Bias-Free Measure of Distractor Avoidance in Visual Search

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OSF data repository: https://osf.io/j8zq4

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Abstract

Recent findings suggest that it is possible for people to proactively avoid attentional capture by salient distractors during visual search. The results have important implications for understanding the competing influences of top-down and bottom-up factors in visual attention. Nevertheless, questions remain regarding the extent to which apparently ignored distractors are processed. To assess distractor processing, previous experiments have used a probe method in which stimuli are occasionally superimposed on the search display--requiring participants to abort the search and identify the probe stimuli. It has been recently shown that such probe tasks may be vulnerable to decision-level biases, such as a participant's willingness to report stimuli on to-be-ignored items. We report here results from a new method that is not subject to this limitation. In the new method, the non-target search elements, including the salient distractors, contained features that were either congruent or incongruent with the target. Processing of the non-target elements is inferred from the effects of the compatibility of the shared features on judgments about the target. In four experiments using the technique we show that ignored salient distractors are indeed processed less fully than non-target elements that are not salient, replicating the results of earlier studies using the probe methods. Additionally, the processing of the distractors was found to be reduced at least in part at early perceptual or attentional stages, as assumed by models of attentional suppression. The study confirms the proactive avoidance of capture by salient distractors measured without decision-level biases and provides a new technique for assessing the magnitude of distractor processing.

Key words: visual attention, visual search, attentional capture, attentional suppression, inhibitory control

Salient stimuli appear to capture attention automatically (e.g., Abrams & Christ, 2003; Christ & Abrams, 2006; Theeuwes, 1992; Yantis & Jonides, 1990). Yet there are also situations in which top-down control seems to prevent capture (Folk et al., 1992). Recently, a number of researchers have suggested that the ability to avoid capture may be facilitated by proactive suppression of the to-be-ignored item based on its features or saliency (e.g., Chang & Egeth, 2021; Gaspar & McDonald, 2014a; Gaspelin et al., 2015, 2017, 2019; Gaspelin & Luck, 2018a; Ma & Abrams, 2023a, 2023b; Stilwell & Gaspelin, 2021; Vatterott et al., 2018). In contrast, some other theories, such as the Guided Search model (Wolfe, 2021), consider the avoidance of capture by salient distractors a consequence of attentional prioritization of the target features. Recent research suggests both distractor suppression and target feature enhancement may contribute to the observed effect of avoidance of salient distractors in visual search (Chang & Egeth, 2019, 2021; Oxner et al., 2023). Distractor avoidance (also referred to as distractor suppression in many studies), revealed by relatively reduced processing of salient distractors, has been supported by many different sources of evidence: Manual responses to the target in visual search tasks are sometimes faster when a salient distractor is present (Gaspelin et al., 2015; Ma & Abrams, 2023b); eye movements to salient distractors occur at less than chance levels (Gaspelin et al., 2017, 2019; Ipata et al., 2006); and in ERP studies, instead of an N2pc component suggestive of attentional capture, salient distractors induce a distractor positivity (P_D) component that is thought to index inhibition of attention (Gaspar & McDonald, 2014; Gaspelin & Luck, 2018a; Hickey et al., 2009; Jannati et al., 2013; Sawaki & Luck, 2010; Stilwell et al., 2022; for a review, see Gaspelin et al., 2023). The existence of an attentional mechanism that reduces the processing of salient distractors has been argued to help resolve the apparent conflict between results suggestive of automatic capture on the one hand, and results that indicate the ability to exert top-down control to avoid such capture, on the other hand (Gaspelin & Luck, 2019; Wolfe, 2021).

In psychophysical studies, a commonly used method to show active distractor avoidance involves *probe tasks* in which symbols are occasionally superimposed on the search display during an experiment. On those trials, participants are expected to abandon the search and instead report the identity of the superimposed symbols. Typical findings are that people are less likely to report the probe symbols on the to-be-ignored salient distractors (typically featural singletons)—suggesting reduced allocation of attention to salient distractors relative to non-salient ones (Gaspelin et al., 2015; Ma & Abrams, 2023b; Stilwell & Gaspelin, 2021). Nevertheless, it has recently been shown that responses in the probe task may reflect not only changes in *perceptual* processing of the display items (the presumed influence of distractor avoidance), but also *decision-level* influences such as an individual's willingness to report information about the distractors (Kerzel & Renaud, 2023). In particular, because the search task instructions require participants to ignore any salient singleton, participants may also be somewhat reluctant to report probes on singletons on the probe trials. Because of this possibility, the probe task may not provide an uncontaminated index of attentional processing, as it has been assumed to do.

