

Salient collinear grouping diminishes local salience in visual search: An eye movement study

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Our eyes and attention are easily attracted to salient items in search displays. When a target is spatially overlapped with a salient distractor (overlapping target), it is usually detected more easily than when it is not (nonoverlapping target). Jingling and Tseng (2013), however, found that a salient distractor impaired visual search when the distractor was comprised of more than nine bars collinearly aligned to each other. In this study, we examined whether this search impairment is due to reduction of salience on overlapping targets. We used the short-latency saccades as an index for perceptual salience. Results showed that a long collinear distractor decreases perceptual salience of local overlapping targets in comparison to nonoverlapping targets, reflected by a smaller proportion of the short-latency saccades. Meanwhile, a salient noncollinear distractor increases salience of overlapping targets. Our results led us to conclude that a long collinear distractor diminishes the perceptual salience of the target, a factor which poses a counter-intuitive condition in which a target on a salient region becomes less salient. We discuss the possible causes for our findings, including crowding, the global precedence effect, and the filling-in of a collinear contour.

Introduction

Searching for a target among distractors is largely influenced by the relative salience of the target and the distractor; a target that is distinct to the distractors could facilitate search (e.g., Nothdurft, 1992; Treisman & Gelade, 1980; for a review, see Wolfe, 2007), whereas

a distractor that is unique in the display could interfere with a search (Rauschenberger, 2003; Theeuwes, 1994; for a review, see Theeuwes, 2010). For instance, searching for a large item among small ones is easy and efficient because the target's large size is distinct and salient in the display. Meanwhile, a target search is more difficult in the presence of a distractor that is too salient to ignore (e.g., Theeuwes, 1994). Under this circumstance, attention is captured by the salient distractor, and the priority processing of the salient distractor results in a slowing down of the target search. When the salient distractor spatially overlaps with the target, the priority processing toward the distractor persists and facilitates discrimination of an overlapping target (Turatto & Galfano, 2000, 2001; Turatto, Galfano, Gardini, & Mascetti, 2004).

Salient items attract not only attention, but also the eyes (Engel, 1977; Godijn & Theeuwes, 2002; Irwin, Colcombe, Kramer, & Hahn, 2000; Ludwig & Gilchrist, 2002; Theeuwes & Godijn, 2001; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999; van Zoest, Donk, & Theeuwes, 2004; van Zoest & Donk, 2006). Research has shown that, while viewing a natural scene, 60% of eye fixations can be estimated from stimulus saliency, which can be computed from image information (Schütz, Braun, & Gegenfurtner, 2011). In visual searches, saccadic eye movements to a salient item were faster than to a nonsalient item, regardless of the feature dimensions of the salient item (Engel, 1977; Irwin et al., 2000). Shorter saccade latency was also found for salient, but task-irrelevant, distractors (Ludwig & Gilchrist, 2002; Theeuwes & Godijn, 2001), and potentially biases the saccadic trajectory (Godijn

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& Theeuwes, 2002; Theeuwes & Godijn, 2001). In addition, a distributional analysis of saccade latency revealed that short-latency saccades usually fall into areas with the highest feature contrast, even when they are not relevant to the task requirement (van Zoest et al., 2004; van Zoest & Donk, 2006). Later investigation showed that only the initial saccades (the first saccade since the search display onset) and short-latency saccades are signatures for bottom-up defined salience, while second or later saccades or long-latency saccades are determined by a mixed effect of both top-down (e.g., task-relevant, but with smaller feature contrast) and bottom-up (e.g., task-irrelevant, but with larger feature contrast) factors (Donk & van Zoest, 2008; Ludwig & Gilchrist, 2002; Schütz et al., 2011; Siebold, van Zoest, & Donk, 2011; van Zoest et al., 2004). In this study, we took the short-latency saccades as markers for bottom-up perceptual salience.

