visual tasks has suggested that the visual system's limits are not uniform within and across the lateral hemifields, and instead exhibit a bilateral (across hemifield) advantage. For example, character discrimination (Ludwig, Jeeves, Norman, & DeWitt, 1993; Sereno & Kosslyn, 1991) and letter identification in crowded displays (Awh & Pashler, 2000; Chakravarthi & Cavanagh, 2006) are both better when the targets are presented bilaterally than when presented unilaterally. The ability to track rotating disks for three seconds (a long duration by low-level psychophysical standards) is also characterized by bilateral superiority. Specifically, Alvarez and Cavanagh (2005) presented a pair of rotating disks unilaterally or bilaterally while participants tracked a target on one or both of the disks. When two targets were presented within the same hemifield (unilateral trials), participants could accurately track one of the targets but performance on the second target fell to chance. By contrast, participants could track two targets just as well as one target if the two targets were positioned in separate lateral hemifields (bilateral trials). This pattern of results is consistent with independent resources for attentional selection in the left and right visual hemifields, and shared resources within each hemifield.

Motivated by the above-mentioned studies that tested relatively high-level stimuli (language dependent symbols) and tasks (motion tracking for three seconds), here we extended the exploration of laterality effects to low-level stimuli and tasks. Gabor patches were chosen as low-level stimuli because their luminance profiles provide a good match to the receptive fields of neurons in the early visual pathway (Marcelja, 1980). Similarly, orientation discrimination and detection were chosen as low-level tasks because both are easily relatable to the activity of neurons in the early visual pathway (Regan & Beverley, 1985; Westheimer, Shimamura, & McKee, 1976). Notably, orientation discrimination and detection are controlled by separable neural events (Westheimer et al., 1976; Regan & Beverley, 1985), with detection occurring earliest in the sequence. Investigating both of these tasks therefore permitted the possibility of determining whether laterality effects are present at the earliest stage (i.e., detection), or emerge soon thereafter (e.g., discrimination).

Other aspects of the present stimuli and tasks render various types of target–distracter phenomena more or less likely. For example, the present stimuli and tasks make the phenomenon of spatial crowding unlikely for several reasons. First, spatial 'crowding occurs only in tasks that cannot be done based on a single detection by coarsely coded feature detectors' (Pelli, Palomares, & Majaj, 2004, p. 1136). Contrarily, we explicitly chose Gabor stimuli

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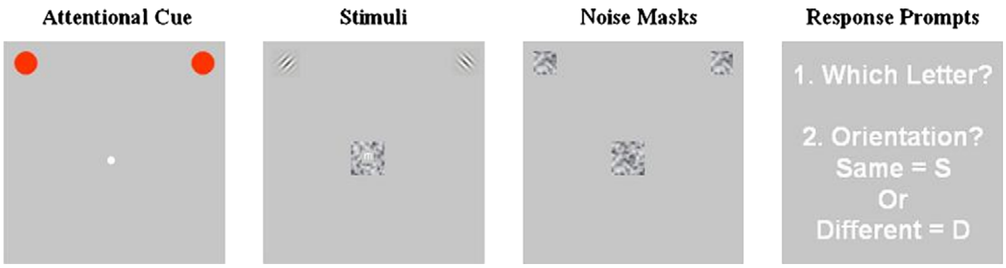

Fig. 1. Stimulus sequence for experiment 1A. The actual stimulus parameters are detailed in the text.

and elementary tasks to probe coarsely coded feature detectors in the early visual pathway (Marcelja, 1980; Regan & Beverley, 1985; Westheimer et al., 1976). Second, spatial crowding occurs when the center-to-center distance between targets and distracters is 0.1 times the target eccentricity in the tangential direction, and 0.5 times the target eccentricity in the radial direction (Toet & Levi, 1992). Our distracters were positioned beyond this bound for spatial crowding. Third, the brevity of our multiple item displays created time pressure that is less characteristic of spatial crowding than of temporal crowding (Pelli et al., 2004). Temporal crowding is a form of inappropriate target–distracter integration that occurs – independent of spatial proximity – when stimuli are flashed briefly enough to overload attentional selection (Pelli et al., 2004). The failure of attentional selection that characterizes temporal crowding would be evidenced on our detection task to the extent that distracters are mistaken for physically absent targets, i.e., a distracter-induced increase in 'false alarms'. A distracter-induced reduction in 'hits' would instead implicate surround suppression, the phenomenon in which sensitivity to a target's luminance contrast is reduced by a spatially displaced distracter (Petrov, Popple, & McKee, 2007). In short, the present stimuli and tasks preclude spatial crowding (as defined by Pelli et al., 2004) while creating the opportunity to test diverging predictions. Temporal crowding predicts distracter-induced increases in false alarms; surround suppression predicts distracter-induced decreases in hits.

To anticipate the present results, a bilateral advantage emerged reliably on each task – but only when the Gabor targets had to be discriminated or detected *to the exclusion of the distracters*. Distracters on the detection task did not reduce the visibility of physically present targets, but rather increased false alarms when targets were physically absent. This inappropriate integration of the distracters is characteristic of the temporal crowding that arises when briefly flashed displays overload attentional selection (Pelli et al., 2004). The present findings therefore independently confirm the previously reported bilateral advantages in attentional selection (Alvarez & Cavanagh, 2005; Awh & Pashler, 2000; Chakravarthi & Cavanagh, 2006) and extend that principle to the most elementary visual tasks of Gabor orientation discrimination and detection.

2. Discrimination experiments

2.1. Experiment 1A: orientation discrimination

2.1.1. Method

Some portions of the Method were identical to those of Matthews, Rojewski, and Cox (2005), and Strong, Kurosawa, and Matthews (2006). All portions of the Method are described here again for completeness.

2.1.2. Apparatus

The experiment was conducted on a 21 in. (53.34 cm) ViewSonic P225 monitor that was controlled by a Macintosh G4 computer with a 733 MHz processor and software from the psychophysics toolbox (Brainard, 1997; Pelli, 1997). The vertical refresh rate of the monitor was 120 Hz, and the spatial resolution was 1024 × 768 pixels. A chin rest helped to stabilize head position at 57 cm from the monitor.

2.1.3. Discriminanda

The discriminanda were achromatic Gabor patches, created by multiplying a sinusoidal luminance profile by a two-dimensional Gaussian envelope. The Gabor patches had maximum (108.00 cd/m^2) and minimum (5.83 cd/m^2) luminances that rendered high contrast (Michelson contrast = 89.76%) within the apparently gray surround (16.1 cd/m^2). The spatial frequency was 1.286 cycles per degree; each Gabor patch comprised four randomly phase-shifted light-dark cycles that collectively spanned a 3.2 × 3.2 deg (84 × 84 pixels) square region. The discriminanda were oriented at either 45 or 135 deg, randomly.

2.1.4. Stimulus sequence

The stimulus sequence is shown in Fig. 1. Each trial began with a central white fixation circle (99 cd/m^2; 72.02% contrast; 0.19 deg diameter) that appeared simultaneously with a pair of peripheral cues. The peripheral cues were equiluminant solid red circles[1] (16.1 cd/m^2; CIE 0.615, 0.345; 3.2 deg (84 pixel) diameter) at the positions where the discriminanda (Gabor patches) were to appear. A computerized voice synchronized with the peripheral visual cues also indicated whether the two discrminanda on the present trial were to appear in the 'top', 'bottom', 'left', or 'right' quadrants. Within each quadrant, the nearest corner of the square region that contained the discriminandum was, diagonally, 12.3 deg from fixation. The center of each discriminandum was, diagonally, 14.55 deg from fixation. After 350 ms, the peripheral cues were replaced by the gray surround (16.1 cd/m^2) for 200 ms. Subsequently, the discriminanda appeared at the cued positions while one of 15 randomly selected letters (31.20 cd/m^2; 31.92% contrast; 12 point Helvetica, lower case) appeared at fixation, all for 183 ms (22 frames). The central letter was contained in a small gray square (16.1 cd/m^2; 0.44 deg or 12 pixels per side) which was inscribed in a larger square (1.33 deg or 36 pixels per side) of noise that rendered the central letter difficult to identify unless fixated directly. The noise surrounding the letter's region comprised 0.11 deg (3 × 3 pixel) squares that were either dark or light (respectively, 1.6 or 99 cd/m^2; 96.82% contrast), randomly. To reduce neural persistence, the central letter and all Gabor patches were followed by noise masks for 8.33 ms (one frame). The central letter was replaced by noise with parameters identical to those in its surround. The noise that replaced each Gabor patch comprised 49 (7 rows by 7 columns) separate 0.44 deg squares (12 pixels on each side) that were either dark or light, randomly. The actual dark and light luminance values within the mask for each Gabor patch depended

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[1] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.

