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Perceptual Grouping Strength can Modulate the Size of the Collinear Masking Effect in a Visual Search

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Visual search efficiency can usually be promoted if the target is salient. However, Jingling & Tseng (2013) found that if the salient structure was composed of collinear bars, search would be more difficult — a phenomenon called the collinear masking effect. In their experiment, the collinear structure was composed of bars in a head-to-tail alignment. Thus, it is possible that perceptual grouping of the collinear distractor may play a role in the collinear masking effect. The current study aimed to reduce the strength of the perceptual grouping of the whole search display and to test whether the size of collinear masking effect also reduced. In Experiment 1, the scale of the bars (the size ratios of bars and spacing) was increased, and in Experiment 2, the spacing between bars was increased to reduce the grouping strength of the whole display. In Experiment 3, possible confounding of bar orientation of the target was removed. Our data showed that the strength of the collinear masking effect was indeed reduced because of the weakening of the perceptual grouping of the search display. Simply changing the orientation of the bar where target was on did not affect responses. We infer that the reduction of perceptual grouping strength of the whole display also reduced the grouping strength of collinear distractor, and hence the size of the effect. Therefore, collinearity grouping strength might be an important factor for the emergence of the collinear masking effect.

Keywords: *collinear masking effect, perceptual grouping, perceptual salience, visual search*

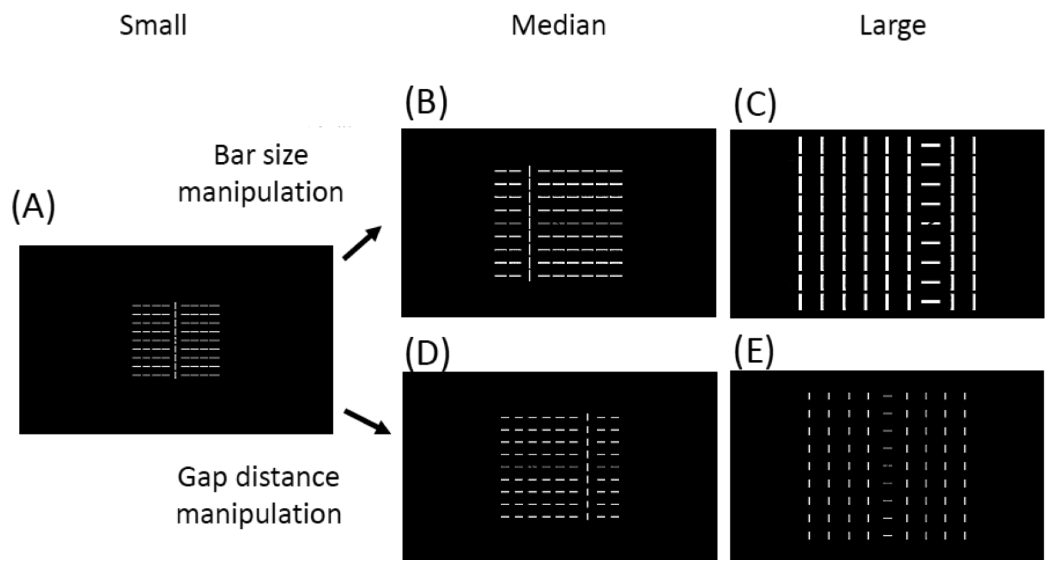
Extended Abstract

Visual search can usually be facilitated by stimulus salience and perceptual grouping (Wolfe, 2010). However, our previous studies (Jingling & Tseng, 2013) established a phenomenon called the collinear masking effect, in which a target can be masked by a salient and well-grouped distractor. Figure 1A shows examples of the search displays. In particular, a column of bars, which form the distractor, has a 90-degree orientation contrast to its neighbors, and is oriented head-to-tail, aligned at the column. Such a collinear distractor was shown to be perceptually more salient (Zhaoping & Jingling, 2008) than a distractor that has only orientation contrast, without collinear alignment (e.g., Figure 1C, the non-collinear distractor). However, in searching for a local target, responses to a target overlapping with the collinear distractor (e.g., Figure 1A) took longer and were less accurate than those in the background (e.g., Figure 1B). The reverse was found for the non-collinear distractor. Consistent with the attentional capture literature (e.g., Duncan & Humphreys, 1989; Jingling & Tseng, 2013; Lamy & Zoaris, 2009; Turatto & Galfano, 2000, 2001; Turatto et al., 2004), a non-collinear distractor was found to facilitate the search, such that the response was faster and more accurate in the overlap condition (e.g., Figure 1C) than in the non-overlap condition.