Jingling and Tseng (2013) reported a condition in which a local target in a salient region was less discriminable than that in a nonsalient region in a visual search display. This counterintuitive situation was observed in a specific search display, shown in Figure 1. The search display was filled with regularly spaced bars in the same orientation, except that one of the columns consisted of orthogonally oriented bars. This column was salient and served as a task-irrelevant distractor. Figures 1A and 1B show distractors formed by horizontal elemental bars (hereafter called “horizontal distractor”), and Figures 1C and 1D show distractors with vertical elemental bars (hereafter called “vertical distractor”). The task was to discriminate a small black bar (enlarged in Figure 1A), either tilted leftward or rightward, on top of one of the white elemental bars. The target and the distractor overlapped by chance, so that the distractor location did not predict target location. Figures 1A and 1C show the nonoverlapping conditions, whereas Figures 1B and 1D show the overlapping conditions. Jingling and Tseng (2013) predicted that the salient distractor captured attention and therefore facilitated overlapping targets’ search, in comparison to nonoverlapping targets (Turatto & Galfano, 2000, 2001; Turatto et al., 2004). However, in the previous study, this prediction only held true for trials with horizontal distractors (Figures 1A and 1B). When the distractor was a long, vertical collinear bar (Figure 1D), it impaired the overlapping target search, which is opposite to what has been previously reported in visual searches (e.g., Duncan & Humphreys, 1989; Itti & Koch, 2001; Jonides & Yantis, 1988; Nothdurft, 1992; Treisman & Gelade, 1980; Turatto & Galfano, 2000, 2001; Turatto et al., 2004; Wolfe, Cave, & Franzel, 1989; Yantis & Egeth, 1999). Furthermore, such impairment from the collinear distractor was found only when the distractor was long

enough (more than nine elemental bars; Figure 1D, but not Figure 1C), a condition which suggests that grouping strength was crucial in forming the impairment of the overlapping target search. Furthermore, the impairment is independent of the orientation of the elemental bars. In summary, the main finding in Jingling and Tseng (2013) is that a salient, long collinear distractor can impair, rather than facilitate, local visual search.

This study aims to further elucidate why such a long collinear distractor impaired visual search in our previous study. First of all, we ensure that the long collinear distractor in the search display is salient. Using image-based, bottom-up computation, existing attention salience models suggest that the distractors in our display are salient. For example, the salience model by Itti and Koch (2001, see also Koch & Ullman, 1985; Nothdurft, 1992; Treisman & Gelade, 1980; Wolfe et al., 1989) predicts that both collinear and noncollinear distractors should stand out from the search display, as they were both made of bars 90° away from their neighboring bars (i.e., the maximum orientation contrast). Simulation data from the salience toolbox in Matlab (Walther & Koch, 2006) confirmed this conjecture—that regardless of the length or collinearity of the distractors, they generate higher salience values than the other areas in the search display. Zhaoping’s V1 model of salience (Li, 2002; Zhaoping, 2003, 2005) also marks the distractor columns as salient zones, and the vertical distractors are more salient than the horizontal ones for additional collinear facilitation (Jingling & Zhaoping, 2008).

However, we did not have direct evidence showing that the local target was perceptually more salient when it overlapped with the long collinear distractor. If we agree that more salient items were discriminated faster and vice versa, then the reduced discriminability of a target overlapping with a collinear structure implies reduced salience of the target. For example, some factors—such as crowding (Chakravarthi & Pelli, 2011; Dakin & Baruch, 2009; Gheri, Morgan, & Solomon, 2007; Livne & Sagi, 2007, 2010; May & Hess, 2007; Saarela, Sayim, Westheimer, & Herzog, 2009; Whitney & Levi, 2011; Yeotikar, Khoo, Asper, & Suttle, 2011), global interference to local items (Han & Humphreys, 1999, 2002; Kimchi, 1994; Kimchi & Razpurker-Apfele, 2004; Navon, 1977, 2003), or filling-in from the collinear structure (Yantis & Nakama, 1998; Zhaoping & Jingling, 2008)—may additionally interfere with perceptual salience, but were not included in the abovementioned computational models. Thus, it is possible that an overlapping target becomes less salient than a nonoverlapping target when the distractor is long and collinear, leading to a slower response to target discrimination. Meanwhile, an overlapping target is more salient than a nonoverlapping target