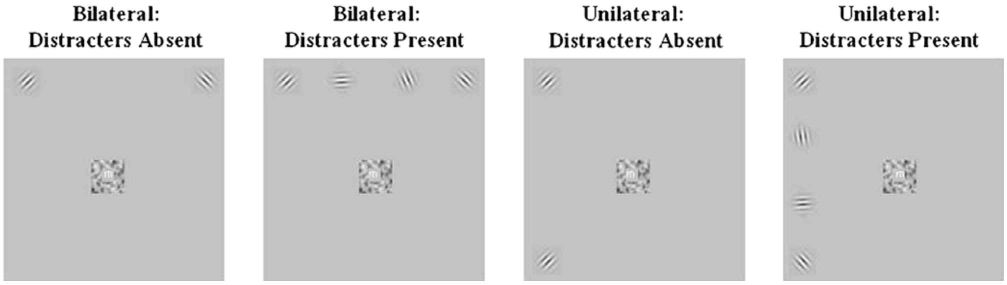

Fig. 2. Stimuli for experiment 1A. Sample stimuli from the bilateral condition and unilateral condition are shown in the left and right pairs of panels, respectively. On distracter trials (second and fourth panels), the distracters were presented between the two corner targets. The center-to-center distance between a target and the nearest distracter was beyond the critical region for spatial crowding (Toet & Levi, 1992).

on the participant's performance, and will be described below in the Procedure.

2.1.5. Task

The task on each trial was two-fold. First, to control fixation, the participant was required to correctly identify the central letter. An incorrect letter response immediately aborted the trial, and automatically restarted the trial sequence.[2] If the letter response was correct, then the participant judged the Gabor patches at the two peripherally cued locations to be either the same or different in orientation. To maintain motivation, immediate auditory feedback identified each letter response and each orientation response as either correct or incorrect. The computer also announced the percentage of correct letter responses and the percentage of correct orientation responses after every 80 trials.

2.1.6. Participants

Denison University's Human Subject Committee approved the study, which was conducted with the understanding and written consent of each participant. Fifty-two naive Denison University undergraduates completed experiment 1A. Each participant had normal or corrected-to-normal acuity.

2.1.7. Procedure: practice trials

Participants completed a series of practice trials to establish that the task was understood, i.e., could be performed at greater-than-chance levels, before the actual trials began. Initially, each participant was required to make ten consecutive correct responses at each of the following three stimulus durations before proceeding: 2000, 1000, and 500 ms. In those initial practice trials, there were no masks. Subsequently, the masks were added and each participant was required to make ten consecutive correct responses to 500 ms stimuli. Lastly, the 500 ms stimuli were masked and Gabor distracters were added between the discriminanda, as shown in the second and fourth panels of Fig. 2. Participants were again required to make 10 consecutive correct responses – which could occur by chance with a probability of only 1/1024. Each participant successfully met this behavioral criterion, indicating that any performance limitations on the subsequent 200 ms actual trials would be sensory rather than conceptual.

2.1.8. Procedure: actual trials

The four experimental conditions in experiment 1A are shown in Fig. 2. The pair of discriminanda on each trial appeared in the top or bottom quadrants randomly on bilateral trials (left panels), and in the left or right quadrants randomly on unilateral trials (right panels). Within each of those two laterality conditions, a pair of Gabor distracters was either absent (first and third panels), or presented at even spatial intervals between and co-linearly with the discriminanda (second and fourth panels). Specifically, the center-to-center distance between a discriminandum and the nearest Gabor distracter was 7.1 deg, which is beyond the critical region for spatial crowding (Toet & Levi, 1992).[3] Each Gabor distracter was centered 11 deg from fixation, randomly oriented, randomly phase shifted, but identical to the discriminanda in all other ways. All Gabor distracters and discriminanda were followed by noise masks. The initial luminance contrast of the noise masks was 6%. After every ten trials, the luminance contrast of the noise masks was set according to the cumulative percentage of correct orientation responses: 6% contrast for <68% correct; 15% contrast for <71% correct; 45% contrast for <74% correct; and 90% contrast for >74% correct. This reduced floor and ceiling effects. For each participant, the various experimental conditions (shown in Fig. 2) were block-randomly sequenced. The target orientations were the same on half the trials, and differed by 90 deg on the remaining trials, randomly.

2.1.9. Procedure: data analysis

In experiment 1A there were two independent variables, laterality (bilateral versus unilateral) and distracters (absent versus present). The dependent variable – orientation discrimination (d') – was computed using standard signal detection procedures (Green & Swets, 1966). A performance level of 84% correct without response bias corresponded to $d' = 1.0$. Hits and false alarms were defined, respectively, as 'different' responses to differently oriented versus identically oriented discriminanda. There were 20 chances to hit and 20 chances to false alarm (40 trials total) in each of the four stimulus conditions for each participant. Unless otherwise noted, we used a within subject *t*-test to directly evaluate the laterality effect (i.e., bilateral versus unilateral discriminability) in each distracter condition. Because these were planned (*a priori*) comparisons – indeed, the very motivation for the study – we did not evaluate laterality by distracter interactions, and made no adjustment for cumulative type 1 error (Keppel, Saufley, & Tokunaga, 1992). For each *t* statistic, however, partial η^2 is reported as an index of effect size independent of statistical significance. Lastly, the error bars shown on figures throughout this study reflect 1 *SEM*, and asterisks indicate significant differences in the laterality variable.

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[2] In all experiments reported here, the accuracy of the letter response for each participant far exceeded the chance-performance level of 0.067% correct.

[3] Toet and Levi (1992) found that spatial crowding occurs when the center-to-center distance between targets and distracters is 0.1 times the target eccentricity in the tangential direction, and 0.5 times the target eccentricity in the radial direction. Our targets were centered 14.55 deg diagonally from fixation, rendering target-distracter critical spacings of 1.455 and 7.275 deg along the tangential and radial directions, respectively. Our distracters were centered 7.1 deg from the nearest target and halfway between the tangential and radial axes, i.e., well beyond the bound for spatial crowding at that position.

2.1.10. Results and discussion

The data from the 52 participants who completed experiment 1A are shown in Fig. 3. Visual inspection immediately reveals that bilateral orientation sensitivity ($d' = 0.813$) and unilateral orientation sensitivity ($d' = 0.794$) were virtually identical when there were no distracters ($t(51) = 0.373$, $p = 0.711$, n.s., partial $\eta^2 = 0.003$). By contrast, when distracters were present, orientation sensitivity for bilateral stimulation ($d' = 0.377$) was more than twice that for unilateral stimulation ($d' = 0.133$). A *t*-test confirmed that the bilateral superiority was significant in the target-present condition ($t(51) = 4.758$, $p < 0.001$, partial $\eta^2 = 0.307$). In short, experiment 1A provides evidence for distracter-induced bilateral superiority in orientation discrimination.

In principle, the bilateral superiority in experiment 1A could have emerged because of the distracters per se, or simply because the distracters reduced the overall performance level. In other words, it is possible that bilateral superiority occurs whenever performance is relatively low (for any reason), but not when performance is relatively high. We next explored this possibility by considering a manipulation in which d' levels were systematically reduced – even in the absence of distracters – by shortening the stimulus duration.

2.2. Experiment 1B: stimulus duration

2.2.1. Method

Fourteen of the 52 participants who completed experiment 1A also completed experiment 1B on stimulus duration. Previous work indicated that orientation sensitivity improves significantly with masked-stimulus duration across the tens of ms after reliable orientation sensitivity first emerges (Matthews et al., 2005; Strong et al., 2006). The present experiment 1B assessed the extent to which laterality effects in orientation sensitivity depend on stimulus duration, even in the absence of distracters. Consequently, no distracters were presented. The two new stimulus durations in this experiment were 50 ms (6 frames) and 117 ms (14 frames), each temporally centered within the 183 ms (22 frames) duration that had been tested in experiment 1A. All other aspects of the Method for experiment 1B were identical to those for experiment 1A.