Our previous studies showed that the perceptual salience of the collinear distractor did not contribute to the collinear masking effect (Jingling & Tseng, 2013; Jingling et al., 2017; Lu & Jingling, 2017). Specifically, the non-collinear distractor, as shown in Figure 1C, has exactly the same orientation contrast as that of the collinear distractor; however, it results in facilitation rather than masking (Chiu & Jingling, 2014; Jingling, et al., 2017). Moreover, decreased salience of the collinear

Figure 1

Examples of the search displays used in this study. (A), (B), and (C) were used in Experiment 1 for bar size manipulation, and (A), (D), and (E) were used in Experiment 2 for gap distance manipulation. The search display was composed of 9 by 9 bars, and the target would be randomly placed at the central row of one of the 3rd, 5th, or 7th columns. The distractor was also possibly located at the 3rd, 5th, or 7th column. The target and the distractor were designed to be overlap in one third of trials, making the distractor task-irrelevant. Participants judged whether the target was leftward or rightward tilted in that display. (A) the original search display used in previous study with a collinear distractor and the target overlapped with the distractor. (B) A display with collinear distractor and non-overlap with the target, while each bar enlarge size from that of (A) in 1.5 times. (C) A display with non-collinear distractor overlapped with the target, and the bars enlarge size from that of (B) in 1.5 times. (D) A display with collinear distractor non-overlap with the target and the distance between bars enlarge 1.5 times from that of (A). (E) A display with non-collinear distractor overlapped with the target and the distance between bars enlarge 1.5 time from that of (D)



distractor (Lu & Jingling, 2017) or increased salience of the target (Jingling, et al., 2017) does not eliminate the collinear masking effect. Meanwhile, an increase in the length of the collinear bars of the distractor can enlarge the effect (Jingling & Tseng, 2013). Thus, the grouping strength seems to be more critical than the salience strength of the collinear distractor for producing such a search impairment.

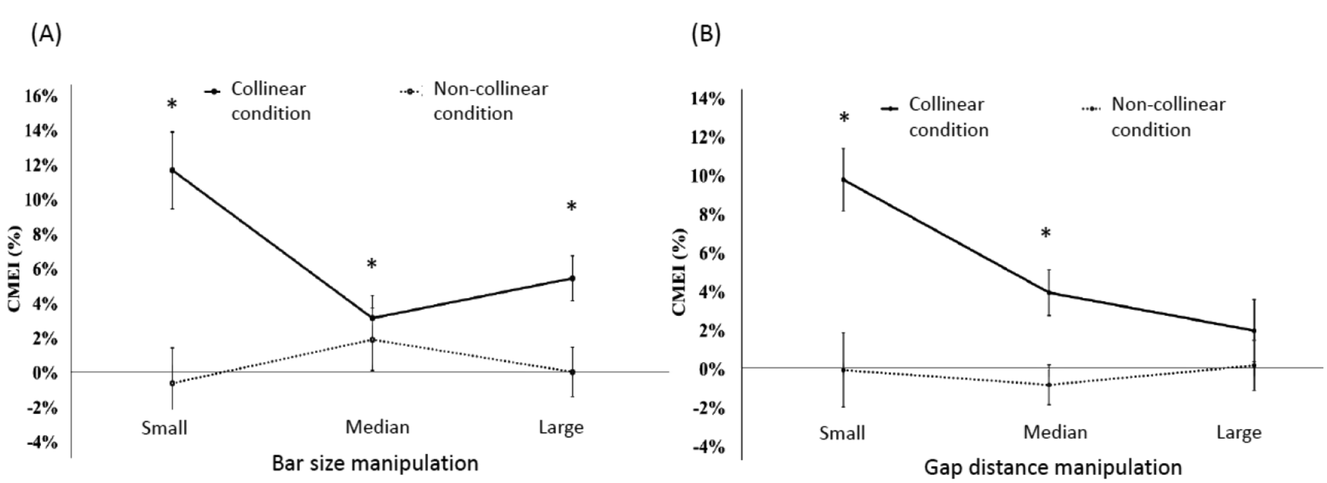
The current study explored whether the grouping strength of the search display could alter the size of the collinear masking effect. Perceptual grouping strength, regardless of grouping laws, is usually affected by some physical features, such as the size of the items or the distance between items (Bex et al., 2003; Hess et al., 2003; Tannazzo et al., 2014; Wagemans et al., 2012). However, if we manipulate the grouping strength of the distractor but do not vary the items in the background, some other factors, such as salience level, may also vary. Therefore, in the current study, we decided to manipulate the grouping strength of the entire display. To reduce the grouping strength of the search display, we chose to increase the bar size (Experiment 1; Figure 1A, B, and C) and increase the distance between the bars (Experiment 2, Figure 1A, D, and E). The non-collinear condition was also interleaved to serve as a control. The participants completed three sizes or scales in a random order. Experiment 3 was conducted to exclude possible confounds. To understand the size of the effect, the response speed results were subtracted between the overlap and non-overlap conditions and were scaled with the average response speed to calculate the collinear masking effect index (CMEI). A positive CMEI value indicates a masking effect, whereas a negative CMEI value indicates a facilitation effect in the overlap condition compared with the non-overlap condition.