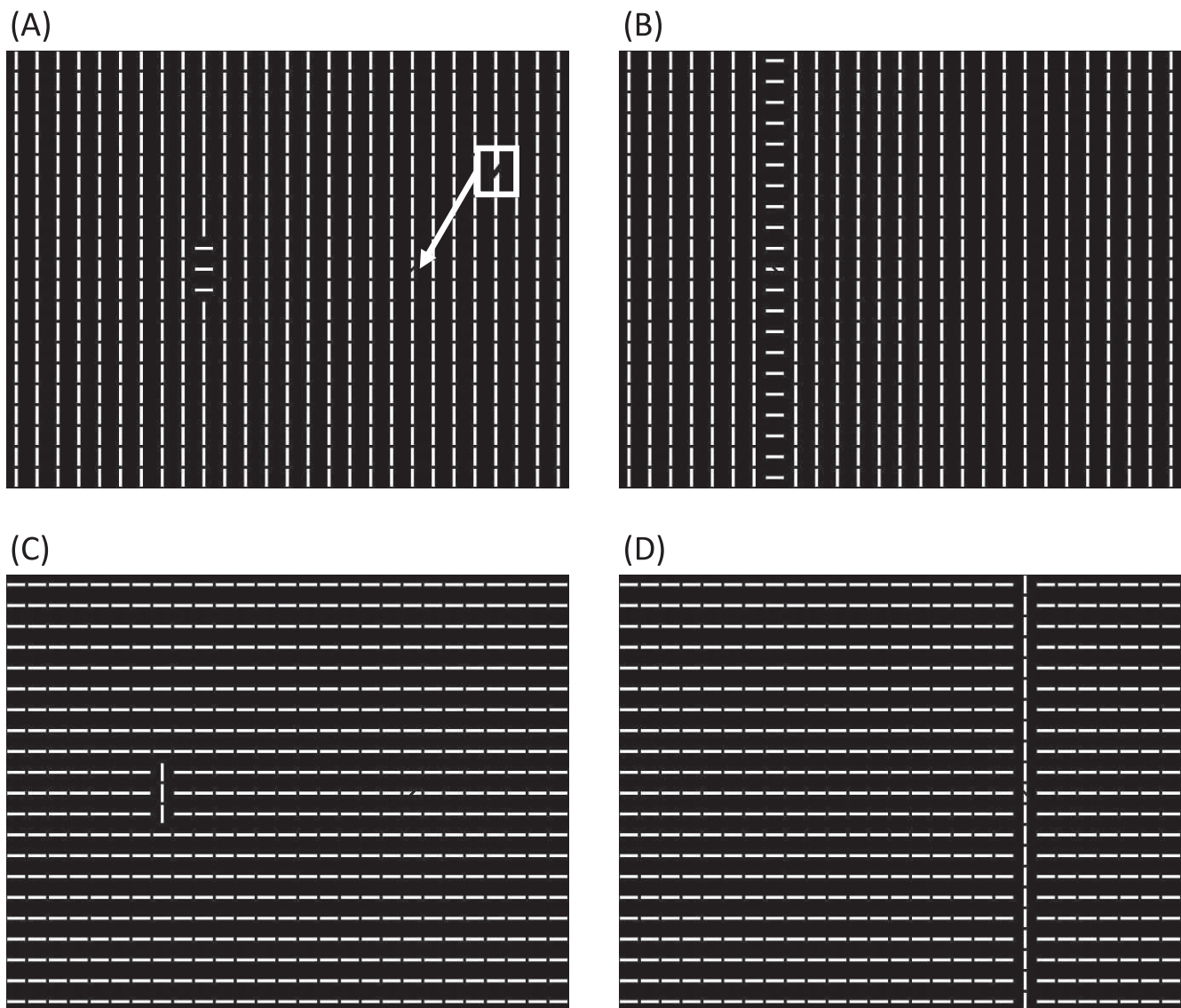


Figure 1. An example of the search display used in this study. The target is highlighted in (A), but the highlight per se was not shown in the experiment. The correct responses are right-tilt in (A) and (C) and left-tilt in (B) and (D). The salient distractor (the column with orthogonal-oriented bars) is 3-bar horizontal (A), 21-bar horizontal (B), 3-bar vertical (C), or 21-bar vertical (D).

when the distractor is noncollinear, as reported in attentional capture literatures (e.g., Turatto et al., 2004; Turatto & Galfano, 2000, 2001; Turatto et al., 2004); thus, no such search impairment was found for horizontal distractors.