2.2.2. Results and discussion

Fig. 4 shows the data from the 14 (of 52) participants who completed experiment 1A (Fig. 3), and who also completed experiment 1B. The left panel of Fig. 4 confirms that in experiment 1A – when the stimulus duration was 183 ms – these 14 participants exhibited the same general pattern as that in Fig. 3. That is, orientation discrimination for these 14 participants was characterized by comparable bilateral and unilateral performance when distracters were absent ($t(13) = 1.972$, $p = .07$, n.s., $\eta^2 = 0.230$), and significant bilateral superiority when distracters were present ($t(13) = 4.036$, $p = .001$, partial $\eta^2 = 0.556$).[4] However, as is visually evident in the right panel of Fig. 4, when distracters were absent bilateral superiority was non-significant at stimulus durations of 50 ms ($t(13) = 1.365$, $p = 0.195$, n.s., partial $\eta^2 = 0.125$), and 117 ms ($t(13) = 0.164$, $p = 0.872$, n.s., partial $\eta^2 = 0.002$). Importantly, bilateral superiority was non-significant at 50 ms with no distracters even though bilateral performance in that condition ($d' = 0.488$) was slightly lower than that at 183 ms with distracters ($d' = 0.532$), where significant bilateral superiority occurred. This pattern rules out the possibility that bilateral superiority emerges whenever performance is relatively low (e.g., bilateral $d' < 0.532$). Instead, the critical factor appears to be the presence of distracters. Indeed, unilateral performance in the 183-ms-distracter condition ($d' = 0.117$) was one-third that of the 50-ms-no-distracter condition ($d' = 0.354$), and that difference was significant ($t(13) = 2.216$, $p = 0.045$, partial $\eta^2 = 0.274$). This demonstrates how vulnerable unilateral performance is to distracters.

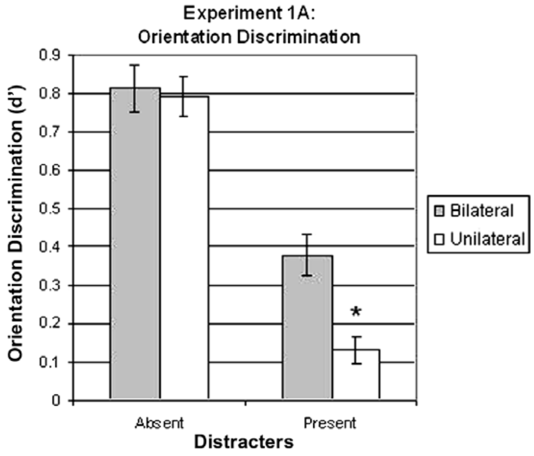

Fig. 3. Data are shown from the 52 participants who completed experiment 1A, on orientation discrimination.

2.2.3. Detection experiments

In addition to orientation discrimination experiments 1A and 1B, we conducted a series of five detection experiments (2A through 2E). As noted in the Introduction, orientation discrimination and detection are controlled by separable neural events (Regan & Beverley, 1985; Westheimer et al., 1976), with detection occurring earliest in the sequence. Experiments 2A through 2E therefore allowed us to determine the extent to which the distracter-induced bilateral superiority that occurred in orientation discrimination also extends to the earlier stage of detection.

2.3. Experiment 2A: one versus two targets

2.3.1. Method

Twenty-four new naïve participants completed experiment 2A. The trial sequence was identical to that of the primary discrimination task (experiment 1A, as shown in Fig. 1) except that the second prompt read, “Target present? Yes (y) or No (n)”. Gabor targets were present on only half the trials, randomly. Hits and false alarms corresponded to ‘yes’ responses in the presence and absence of targets, respectively. Each participant completed a two-target block and a one-target block. The block sequence was counter-balanced across participants. In the two-target block, target-present trials were identical to those in our primary discrimination task (experiment 1A), as shown in Fig. 2. However, correct discrimination (experiment 1A) required information from *both* spatially cued positions, whereas information from just *one* spatially cued position was sufficient for correct responses in the two-target detection block. Therefore one of the two targets in the two-target detection block provided redundant information. The extent to which participants exploited that redundant information was revealed by a comparison to performance in the one-target block. On each target-present trial in the one-target block

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[4] When the distracters were absent in the 183 ms condition, bilateral performance was not significantly greater than unilateral performance ($p = 0.07$), but the difference approached the $p = 0.05$ alpha level. Thus, the statistically significant bilateral superiority when the distracters were present could reflect mere chance variation beyond the near-significant bilateral bias without distracters. To investigate this possibility, an Analysis of Covariation (ANCOVA) was conducted for the distracter-present condition, after defining the bilateral bias in the distracter-absent condition as a covariate. Specifically, the covariate was defined as the bilateral-versus-unilateral difference when distracters were absent. The ANCOVA revealed that bilateral superiority when the distracters were present remained statistically significant ($F(1,12) = 9.685$, $p = .009$, partial $\eta^2 = 0.447$).

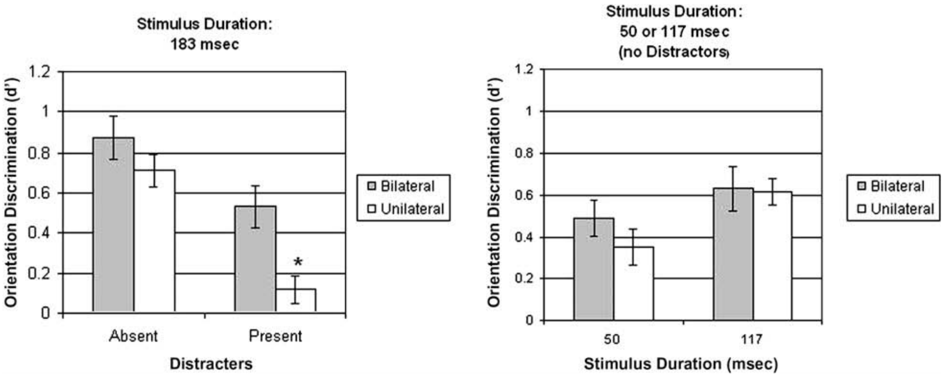

Fig. 4. Data are shown from the 14 participants who completed both experiments 1A (183 ms duration; left panel) and 1B (50 and 117 ms duration, no distracters; right panel), on orientation discrimination.

only one of the two targets, chosen randomly, was presented. Bilateral and unilateral trials in the one-target block were defined by the positions of the attentional cues. All other aspects of the Method in experiment 2A were identical to those in experiment 1A.

2.3.2. Results and discussion

That distracters impair unilateral performance more than bilateral performance was also evident for the 24 new naïve participants who completed experiment 2A – our first experiment on detection. Data from experiment 2A are shown in Fig. 5, where the conventions are the same as those used above for orientation discrimination (Fig. 3). As was the case for orientation discrimination, the ability to detect targets did not depend on laterality when distracters were absent. This was true whether the display contained two targets (left panel, left bars; $t(23) = 1.136$, $p = 0.268$, n.s., partial $\eta^2 = 0.053$) or one target (right panel, left bars; $t(23) = 1.315$, $p = 0.201$, n.s., partial $\eta^2 = 0.070$). By contrast, when distracters were present, bilateral detection significantly exceeded unilateral detection in the two-target condition (left panel, right bars; $t(23) = 4.823$, $p < 0.001$, partial $\eta^2 = 0.503$) and in the one-target condition (right panel, right bars; $t(23) = 4.670$, $p < 0.001$, partial $\eta^2 = 0.487$). In short, the data from experiment 2A indicate that distracter-induced bilateral superiority extends to the elementary task of detecting Gabor targets.

The data from experiment 2A also indicated that mean detection (d') was 1.002 for two targets (left panel) versus 0.844 for one target (right panel), and that difference was statistically significant ($t(23) = 2.277$, $p = 0.032$, partial $\eta^2 = 0.184$). However, the magnitude of the difference ($d' = 0.158$) between the two- and one-target conditions indicates that participants were only modestly able to exploit the redundant information (i.e., the second target) on the detection task.