The results (Figure 2) showed that, only trials with collinear distractors changed the size of the effect with our manipulations. The effect of trials with non-collinear distractors did not vary with bar size or gap distance. Analyzing CMEI data from Experiment 1 (bar size manipulation, Figure 2A) using a two-way repeated measure ANOVA with distractor type (collinear or non-collinear) and bar size (small, median, or large) as the factors, we found a main effect for distractor type ($F(1,19) = 17.044$, $p < .001$, $\eta_p^2 = .474$). That is, the CMEI value was larger for trials with a collinear distractor (6.77%) than those with a non-collinear distractor (0.46%). Moreover, the interaction between distractor type and bar size was significant ($F(2,38) = 6.583$, $p = .004$, $\eta_p^2 = .258$). In particular, CMEI variation with bar size alone was only found in conditions with a collinear distractor ($F(2,76) = 7.236$, $p = .001$, $\eta_p^2 = .158$). Post hoc analysis showed that trials using a smaller bar size generated larger CMEI values (11.70%) than those with medium (3.16%) or large (5.46%) bar sizes ($p < .05$). Therefore, the CMEI value reduced with bar size manipulations if there was a collinear distractor, but the CMEI value did not vary with bar size manipulation if there was a non-collinear distractor.

CMEI values were also calculated from the results of Experiment 2 (gap distance manipulation, Figure 2B) and were analyzed using a two-way repeated ANOVA. Again, CMEI values were larger for trials with a collinear distractor (5.25%) than those with a non-collinear distractor (-0.21%; $F(1,19) = 12.876$, $p = .002$, $\eta_p^2 = .405$). A main effect was also observed for gap distance ($F(2,38) = 4.474$, $p = .018$, $\eta_p^2 = .190$). A post hoc Tukey's test showed that the CMEI value was significantly larger for the small gap condition (4.89%) than the large gap condition (1.10%, $p < .05$). Moreover, the interaction between distractor type and gap distance was signfiicant ($F(2,38) = 5.538$, $p = .008$, $\eta_p^2 = .226$). The effect of gap distance was only observed in trials with a collinear distractor ($F(2,76) = 9.721$, $p < .001$, $\eta_p^2 = .203$). A post hoc analysis showed that the CMEI value was significantly larger in the small gap distance condition (9.81%) than the median (3.96%) and large (1.99%) gap distance conditions ($p < .05$). Thus, similar

Figure 2

The data of Experiment 1 (A) and Experiment 2 (B). CMEI is the collinear masking effect index, which positive is masking and negative facilitation, see text for more information



* indicates CMEI significantly larger than zero.
* $p < .05$.

to the observations from Expeirment 1, we found that gap distance manipulation affected the response in trials with a collinear distractor, but not in those with a non-collinear distractor. The CMEI value decreased as the gap between bars increased.

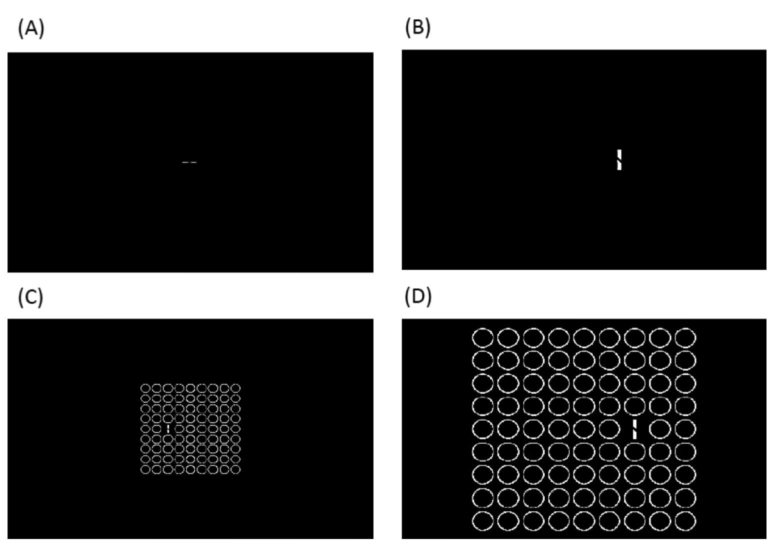
Experiment 3 was carried out to exclude the confounding of bar orientation. As shown in Figure 1, the target was on a vertical bar in the collinear overlap condition (e.g., Figure 1A), but on a horizontal bar in the non-overlap condition (e.g., Figure 1B). Thus, one alternative hypothesis is that the differences between these two conditions were not due to whether or not there was overlapping with the distractor, but rather to whether there was a vertical or horizontal bar. To answer this question, we designed two types of search displays (Figure 3) to single out the target bars and determine if the orientation discrimination of the target (the tilted gap on the bar) varied with bar orientation. Figure 3A and Figure 3B show the conditions of varying bar size with a blank background, with a target location exactly the same as that used in Experiment 1. Figure 3C and 3D show the conditions of varying bar size while replacing all of the bars in the background with circles. The results showed that neither the response time nor accuracy was statistically different for horizontal bars (485 ms, 95.74%) or vertical bars (491 ms, 95.65%) with a blank background, or for horizontal bars (548 ms, 95.09%) or vertical bars (551 ms, 95.83%) with a circle background. The main effect of bar size was significant; however, it did not interact with bar orientation. Therefore, the effect observed in Experiments 1 and 2 could not be attributed purely to the orientation of the bars where the target was located; rather, it may be caused by the context of the bars, e.g., whether they overlapped with a collinear distractor.