The goal of this study is to investigate whether the impairment for the targets overlapping on a collinear distractor is due to lower perceptual saliency in comparison to nonoverlapping targets. To measure perceptual saliency, especially here, we considered saliency to be determined by visual input rather than by task demands, and we took short-latency saccades (Donk & van Zoest, 2008; Siebold et al., 2011; van Zoest et al., 2004; van Zoest & Donk, 2006) as an index. This index excludes corrective saccades, revisits,

or long latency saccades, and thus can reveal the strength of bottom-up saliency of the target. A more salient item should elicit more short-latency saccades. We also manipulated the distractor type (horizontal or vertical) and size (the number of distinctive oriented bars in the salient column being 3, 9, or 21) in this study. According to our previous findings (Jingling & Tseng, 2013), slower manual responses on overlapping compared to nonoverlapping targets are observed only for long vertical distractors. If such prolonged manual responses were due to low perceptual saliency, we would expect to see a smaller proportion of the short-latency saccades on overlapping than on nonoverlapping targets, when the collinear distractor is long enough.

Method

Participants

Sixteen undergraduates or graduates of Tamkang University, Taipei, Taiwan, took part in the experiment for course credit or payment. All participants had self-reported normal or corrected-to-normal vision, and none were color deficient. Although two of the observers passed the calibration at the beginning of the experiment, their eyes failed to arrive at the defined area of the target (i.e., a 30 pixel radius, approximately 2° in visual angle) in more than 20% of the trials. This behavior implied that they may use strategies differently from the majority of the participants; therefore, their data were excluded from further analysis. Thus, only data from 14 participants were reported in this study.

Stimulus and apparatus

The experiment was carried out in a dimly lit room, and each participant sat with a chinrest to view the stimuli from a distance of 60 cm. The stimuli were shown on a 19-in. flat screen monitor that was driven by a personal computer. The resolution of the stimuli display was 1024×768 . The experiment was programmed with Visual Basic.

The observers viewed a fixation display and a search display in each trial. The fixation displays consisted of a central, white cross (with a radius of 0.3°), which served as the fixation point. The search displays consisted of a lattice of 576 white bars arranged in 21 rows and 27 columns against a dark background (Figure 1). Each bar was $0.81^\circ \times 0.18^\circ$ in visual angle and was placed on a regular grid with spacing of 1.04° . The search display was comprised of bars with the same orientation, except for the bars in one column (the distractor). The size of the distractor could be 3 bars (Figures 1A and 1C), 9 bars, or 21 bars (Figures 1B and 1D) in a column. In the vertical distractor condition (Figures 1C and 1D), the column of the distractor was filled with vertical bars for the length of the distractor, and the remaining bars in the display were horizontal. The horizontal distractor condition was the reverse: Horizontal bars were in the distractor and vertical bars were in the background (Figures 1A and 1B). Thus, the vertical distractor was collinear, whereas the horizontal distractor was not. Nevertheless, the two types of distractors were all orthogonal to the background. The target was a broken tilt ($0.63^\circ \times 0.11^\circ$) placed on top of one of the texture bars, oriented either 45° counter-clockwise (left-tilted, Figures 1B and 1D) or clockwise (right-tilted, Figures 1A and 1C).

Design

The locations of the target and the distractor were manipulated to be independent in this experiment, following Turatto and Galfano (2000, 2001) and Jingling and Tseng (2013). The target was always at the central (11th) row and randomly presented on one of four possible columns (the 10th, 12th, 16th, or 18th column of 27 columns in the display). The distractor was also placed in the four possible columns. An overlapping target (Figures 1B and 1D) was the target shown on the distractor. Otherwise, the target shown on the bars in the background texture was a nonoverlapping target (Figures 1A and 1C). The probability for overlapping targets is 25% (chance level, as there are four possible locations), and the distractor column is not informative on the target location. In addition to the target type (overlapping and nonoverlapping), distractor type (horizontal and vertical) and distractor size (3, 9, and 21 bars) were also manipulated. These three factors were randomly interleaved for each participant.

Eye movement recording

An EyeLink 1000 System set at a 250 Hz sampling rate was used. The right eye of the participants was recorded. To ensure that the recorded position was accurate, two calibration and validation procedures were carried out during the experiment: at the beginning and after 150 trials. During calibration, observers were asked to saccade to a yellow, circular disk (size 1°) that appeared sequentially in a 3-by-3 grid. Then, these yellow disks randomly appeared at the nine possible positions or 2° to these positions for validation of eye positions. Observers needed to recalibrate their eye position when the validation was less than 98% accurate. If, after three calibration and validation procedures, the machine still could not correctly record the observer's eye, the observer would not proceed with the experimental session. The definition of saccade onset and offset follows the EyeLink criterion, in which the velocity exceeds $35^\circ/\text{s}$ and acceleration over $9500^\circ/\text{s}^2$.