2.4. Experiment 2B: spatial frequency

2.4.1. Method

Twenty new naïve participants completed experiment 2B, which was designed to assess the spatial frequency dependence of laterality effects in detection. We tested two spatial frequencies (SFs). The high-SF (2.572 c.p.d.) and low-SF (0.643 c.p.d.) conditions differed from each other by two octaves, and were, respectively, twice and half the spatial frequency tested in experiment 2A. Accordingly, the size of the light and dark noise-mask-squares that followed each target and distracter was halved (high-SF conditions) or doubled (low-SF conditions) relative to experiment 2A. Trials were blocked by target-SF. Half of the participants completed the high-SF-target block first, the remaining participants completed the low-SF-target block first. Within each of the two target-SF blocks there were three block-randomized distracter conditions: no distracters; high-SF-distracters; and low-SF-distracters. All other aspects of the Method were identical to the 1-target condition in experiment 2A.

2.4.2. Results and discussion

Data from the 20 new naïve participants who completed experiment 2B are shown in Fig. 6, where visual inspection reveals spatial-frequency effects on both overall performance and the bilateral superiority in detection. Each will be described in turn.

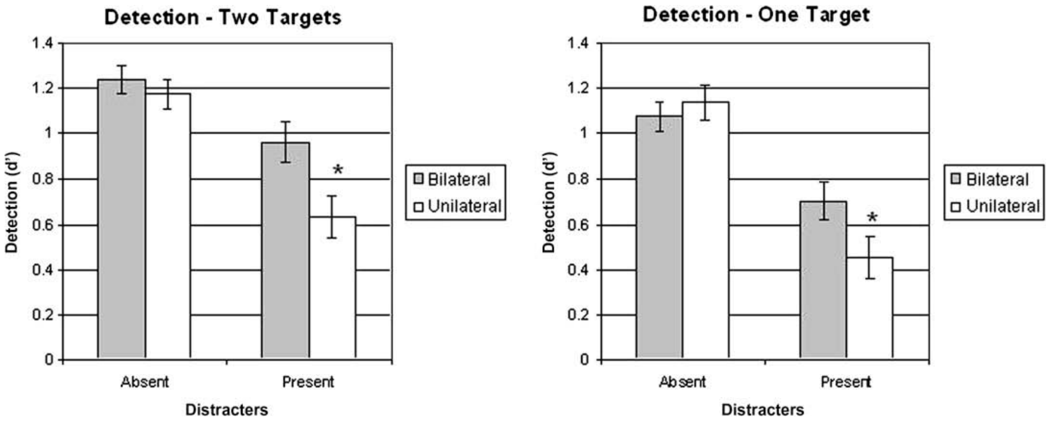

Fig. 5. Data are shown from the 24 new na participants who completed experiment 2A, on detection. The two- and one-target conditions are shown in the left and right panels, respectively.

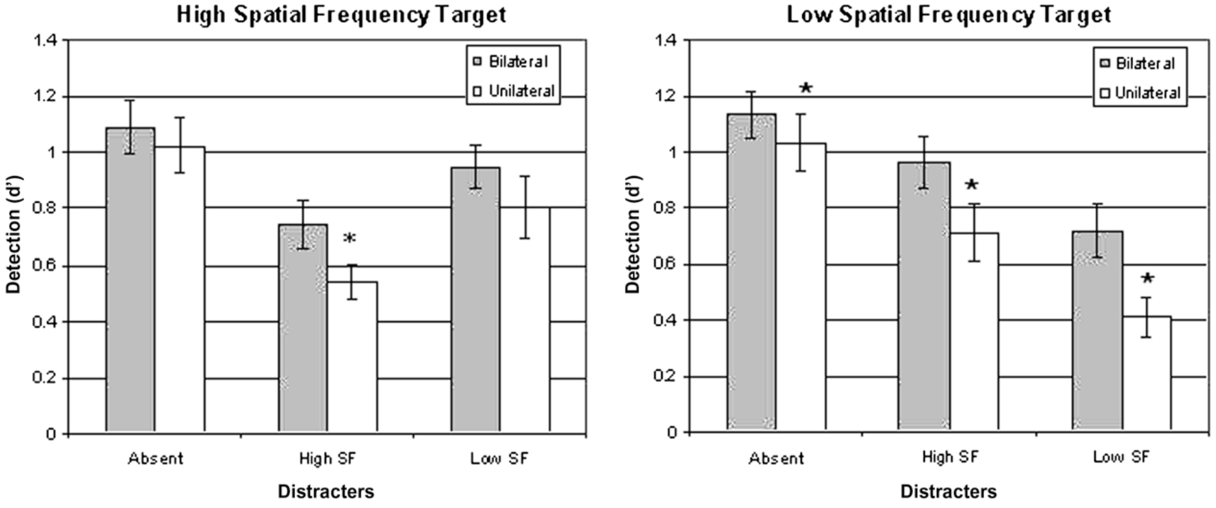

Fig. 6. Data are shown from the 20 new naive participants who completed experiment 2B, on target–distracter spatial-frequency relationships in detection. The high-SF and low-SF target conditions are shown in the left and right panels, respectively.

Each panel of Fig. 6 provides evidence for spatial-frequency effects on *overall performance*. For high spatial frequency targets (left panel), d' was significantly more impaired by high (center bars, mean $d' = 0.643$) than by low spatial frequency distracters (right bars, mean $d' = 0.875$) ($t(19) = 2.633$, $p = 0.016$, partial $\eta^2 = 0.267$). Conversely, for low spatial frequency targets (right panel), d' was significantly more impaired by low (right bars, mean $d' = 0.564$) than by high spatial frequency distracters (center bars, mean $d' = 0.836$) ($t(19) = 3.971$, $p = 0.001$, partial $\eta^2 = 0.454$).

Additionally, at each target-SF, *bilateral superiority* in detection was both statistically significant and largest when the distracter-SF matched the target-SF. Specifically, for high-SF targets (left panel), bilateral superiority was largest with high-SF distracters ($t(19) = 2.842$, $p = 0.010$, partial $\eta^2 = 0.298$), next largest with low-SF distracters ($t(19) = 1.794$, $p = 0.089$, n.s., partial $\eta^2 = 0.145$), and smallest when distracters were absent ($t(19) = 1.169$, $p = 0.257$, n.s., partial $\eta^2 = 0.067$). For low-SF targets (right panel), bilateral superiority was largest with low-SF distracters ($t(19) = 4.477$, $p < 0.001$, partial $\eta^2 = 0.513$), next largest with high-SF distracters ($t(19) = 2.811$, $p = 0.011$, partial $\eta^2 = 0.294$), and smallest when distracters were absent ($t(19) = 2.817$, $p = 0.041$, partial $\eta^2 = 0.201$). This pattern of outcomes demonstrates that bilateral superiority at each target-SF had both distracter dependence and some spatial frequency specificity. However, the bilateral superiority in detection was also evident, albeit to a lesser extent, even when the distracter-SF did not match the target-SF.[5] This implies that the spatial frequency tuning of the mechanisms responsible for the bilateral superiority in detection was likely broader than 2 octaves.

We were surprised by the significant bilateral superiority that occurred with low-SF targets in the absence of distracters. It is tempting to speculate that this effect obtained for low-SF but not high-SF targets because of the relatively coarse spatial resolution of attention (Intriligator & Cavanagh, 2001). To the extent that attentional resources are more available bilaterally than unilaterally, bilateral superiority would be more likely at lower SFs than at higher SFs. However, it is not obvious why attentional selection would be necessary in the *absence* of distracters, i.e., when attentional selection was not needed to exclude the distracters. We therefore suspect that the bilateral superiority in the low-SF-no-distracter condition may reflect mere chance variability. In any event, the effects sizes (partial η^2 values) reveal that – even for low-SF targets – bilateral superiority increased when distracters were added, and especially so when the target-SF and distracter-SF matched.