In summary, in this study we decreased the grouping strength of the search display by increasing the bar size (Experiment 1) and increasing the distance between bars (Experiment 2). We found that the collinear masking effect was reduced if the grouping strength of the search display was reduced. The effect observed in search displays with a non-collinear distractor did not change with grouping strength. Thus, we concluded that the collinear masking effect is associated with grouping strength, rather than the perceptual salience of the distractor.

We noted that the manipulation of bar size and gap distance may vary the grouping strength in different ways,

Figure 3

The examples of the search display used in Experiment 3. (A) a target on a median size bar; (B) A target on a large size bar; (C) a target on a small size bar with circle fillers, and (D) a target on a large size bar with circle fillers



such as the law of proximity and good continuation (Bex et al., 2003; Tannazzo et al., 2014). However, we believe that the law of good continuity, especially collinearity, is the main cause of the collinear masking effect, rather than the law of proximity, for the following reasons. First, we used search displays with collinear and non-collinear distractors, but only displays with a collinear distractor were affected by the grouping strength manipulations. As the differences between these two distractors were collinear, we believe that decreasing the grouping strength of collinearity causes a decrease in the CMEI value. Moreover, the bars in the background of the search displays, regardless of whether the displays had collinear or non-collinear distractors, were all aligned with their neighbors. For instance, the bars in the background of Figure 1A (the collinear distractor condition) were collinear with their horizontal neighbors, and the bars in the background of Figure 1C (the non-collinear distractor condition) were collinear with their vertical neighbors. Therefore, grouping strength variations of the background bars were equivalent in collinear and non-collinear conditions. In this case, any effect due to grouping strength manipulation should be from the distractor, and not from the background. Considering these data together, our manipulation of the grouping strength may be effective due to the collinear strength decrement of the collinear distractors. This observation is consistent with our previous finding that reducing the size of the collinear bars in the collinear distractor reduces the size of the collinear masking effect (Jingling & Tseng, 2013).

The current study also excluded some alternative hypotheses. First, Experiment 3 showed that the collinear masking effect was not due to the orientation of the bars om which the target was located. Second, the target locations of the trials with an increased gap distance were more peripheral than those with a smaller gap distance. However, the CMEI values at the periphery (average, 6.83%) were actually larger than those at the center (3.52%), while CMEI values were larger in trials with a small gap (9.81%) than those with a large gap (1.99%). Thus, retinal eccentricity could not explain why the CMEI values decreased with grouping strength. Consistent with previous studies (Chiu & Jingling, 2014; Chow et al., 2013). we did not observe a significant facilitation effect for trials with non-collinear distractors. Nevertheless, our observation that the effect of the non-collinear distractor did not vary with grouping strength manipulation was consistent with our previous studies, which showed that the non-collinear facilitation effect was due to distractor salience, rather than perceptual grouping (Jingling & Tseng, 2013; Jingling et al., 2017; Lu & Jingling, 2017)

In conclusion, this study revealed that the collinear masking effect in a visual search can be reduced if the grouping strength of the items in the search display are reduced. We propose that the critical factor for this effect is the grouping strength of the collinear distractor. The non-collinear facilitation effect, or in general, the attentional capture effect in a visual search, was not affected by the grouping strength of the search display. Thus, we infer that the collinear masking effect may be a separate phenomenon from attentional capture.