Procedure

Observers initiated each search trial by moving the mouse cursor to the central cross (which their eyes would automatically follow) and slightly shaking the cursor on it. This manipulation ensured that the observers' fixation was at the center at the beginning of each trial. After this step, the cursor disappeared, and the search display was shown on the screen. Observers

discriminated the target orientation (left-tilted or right-tilted) by clicking one of the mouse keys. After 800 ms, the cursor was randomly presented on one of the four corners in the blank display; observers then moved the cursor again and refixated. Ten practice trials were given before data were collected. Participants were encouraged to respond as rapidly as possible while maintaining accuracy. Each participant completed 192 trials.

Data analysis

Both manual responses and saccadic eye movements were recorded in this study. Manual responses include response times (RT) and accuracy, while RT was defined as the duration between the onset of the search display and key presses. Note that only correct responses that were shorter than 2 standard deviations above the total mean were included.

In eye movement data, the eye positions that were within 2° horizontally to the targets were considered to be fixated on the target. The duration between the onset of the search display to the first fixation on the target was taken as the saccadic latency. We excluded the saccadic latency data when (a) participants pressed a wrong key or their manual responses took too long (more than 2 standard deviations above the total mean) in that trial; (b) the eye positions never visited the target before the key press; or (c) the first fixation on the target was a result of anticipatory saccades (i.e., less than 125 ms). To understand salience-driven impulsive saccades (Donk & van Zoest, 2008; Siebold et al., 2011; van Zoest et al., 2004; van Zoest & Donk, 2006), we collected the trials in which the first saccade after search display onset was directed to the target (the initial saccade), and then ranked these trials according to their saccadic latency and divided them into five quintiles. The first quintile (the fastest 20%) was thus defined as short-latency saccades. The proportion of the short-latency saccades in each condition was calculated for further comparison. All data were submitted to a repeated-measures analysis of variance (ANOVA).

Results

Manual responses

Ultimately, 3.64% of trials were removed due to manual responses exceeding two standard deviations of the total mean. The results are shown in Figure 2. The data were submitted to a three-way repeated measures ANOVA, with the factor target type (overlapping or nonoverlapping), distractor type (horizontal or verti-

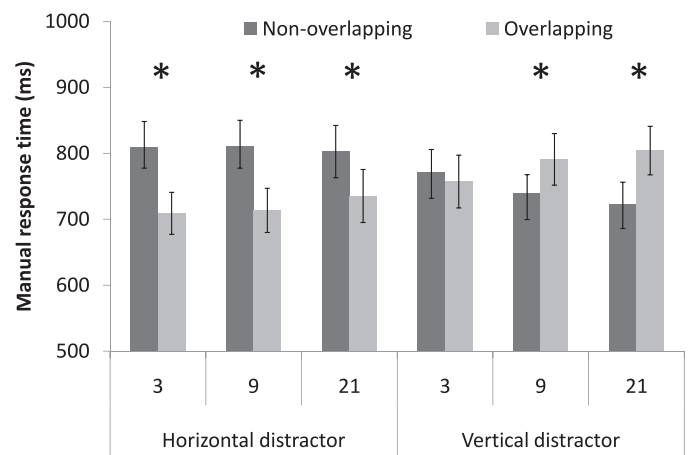


Figure 2. Manual response times as a function of distractor type (horizontal or vertical) and distractor size (3, 9, or 21 bars). The error bar is the standard error of the mean.

cal), and distractor size (3, 9, or 21 bars). The results of the ANOVA are shown in Table 1. Further analysis showed that, in Figure 2, the difference between overlapping and nonoverlapping targets was significant in five out of a total of six conditions, $F(1, 78) = 26.01, 24.53, 11.89, 7.04,$ and 17.01 ($MSE = 2711.09, ps < 0.01$), for horizontal 3-bar, horizontal 9-bar, horizontal 21-bar, vertical 9-bar, and vertical 21-bar distractor conditions, respectively. Therefore, in horizontal distractor conditions, overlapping targets received advantages over nonoverlapping targets; In vertical distractor conditions, however, an opposite pattern was found when the vertical distractor was long enough (sizes 9 and 21).