2.5. Experiment 2C: orientation

2.5.1. Method

Fifteen new naïve participants completed experiment 2C, which was designed to assess the orientation dependence of laterality effects in detection. The target orientation was oblique (45 or 135 deg randomly across trials) in one trial block, and cardinal (horizontal or vertical randomly across trials) in another trial block. Eight of the participants completed the oblique-target block first, the remaining participants completed the cardinal-target block first. Within the oblique-target block, there were three block-randomized distracter conditions: no distracters; randomly oriented distracters (as in all previous experiments); distracters that were identical to the target. Within the cardinal-target block there were also three block-randomized distracter conditions. The first was the no-distracters condition. The second contained distracters that were identical to each other, and had local orientations *perpendicular* to the global configuration: vertically oriented distracters on bilateral (horizontally aligned) trials; horizontally oriented distracters on unilateral (vertically aligned) trials. The third contained distracters that were identical to each other, and had local orientations *parallel* to the global configuration: horizontally oriented distracters on bilateral (horizontally aligned) trials; vertically oriented distracters on unilateral (vertically aligned) trials. This third condition allowed us to evaluate the extent to which laterality effects in detection depend on local and global co-linearity. All other aspects of the Method were identical to the 1-target condition in experiment 2A.

2.5.2. Results and discussion

Data from the 15 new naïve participants who completed experiment 2C are shown in Fig. 7, where bilateral superiority is visually evident whenever distracters were present. For oblique targets

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[5] As was the case for discrimination in experiment 1B, detection in experiment 2B was also characterized by a substantial bilateral-bias even in the absence of distracters. To control for this bias, ANCOVAs were conducted by defining the covariate as the bilateral-versus-unilateral difference in the absence of distracters, separately for the high-SF-target and low-SF-target conditions. The ANCOVAs revealed that the bilaterally superiority remained significant in the high-SF-target-hi-SF-distracter condition ($F(1,18) = 6.610$, $p = 0.019$, partial $\eta^2 = 0.269$), and in the low-SF-target-high-SF-distracter condition ($F(1,18) = 6.656$, $p = 0.019$, partial $\eta^2 = 0.270$), and in the low-SF-target-low-SF-distracter condition ($F(1,18) = 15.571$, $p = 0.001$, partial $\eta^2 = 0.464$).

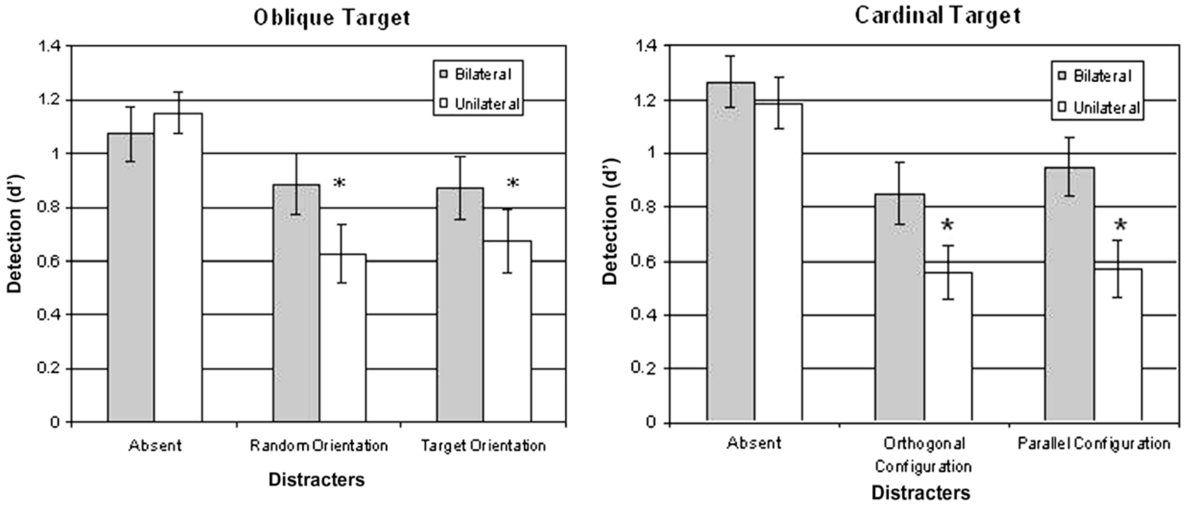

Fig. 7. Data are shown from the 15 new naive participants who completed experiment 2C, on target–distracter orientation relationships in detection. The oblique and cardinal-target conditions are shown in the left and right panels, respectively.

(left panel), detection did not depend on laterality when distracters were absent ($t(14) = 1.097$, $p = 0.291$, n.s., partial $\eta^2 = 0.079$), yet significant bilateral superiority occurred whether distracters were randomly oriented ($t(14) = 2.889$, $p = 0.012$, partial $\eta^2 = 0.373$) or iso-oriented ($t(14) = 2.312$, $p = 0.037$, partial $\eta^2 = 0.276$) with the targets. Similarly for cardinal targets (right panel), detection did not depend on laterality when distracters were absent ($t(14) = 0.906$, $p = 0.381$, n.s., partial $\eta^2 = 0.055$), yet significant bilateral superiority occurred whether the distracters' local orientation was perpendicular ($t(14) = 3.488$, $p = 0.004$, partial $\eta^2 = 0.465$) or parallel ($t(14) = 4.173$, $p = 0.001$, partial $\eta^2 = 0.554$) to the global configuration. Taken together, these data indicate that the distracter-induced bilateral superiority in detection was robust across the various target–distracter orientation relationships.

Given that spatial frequency and orientation are each elementary features that are relevant to visual neurons responsible for detection, why did the observed distracter effects depend on spatial frequency but not orientation? A plausible answer pertains to the manner in which our choice of stimuli likely influenced the participants' strategy. Recall that within each trial block of the present experiments the spatial frequency of the targets was fixed. The orientation of the targets, however, varied randomly between two orthogonal angles across trials. Consequently, the optimal strategy for detection would entail looking for the target's spatial frequency regardless of the target's orientation. This strategy would lead to the observed distracter effects: spatial-frequency dependence and orientation independence. An interesting implication from this is that the distracter effects did not depend simply on target–distracter similarity alone, but rather on whether the targets and distracters were similar on a feature that was *task-relevant*.

2.6. Experiment 2D: Striped versus solid distracters

2.6.1. Method

Forty new naïve participants completed experiment 2D, which was designed to further explore the distracter characteristics that generate bilateral superiority in detection. For each participant, two distracter categories were tested in separate trial blocks. One block comprised 'striped' distracters and the other block comprised 'solid' distracters. Half the participants completed the striped-distracter block first, and half completed the solid-distracter block first. The details of each distracter category will be described in turn.

The striped-distracter block comprised three block-randomly ordered distracter conditions: a no-distracter condition, a randomly oriented Gabor distracter condition (as in experiment 2A), and a bulls-eye distracter condition. The two bulls-eye distracters shown on each bulls-eye trial had opposite luminance phases (i.e., dark-center versus light-center), as schematized in the leftmost panel of Fig. 8a. Each bulls-eye distracter was identical to the Gabor stimuli in size, shape, duration, fundamental spatial frequency, and luminance contrast. Importantly, luminance contrast was evenly distributed across all orientations in the bulls-eye distracters, but concentrated at a single orientation in the Gabor distracters. This difference allowed us to assess the extent to which laterality effects in detection depend on how distracter luminance contrast is distributed across the orientation spectrum.

The solid-distracter block also comprised three block-randomly ordered distracter conditions: a mixed-polarity distracter condition, an all-white distracter condition, and a chromatic-distracter condition, respectively, schematized in the second, third, and fourth panels of Fig. 8a. In the mixed-polarity condition one of the two solid-disk distracters, chosen randomly, was dark gray in appearance (CIE 0.347, 0.346), having a luminance of just 3.99 cd/m^2. The other solid-disk distracter was white in appearance (CIE 0.316, 0.336), having a luminance of 65 cd/m^2. In the all-white condition both distracters were identical to the apparently white distracter presented in the mixed-polarity condition. In the chromatic-distracter condition one of the two distracters, chosen randomly, appeared green (CIE 0.295, 0.588) and the other appeared yellow (CIE 0.444, 0.476). The luminance of each was 65 cd/m^2. Importantly, *every* distracter in the solid-distracter condition had 60.30% luminance contrast with the apparently gray surround. The various solid distracters differed from each other only in chromaticity, and/or how the luminance was distributed across the distracters. Also, because the spatial frequency of the solid distracters was 0 c.p.d., the solid distracters represented an extension of the spatial-frequency manipulation in experiment 2B. All other aspects of the Method were identical to the 1-target condition in experiment 2A.