The manual response time replicated our previous finding (Jingling & Tseng, 2013) in several aspects. First, overlapping targets required a longer duration to discriminate than nonoverlapping targets only when the trial was with vertical collinear distractors. Further, such search impairment was found only when the vertical collinear distractor was long enough (sizes 9 and 21). Horizontal distractors did not impair search; rather, they facilitated target discrimination, as predicted by attentional capture literature (Turatto & Galfano, 2000, 2001; Turatto et al., 2004). Finally, the size of the distractor interacted with target types, especially when the targets were presented with vertical distractors. Therefore, it was again observed that long salient vertical distractors impair local target discrimination.

The accuracy of the selected manual RT (data of Figure 2) is shown in Table 2 and was submitted to a three-way repeated-measures ANOVA test. In general, accuracy was higher for overlapping targets (96.43%) than for nonoverlapping targets (94.39%), $F(1, 13) = 15.34, MSE = 0.001, p < 0.01$. In addition, interactions between target type and distractor type were found,

Factors	Mean square error	Degree of freedom	<i>F</i>	<i>p</i>
Target type (overlapping or nonoverlapping)	2292.18	1, 13	10.99	0.0056
Distractor type (horizontal or vertical)	2069.03	1, 13	0.01	0.9227
Distractor size (3, 9, or 21 bars)	1306.26	2, 26	0.22	0.8028
Target type × distractor type	8232.15	1, 13	20.95	0.0005
Target type × distractor size	1245.16	2, 26	11.69	0.0002
Distractor type × distractor size	1996.84	2, 26	0.233	0.7936
Three-way interaction	1625.96	2, 26	2.92	0.0718

Table 1. Three-way ANOVA results for manual response times. *Note:* Bold numbers are the significant effects, $p < 0.05$.

$F(1, 13) = 7.31$, $MSE = 0.006$, $p < 0.05$. Other effects were not significant. Therefore, we did not find evidence of a speed–accuracy trade-off.

The short-latency saccade

We first obtained saccadic latency according to the three criteria in Data Analysis. On average, saccadic latency is 366.78 ms, and the standard deviation is 161.38 ms. The saccadic latency was shorter for overlapping targets (261.37 ms) than for nonoverlapping targets (406.59 ms); also, the latency was shorter for trials with vertical distractors (347.72 ms) than those with horizontal distractors (386.09 ms). Distractor size does not appear to impact saccadic latency; the latency was 374.92 ms, 368.98 ms, and 356.58 ms for trials with 3-bar, 9-bar, and 21-bar distractors, respectively.

To understand whether the target is salient, the short-latency saccades in each condition were calculated. The average of the short-latency saccade is 234.45 ms, and the standard deviation is 91.08 ms. Figure 3 shows the proportion of the short-latency saccades, and the sum of all bars in Figure 3 is 100%. The results shown in this figure perfectly match those in manual responses (Figure 2): A higher proportion of short-latency saccades to nonoverlapping targets corresponded to faster manual responses to nonoverlapping targets. In particular, our short-latency saccades fell on the overlapping targets much more than they did on nonoverlapping targets when the distractor was horizontal, but less when the distractor was vertical. This reverse pattern was restricted to trials using a long distractor size; when using a short distractor size, however, both horizontal and vertical distractors

showed higher proportions for overlapping than nonoverlapping targets. In other words, delayed discrimination for overlapping targets compared to nonoverlapping targets in the long vertical-distractor condition might be due to the former targets being less salient than the latter.

We carried out a three-way, repeated-measures ANOVA (target type, distractor type, and distractor size) on this proportion of the short-latency saccades. The results are shown in Table 3. Overlapping targets had higher proportions than nonoverlapping targets in general, whereas the effect of overlapping interacted with distractor type and size. Interestingly, the three-way interaction was significant. Further analysis showed that the effect of target type is significant in all conditions (Figure 3), $F(1, 78) = 59.47, 73.70, 50.84, 28.99, 4.15, \text{ and } 14.31$, for horizontal 3-, 9-, and 21-bar and vertical 3-, 9-, and 21-bar distractor conditions, respectively, $MSE = 11.09$, $ps < 0.05$. Note that overlapping targets have higher proportions than nonoverlapping ones in the first five conditions, while a reverse pattern is present in the vertical 21-bar condition. Though the vertical 9-bar condition did not show the same direction of differences as the vertical 21-bar condition, as was observed in manual responses (Figure 2), a reduced advantage of overlapping targets compared to nonoverlapping targets was observed. This tendency matches what was observed in manual responses. In summary, we found that the pattern of proportion of the short-latency saccades mirrors that in manual responses, showing that a longer response is associated with a smaller proportion of the short-latency saccades. Thus, overlapping with a long collinear distractor reduces the perceptual salience of the target.

	Horizontal distractor			Vertical distractor		
	3	9	21	3	9	21
Nonoverlapping	92.56 (8.83)	93.15 (8.89)	93.75 (7.44)	94.94 (4.67)	95.24 (7.81)	95.83 (4.62)
Overlapping	97.32 (5.32)	98.21 (4.54)	100 (0)	94.64 (10.65)	93.75 (10.69)	94.64 (10.65)

Table 2. Mean accuracy (%) and their standard deviation (in parentheses) of manual responses

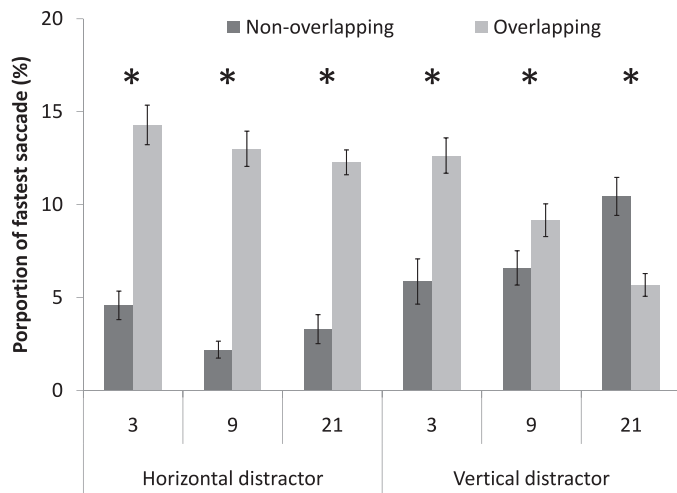


Figure 3. Proportion of the short-latency saccades to targets. The summed proportion for all conditions is 100%. The error bar is the standard error of the mean.

General discussion

In this study, we investigated eye movement patterns in hopes of better understanding the unexpected search impairment caused by a well-grouped salient distractor in visual search (Jingling & Tseng, 2013). In particular, we explored whether overlapping with a collinear salient distractor reduced the perceptual salience of the local target by taking the short-latency saccades as an index of stimulus-driven salience (Donk & van Zoest, 2008; Siebold et al., 2011; van Zoest et al., 2004; van Zoest & Donk, 2006). The results showed that, indeed, a local target became less salient when it overlapped with a long vertical (collinear) distractor. However, when the distractor was noncollinear, overlapping with the distractor increased the perceptual salience of the target. We concluded that the reduction of salience may be the reason for prolonged RT for overlapping targets in the search impairment effect.

By using the short-latency saccade, we found that the reduction of salience for overlapping targets was strongly associated with prolonged manual responses. This is the unique contribution of this study because we

used an independent measure of perceptual salience (short-latency saccade) compared to response times. The contributions of this study are at least twofold. First, we demonstrated again that a salient item can be recognized faster, which is consistent with what was reported in attentional capture literature (e.g., Duncan & Humphreys, 1989; Itti & Koch, 2001; Jonides & Yantis, 1988; Nothdurft, 1992; Treisman & Gelade, 1980; Turatto et al., 2004; Turatto & Galfano, 2000, 2001; Wolfe, Cave, & Franzel, 1989; Yantis & Egeth, 1999). When the salience of the target was reduced by overlapping with a long collinear structure, RT to the target was prolonged. Second, since the index of short-latency saccade reveals bottom-up salience, we argue that any explanations of prolonged RT for overlapping targets purely dependent on top-down attention can be excluded. For instance, some argued that our target was a gap between items, whereas collinear grouping of the distractor is continuity between items; thus, these two were in conflict in the attentional control setting. Another alternative is that our long distractor may enlarge attentional focus, which did not match the size of the target. These speculations, although possibly significant to visual search, are not the primary causes of search impairment effect for overlapping targets. In contrast, the perfect mirror relationship between manual response and the short-latency saccades suggests strong associations between search impairment and the strength of bottom-up perceptual salience.