2.6.2. Results and discussion

Data from the forty new naïve participants who completed experiment 2D –solid versus striped distracters – are shown in Fig. 8b. Visual inspection of the two leftmost distracter conditions reveals the now familiar pattern. The laterality effect was non-sig-

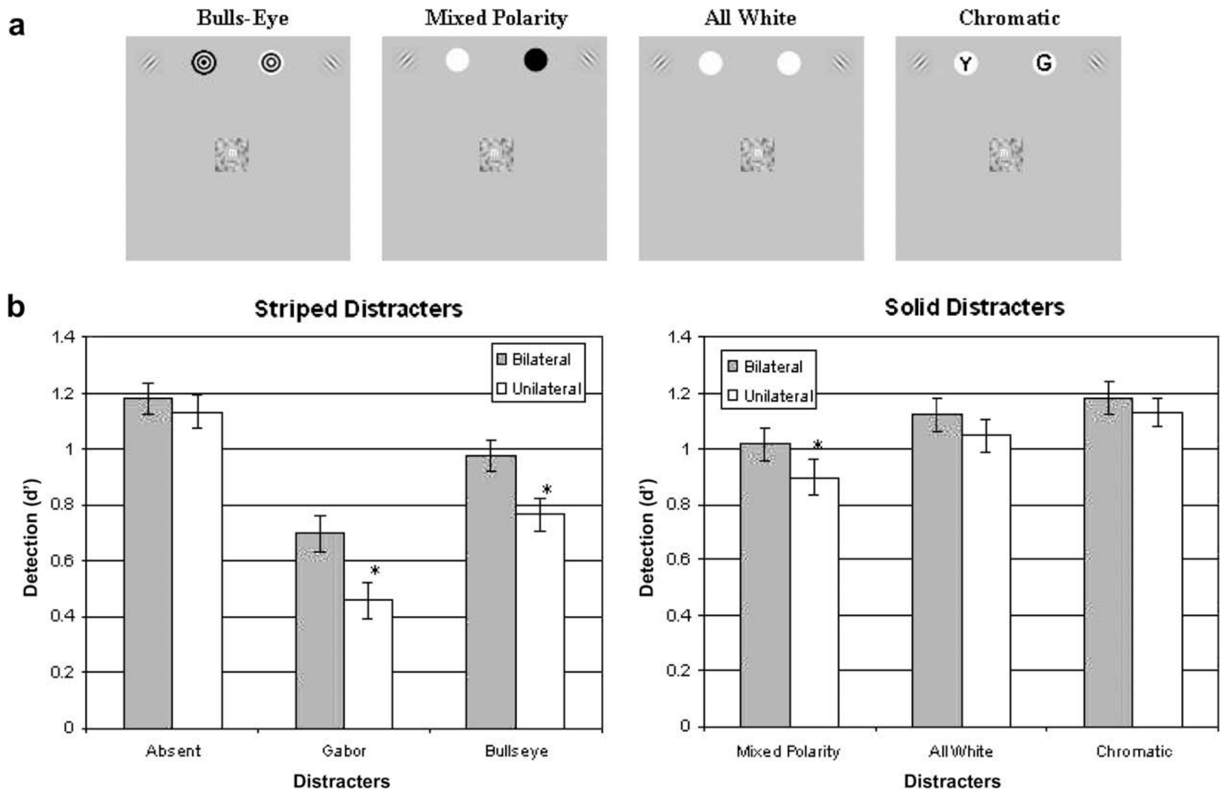

Fig. 8. (a) Schematic of Non-Gabor distracters used in experiment 2D, bilateral condition. The actual stimulus parameters are detailed in the text. (b) Data are shown from the 40 new naive participants who completed experiment 2D, on target–distracter similarity in detection. The "striped" and "solid" distracter conditions are shown in the left and right panels, respectively.

nificant when distracters were absent ($t(39) = 1.001$, $p = 0.323$, n.s., partial $\eta^2 = 0.025$), but significant bilateral superiority occurred when Gabor distracters were present ($t(39) = 4.239$, $p < 0.001$, partial $\eta^2 = 0.315$).

An additional pattern emerges in Fig. 8b when scanning the conditions to the right of the Gabor-distracter condition: Mean detection (d') *increased* monotonically while bilateral superiority *decreased* monotonically. These trends occurred as the targets and distracters became more dissimilar to each other.

The progression of target–distracter dissimilarity across the conditions in experiment 2D may provide some insight into the results from the Gabor distracter and bulls-eye distracter conditions. Overall detection was significantly lower with Gabor distracters (mean $d' = 0.5784$) than with bulls-eye distracters (mean $d' = 0.8716$) ($t(39) = 6.216$, $p < 0.001$, partial $\eta^2 = 0.498$). Additionally, although bilateral superiority was smaller for bulls-eye than for Gabor distracters whether expressed as the ratio of or difference between bilateral and unilateral detection, bilateral superiority was both significant and large for bulls-eye distracters ($t(39) = 4.307$, $p < 0.001$, partial $\eta^2 = 0.322$). Indeed, the partial η^2 value for bilateral superiority with bulls-eye distracters (0.322) was virtually identical to that with Gabor distracters (0.315). Recall that the bulls-eye and Gabor distracters had identical fundamental spatial frequencies but differed in how the luminance contrast was concentrated across the orientation spectrum. The large bilateral superiority in the bulls-eye condition therefore implies that the bilateral superiority in detection depended more on target–distracter similarity in spatial frequency than on target–distracter similarity in orientation. This implication from experiment 2D is consistent with those of experiments 2B and 2C.

Target-distracter similarity in spatial frequency may also provide some insight into the results from the remaining distracter conditions in experiment 2D (Fig. 8b). Overall detection in the mixed-polarity (MP) condition (mean $d' = 0.9578$) was significantly lower than that in the all-white (AW) condition (mean $d' = 1.0842$) ($t(39) = 3.812$, $p < 0.001$, partial $\eta^2 = 0.271$). Additionally, bilateral superiority was statistically significant (albeit modest) in the MP condition ($t(39) = 2.367$, $p = 0.023$, partial $\eta^2 = 0.126$) but not in the AW condition ($t(39) = 1.581$, $p = 0.122$, n.s., partial $\eta^2 = 0.060$). These differences might seem surprising given that the spatial frequency of each distracter was 0 c.p.d. in both the MP and AW conditions. However, if one considers the spatial distribution of luminances *across the two distracters* on each trial, the spatial frequency was higher in the MP condition than in the AW condition. Consequently, the target-SF (1.286 c.p.d.) more closely matched the distracter-SF in the MP condition than in the AW condition. Also, bilateral superiority was non-significant and comparable in the AW ($t(39) = 1.581$, $p = 0.122$, n.s., partial $\eta^2 = 0.060$) and the chromatic-distracter ($t(39) = 1.108$, $p = 0.275$, n.s., partial $\eta^2 = 0.030$) conditions, which comprised distracters that were identical to each other – but very different from the targets – in luminance defined spatial frequency. In short, the trends across Fig. 8b indicate that target–distracter similarity in spatial frequency was an important stimulus feature for generating bilateral superiority on the present detection task.

2.7. Experiment 2E: distracter displacement control

2.7.1. Method

Eighteen new naïve participants completed experiment 2E, which was designed to control two factors that co-varied with laterality in the preceding experiments. One previously co-varying factor was the *orientation* of the target–distracter displacement: the distracters in the preceding experiments were horizontally displaced from bilateral targets, but vertically displaced from unilateral targets. The other previously co-varying factor was the *distance* from each distracter's center to the vertical meridian; 3.6 deg for bilateral distracters versus 10.6 deg for unilateral distracters (2 versus 9 deg, respectively, for each distracter's nearest point). The primary question to be addressed in experiment 2E, therefore, was whether distracter-induced bilateral superiority would occur after controlling both the orientation of the target–distracter displacement and the distracters' distance from the vertical meridian.