However, for some reason, the target becomes less salient when it overlaps with a long, salient collinear structure. We speculated several possibilities for the salience reduction for targets overlapping with a long collinear distractor. First, it is possible that a crowding effect is caused by collinear grouping of the distractor. May and Hess (2007) proposed that the integration field of contour integration (e.g., collinear grouping) may be the same as the confusion field of crowding. They showed that contours that are less integrated became less detectable when moving to the periphery, whereas the well-integrated contours did not change detectability at the periphery. Recently, Chakravarthi and Pelli (2011) showed that contour integration and crowding responded to the same parameters in a

Factors	Mean square error	Degree of freedom	<i>F</i>	<i>p</i>
Target type (overlapping or nonoverlapping)	18.5	1, 13	73.2	0
Distractor type (horizontal or vertical)	12.01	1, 13	0.052	0.8229
Distractor size (3, 9, or 21 bars)	12.11	2, 26	3.56	0.0431
Target type × distractor type	9.31	1, 13	77.77	0
Target type × distractor size	10.29	2, 26	13.85	0.0001
Distractor type × distractor size	13.75	2, 26	0.071	0.9315
Three-way interaction	9.08	2, 26	11.25	0.0003

Table 3. Three-way ANOVA results for the proportion of the short-latency saccades. Note: Bold numbers are the significant effects, $p < 0.05$.

reverse pattern and suggested that these two phenomena might have a shared underlying mechanism. Yeotikar et al. (2011) showed that a snake contour produced a larger crowding effect than a ladder contour. Meanwhile, Dakin and Baruch (2009) showed that sensitivity to a snake contour varied with contextual contrast, in that perpendicular surroundings increased sensitivity, whereas parallel surroundings reduced sensitivity, with random surroundings in between. In other words, a collinear contour grouped better when it was salient in a display. Sensitivity to a ladder contour, on the other hand, did not alter with contextual contrast. Therefore, it is possible that such a “super-grouped” contour produced a stronger crowding effect on our target and impaired saccadic speed and manual responses.

A second possibility is that the effort to break down the global object (distractor) prolonged responses to the local target (Driver, Davis, Russell, Turatto, & Freeman, 2001; Hillstrom & Yantis, 1994; Zhaoping & Guyader, 2007). This conjecture is similar to the global-to-local interference effect (Navon, 1977, 2003), in which discriminating the local target suffers from interference from the global configuration, but not vice versa. Since the grouping strength of the global configuration could affect the strength of interference (Han & Humphreys, 1999, 2002; Kimchi, 1994; Kimchi & Razpurker-Apfele, 2004), it is possible that collinear distractors elicit stronger impairment than noncollinear distractors because the former have a stronger grouping. According to Han and Humphreys (1999, 2002), increasing salience of the local items can reduce interference from the global structure, and thus, a more salient target might be able to overcome this search-impairment effect.

A third possibility is that filling-in of the collinear structure (the distractor) masked the discrimination of the local target. In particular, the task requires participants to discriminate a broken target, which might specifically act against collinear grouping because the gaps between the collinear distractor are smaller than those of the noncollinear distractor. The search impairment when targets overlapped with a collinear bar may be a result of filling-in by the collinear structure that confuses gap orientation. Zhaoping and Jingling (2008) found that a collinear structure, especially when it was strong in luminance, produced filling-in of the gap between collinear elements. Yantis and Nakama (1998) also showed that a letter on the path of apparent motion was discriminated more slowly than that not on the path. They argued that the path was filled-in by motion and, thus, masked discrimination of letters on the path. This kind of filling-in effect may reduce perceptual visibility (or salience) of the local target in our display, making a

local target less discriminable by overlapping a collinear structure.

In summary, although salient distractors might capture attention, they can reduce target salience when the target overlaps spatially with a salient distractor. The reduction was observed exclusively for a long, collinear distractor, implying that the mechanisms related to contour integration play a role. We discussed the possibility that contour integration might slow manual responses by imposing a crowding effect on the local target, forming a global structure to interfere with local discrimination, or producing filling-in and masking the target.

Keywords: collinearity, salience, saccades, visual search, attentional capture

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