To control these two previously co-varying factors, each participant in experiment 2E completed two trial blocks. In one trial block the distracters were collinear with the target positions, as in the preceding experiments and as shown (again) in the first and third panels of Fig. 9. The other trial block comprised distracters in the control positions, which were simply new combinations of the distracter positions from the collinear configurations. In the bilateral control configuration (second panel of Fig. 9), the distracters were vertically displaced from the cued target locations and centered 10.6 deg from the vertical meridian. In the unilateral control configuration (fourth panel of Fig. 9), the distracters were horizontally displaced from the cued target locations and centered 3.6 deg from the vertical meridian. Half of the participants completed the collinear-configuration block first, and the remaining participants completed the control-configuration block first. All other aspects of the Method were identical to the 1-target condition in experiment 2A.

2.7.2. Results and discussion

Data from the 18 new naïve participants who completed experiment 2E are shown in Fig. 10. Despite complete counter-balancing across the collinear and control configurations (see Fig. 9), visual inspection of the leftmost panel in Fig. 10 reveals the pattern seen in all preceding experiments. Specifically, the laterality effect was non-significant when distracters were absent ($t(17) = 0.700$, $p = 0.493$, n.s., partial $\eta^2 = 0.028$), but significant bilateral superiority occurred when distracters were present ($t(17) = 2.640$, $p = 0.017$, partial $\eta^2 = 0.291$). This indicates that significant distracter-induced bilateral superiority emerges even after controlling (1) the orientation of the target–distracter displacement and (2) the distracters' distance from the vertical meridian.

The center and left panels of Fig. 10 reveal information about *how* the distracters impaired detection. In principle, the distracter-induced impairments in detection could reflect temporal crowding (inappropriate integration), or surround suppression (inhibition), or both. In the context of the present experiment, temporal crowding would be evident to the extent that distracters were mistaken for physically absent targets. Surround suppression would be evident to the extent that the distracters reduced the visibility of physically present targets. Importantly, these two phenomena make diverging predictions in experiment 2E. Temporal crowding predicts a distracter-induced *increase in the false alarm rate* i.e., an increase in 'yes' responses on target-absent trials. Contrarily, surround suppression predicts a distracter-induced *decrease in the hit rate* i.e., a decrease in 'yes' responses on target-present trials.

Visual inspection of the center panel in Fig. 10 reveals support for temporal crowding. Specifically, distracters significantly increased the false alarm rate in the bilateral condition (from 0.217 to 0.344; $t(17) = 3.305$, $p = 0.004$, partial $\eta^2 = 0.391$), and in the unilateral condition (from 0.225 to 0.410; $t(17) = 3.629$, $p = 0.002$ partial $\eta^2 = 0.437$). Moreover, the bilateral (0.217) and unilateral (0.225) false alarm rates were virtually identical when distracters were absent ($t(17) = 0.508$, $p = 0.618$, n.s., partial $\eta^2 = 0.015$), but when distracters were present the false alarm rate was significantly greater unilaterally (0.410) than bilaterally (0.344) ($t(17) = 2.653$, $p = 0.017$, partial $\eta^2 = 0.437$). Taken together, these false-alarm data indicate that (1) the distracters induced temporal crowding, and that (2) the temporal crowding effect was significantly larger unilaterally than bilaterally. Because temporal crowding reflects a failure of attentional selection (Pelli et al., 2004), the false alarm data in experiment 2E implicate a bilateral advantage in attentional selection.

In contrast, visual inspection of the right panel in Fig. 10 reveals that the hit rates fluctuated only modestly across conditions. *T*-tests indicated that all of these fluctuations were non-significant. This disconfirms the predictions from surround suppression.

In summary, experiment 2E generated three notable findings. First, the distracter-induced bilateral superiority remained significant even after controlling the orientation of the target–distracter displacement and the distracters' distance from the vertical meridian. Second, the distracters induced significant increases in false alarm rates but did not significantly alter hit rates – a finding that implicates temporal crowding rather than surround suppression. Third, the temporal crowding effect was significantly larger unilaterally than bilaterally, consistent with a bilateral advantage in attentional selection.

3. General discussion

This study was conducted to explore bilateral (cross-hemifield) versus unilateral (within-hemifield) differences on elementary visual tasks. Each trial comprised a foveal component and a peripheral component. The foveal component required identifying a low contrast letter embedded in noise. This ensured fixation and rendered the subsequent peripheral component more difficult. The peripheral component required either discriminating the orientation of Gabor targets (experiment 1) or detecting them (experiment 2). Hemifield capacity was tested by the presence or absence of Gabor distracters positioned between the peripherally cued

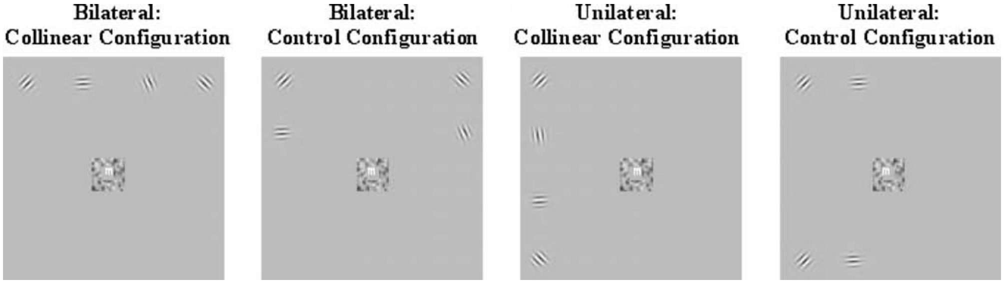

Fig. 9. Distracter configurations for experiment 2E. In the collinear distracter configurations that were used in the preceding experiments, the bilateral distracters (first panel) were horizontally displaced from the targets and relatively near (3.6 deg) to the vertical meridian; the unilateral distracters (third panel) were vertically displaced from the targets and relatively far (10.6 deg) from the vertical meridian. These differences were completely counter-balanced in experiment 2E with the bilateral (second panel) and unilateral (fourth panel) control configurations. Targets remained in the corners, as in all preceding experiments.

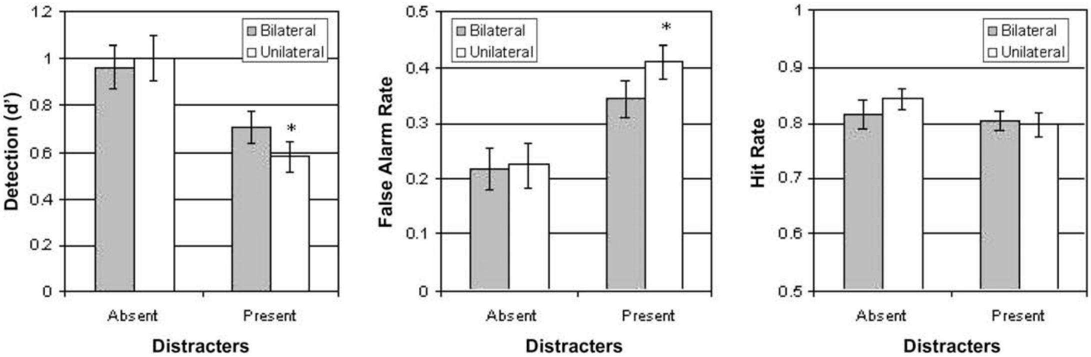

Fig. 10. Data are shown from the 18 new naive participants who completed experiment 2E, on target–distracter offset relationships. Detection (d') results are shown in the left panel, false alarms and hits are shown in the center and right panels, respectively.

Gabor target locations. A bilateral advantage emerged reliably on each peripheral task – but only when the Gabor targets had to be discriminated or detected *to the exclusion of the distracters*.

The consistency of the distracter-induced bilateral advantage is readily seen in Table 1. The table summarizes the *p* values (center, light gray columns) and effect sizes (right, dark gray columns) for the twenty task and stimulus variations tested here – each shown in a different row. Each column reflects the bilateral versus unilateral comparison, either when distracters were absent (first and third data columns) or present (second and fourth columns). Within every experiment, the bilateral advantage became larger (*p* values decreased; partial η^2 values increased) when distracters were added to the display. Notably, the distracters increased the *magnitude* of the bilateral superiority even in those conditions that exhibited considerable bilateral superiority when distracters were absent (experiment 1B, and experiment 2B low-SF target).

Visual inspection of Table 1 also reveals that the magnitude of the distracter-induced bilateral superiority depended on some elementary stimulus features more than others. As can be seen in the rows with bold type, bilateral superiority was particularly enhanced (i.e., large partial η^2 values) when distracters matched the targets in fundamental spatial frequency. By contrast, a target–distracter match in orientation did not reliably enhance the magnitude of the distracter-induced bilateral superiority. For example, bilateral superiority was slightly larger when the distracters were randomly oriented than when the distracters matched the oblique target orientations in experiment 2C. Similarly, in experiment 2D, bulls-eye distracters generated a large bilateral superiority effect despite the fact that their orientation profiles differed markedly from those of the Gabor targets.

The relatively strong spatial-frequency dependence and weak orientation dependence across the present detection experiments can likely be attributed to the participants' strategy. That is, given our stimuli, the optimal detection strategy entailed looking for the target's spatial frequency regardless of the target's orientation. Interestingly, the relatively strong spatial-frequency dependence and weak orientation dependence indicates that the distracter-induced bilateral superiority did not depend on target–distracter similarity per se. Instead, the distracter-induced bilateral superiority depended on whether the targets and distracters were similar on a feature that was *task-relevant*.

That the magnitude of the distracter-induced bilateral superiority was more strongly associated with an elementary task-*relevant* feature (spatial frequency) than with an equally elementary

Table 1

Summary of *p* values (light gray columns, center) and partial η^2 values (dark gray columns, right) associated with the laterality effects in all experiments. Relative to the distracter-absent conditions (first and third data columns), bilateral superiority increased in the distracter-present conditions (second and fourth data columns), particularly when the distracters and targets were identical in fundamental spatial frequency (bolded rows).

Experiment	Bi vs uni *p* value		Bi cs uni partial η^2	
	No distracter	Distracter	No distracter	Distracter
1A: orientation discrimination	**0.711**	**<0.001**	**0.003**	**0.307**
1B: stimulus duration 183 ms	**0.070**	**0.001**	**0.230**	**0.556**
1B: stimulus duration 50 ms, no dist.	0.195	–	0.125	–
1B: stimulus duration 117 ms, no dist,	0.873	–	0.002	–
2A: detection – two targets	**0.268**	**<0.001**	**0.053**	**0.503**
2A: detection – one targets	**0.201**	**<0.001**	**0.070**	**0.487**
2B: high-SF target : high-SF dist.	**0.257**	**0.010**	**0.067**	**0.298**
2B: low-SF target : low-SF dist.	–	0.089	–	0.145
2B: low-SF target : low-SF dist.	**0.041**	**<0.001**	**0.201**	**0.513**
2B: low-SF target : high-SF dist.	–	0.011	–	0.294
2C: oblique target: random dist.	**0.291**	**0.012**	**0.079**	**0.373**
2C: oblique target: iso-orient dist.	**–**	**0.037**	**–**	**0.276**
2C: oblique target: perpendicular dist.	**0.381**	**0.004**	**0.055**	**0.465**
2C: oblique target: parallel dist.	**–**	**0.001**	**–**	**0.554**
2D: striped – Gabor dist.	**0.323**	**<0.001**	**0.025**	**0.315**
2D: striped – bulls-eye dist.	**–**	**<0.001**	**–**	**0.322**
2D: solid – mixed-polarity dist.	–	0.023	–	0.126
2D: solid – all-white dist.	–	0.126	–	0.060
2D: solid – chromatic dist.	–	0.275	–	0.030
2E: distracter displacement control	**0.493**	**0.017**	**0.028**	**0.291**

task-*irrelevant* feature (orientation) poses a challenge to purely stimulus-driven explanations. That is, it is not obvious why the distracters would overload a spatial frequency channel but not an orientation channel, particularly because many individual neurons in the early visual pathway are tuned to both spatial frequency and orientation. By contrast, the fact that the distracter-induced bilateral superiority aligned well with the optimal participant *strategy* – i.e., selecting the target's spatial frequency regardless of the target's orientation – is consistent with the influence of attentional selection.

Two other observations provide evidence that attentional selection played an important role in the present results. First the data analysis in detection experiment 2E revealed that distracters significantly increased the false alarm rate without significantly decreasing the hit rate. That finding is contrary to an explanation based on surround suppression, but consistent with the inappropriate integration that is characteristic of temporal crowding – which arises when briefly flashed displays overload attentional selection (Pelli et al., 2004). Second, discrimination experiment 1B demonstrated that bilateral superiority did not arise simply whenever discriminability was relatively low. Recall that when discriminability on distracter-absent trials was reduced – via shorter stimulus durations – to match discriminability on distracter-present trials, bilateral superiority was *not* observed. In fact, unilateral discriminability at 50 ms without distracters was three-fold greater than that at 183 ms with distracters. This shows how vulnerable unilateral orientation discrimination is to the additional requirement of selecting targets *to the exclusion of the distracters* – an attentional demand.

Intriguingly, some earlier studies have revealed instances of *unilateral superiority*. For example, Pillow and Rubin (2002) found that illusory-contour completion was significantly better when the relevant inducers were on the same side (versus opposite sides) of the vertical meridian. Preliminary reports on detecting repetitions in physically matched stimuli (Butcher & Cavanagh, 2004) and detecting matched motion paths (Butcher & Cavanagh, 2005) have similarly indicated unilateral superiority. Given those findings, it may seem surprising that there were no unilateral superiority effects on the present orientation discrimination task, which also required a form of stimulus matching (in orientation). Although further studies are necessary to elucidate the conditions for generating unilateral superiority, Pillow and Rubin (2002) suggest that unilateral superiority is more likely to occur on tasks that require perceptual grouping. Indeed, they found that the unilateral superiority effect in illusory-contour completion – which requires perceptual grouping – can be eliminated when the inducing disks are replaced with simple line segments that do not group perceptually. Consistent with Pillow and Rubin's (2002) explanation, the Gabor targets in the present orientation discrimination experiments generated neither perceptual grouping nor unilateral superiority.

Pillow and Rubin's (2002) finding of *unilateral superiority* on tasks that require perceptual grouping may provide insight about the origin of the distracter induced *bilateral superiority* observed here. Ironically, these seemingly incongruent effects may reflect opposite sides of the same coin – namely, enhanced unilateral integration. Pillow and Rubin (2002) suggest that spatial integration is more efficient unilaterally than bilaterally because neural activity that cascades across neighboring cortical units does not have to traverse the corpus callosum under unilateral stimulation. To the extent that spatial integration is more efficient within than between lateral hemifields, one would expect *unilateral superiority* on grouping tasks *and unilateral inferiority* (excessive false alarms) on tasks requiring distracter exclusion. In this way, a single mechanism – enhanced unilateral integration – might generate either unilateral superiority or unilateral inferiority, depending on whether the task demands grouping or exclusion, respectively.

It is noteworthy that the lateral hemifield effects reported here and by Pillow and Rubin (2002) differ with respect to attention. In a control experiment, Pillow and Rubin (2002) demonstrated that the unilateral superiority on their illusory-contour completion task did *not* depend on attention. By contrast, Table 1 of the present study demonstrates that the bilateral superiority reported here was strongest and reliable only when participants had to exclude distracters containing task-relevant features – an attentional demand.

4. Conclusion

In the present experiments, the elementary visual tasks of discriminating and detecting Gabor targets did not exhibit reliable lateral hemifield effects in the absence of distracters. By contrast, reliable bilateral (cross-hemifield) advantages emerged when Gabor targets had to be discriminated or detected to the exclusion of distracters – an attentional requirement. This finding extends the bilateral attentional advantages that had been previously reported for higher-level tasks (Alvarez & Cavanagh, 2005; Awh & Pashler, 2000) to the most elementary visual tasks. Indeed, it now seems that a wide range of visual tasks – motion tracking, letter identification, Gabor orientation discrimination, Gabor detection – can be used to demonstrate a bilateral advantage in attentional selection.

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