We report here a new task that provides a good index of attentional processing in the presence of salient distractors, but does not suffer from the limitation noted above. In the experiments reported below, non-target elements in the search displays contained visual features that were either congruent or incongruent with the feature to be reported about the target item. Processing of the non-targets (including the salient distractor) can be inferred on the basis of facilitation or inhibition in target judgments caused by the features of the non-targets. The method is rooted in a long history of the study of effects of “flankers” (i.e., to be ignored stimuli) on perception (e.g., B. A. Eriksen & Eriksen, 1974). Importantly, the method is not susceptible to the decision-level factors identified in probe tasks, because participants’ only task in this paradigm is to report about the target—any distractor processing is simply inferred from the extent to which the distractors interfere with or facilitate target reports. A similar approach was taken by Theeuwes (1996) and Theeuwes and Burger (1998), who were the first to manipulate stimulus compatibility in a visual search task to assess the level of processing of distractors. In the present study, we further compare the level of distractor processing to that of other non-salient stimuli, as a measure of the magnitude of relative avoidance of the distractor. Using the technique, we confirm that salient distractors are indeed processed to a lesser extent than non-salient distractor items, replicating the results of earlier studies using the probe method—revealing proactive prevention of capture. We also report new findings that reveal additional details about the stages of information processing that are influenced by distractor avoidance.

Most of the authors of the distractor avoidance research discussed earlier have attributed their results to the existence of a unique suppressive mechanism that downweights salient distractors. However, it is important to note that an alternative possibility is that the apparently reduced processing of a salient distractor instead reflects enhanced processing of non-salient distractors. For example, Chang and Egeth (2019, 2021) had participants search for a target of a specific color and ignore distractors that were salient color singletons in another color. They showed that in some situations target-colored items receive attentional prioritization relative to neutral-colored items. Thus, the reduced processing of color singleton distractors that many researchers have reported might in part reflect enhanced processing of target-color items. Distinguishing between the two possibilities has proven to be difficult (Gaspelin & Luck, 2018c). Given this situation, we use the term “avoidance” here with respect to the distractor to include not only suppression of salient search elements, but potentially also upweighting or enhancement of non-salient ones. Further discussion of this issue is in the General Discussion.

Experiment 1

In our first experiment we sought to validate the basic approach. Participants searched an array of heterogenous shapes for one specific shape, and were asked to report the location of a gap on that shape. The other shapes in the array also had gaps, and on some trials one of the non-target shapes was presented in a unique, non-target color, making it highly salient. Participants knew that the color-singleton distractor was never the target and should be ignored. On one-half of the trials that contained a color-singleton distractor, the gap on the singleton distractor was at the same location as the gap on the target, and on the other half of trials, the gap was at a different location. Of interest was the extent to which the relation between the target and distractor gap locations affected judgments about the target.

Method

Participants. Twenty-four undergraduate students (18 females, 6 males) participated in the experiment for course credit. The sample size was determined based on earlier experiments that also studied salient distractors (Gaspelin et al., 2015, Experiments 2 – 4). With a d_z = .78 for the effect of a distractor presence benefit on reaction time, a sample size of 20 would permit a power of .9 (Erdfelder et al., 1996). We recruited a few additional participants to prepare for potential participant exclusion. Each participant was screened for normal visual acuity and normal color vision, and provided informed consent. All experiments in the present study were reviewed and approved by the university Institutional Review Board, to ensure adequate protections of participants.

Stimuli and procedure. The experiment was programed in PsychoPy (Peirce et al., 2022). Stimuli were presented against a black background. Examples of the displays are shown in Figure 1. Each trial began with the presentation of a white fixation cross at the center of the screen for 1,000 ms, which then remained on the screen accompanying the search array. The search array then appeared, consisting of a circle (1.5°×1.5°), a square (1.4°×1.4°), a diamond (1.4°×1.4°), and a hexagon (1.7°×1.7°), separately displayed 2° above, below, to the left and to the right of center. The shapes were all unfilled and had thick borders (0.3° line thickness), and each contained a gap (0.63° in width) on either the left or right side. The target shape was prespecified as either a circle or a square for different participants. The task was to report the location of the gap (left or right) on the target shape by pressing the corresponding arrow key on a computer keyboard. On *color-singleton distractor absent* trials, all four shapes were homogeneously colored in either red or green (the color used was constant throughout the session, but varied between participants). On *color-singleton distractor present* trials, one non-target shape appeared in the alternate color (e.g., a red shape amongst a green array). The search array was displayed for 2,000 ms or until a response was received. Missing or incorrect responses were followed by a “Too slow!” or “Incorrect!” message and an error tone for 1,000 ms. The next trial began after an intertrial blank screen of 1,000 ms.

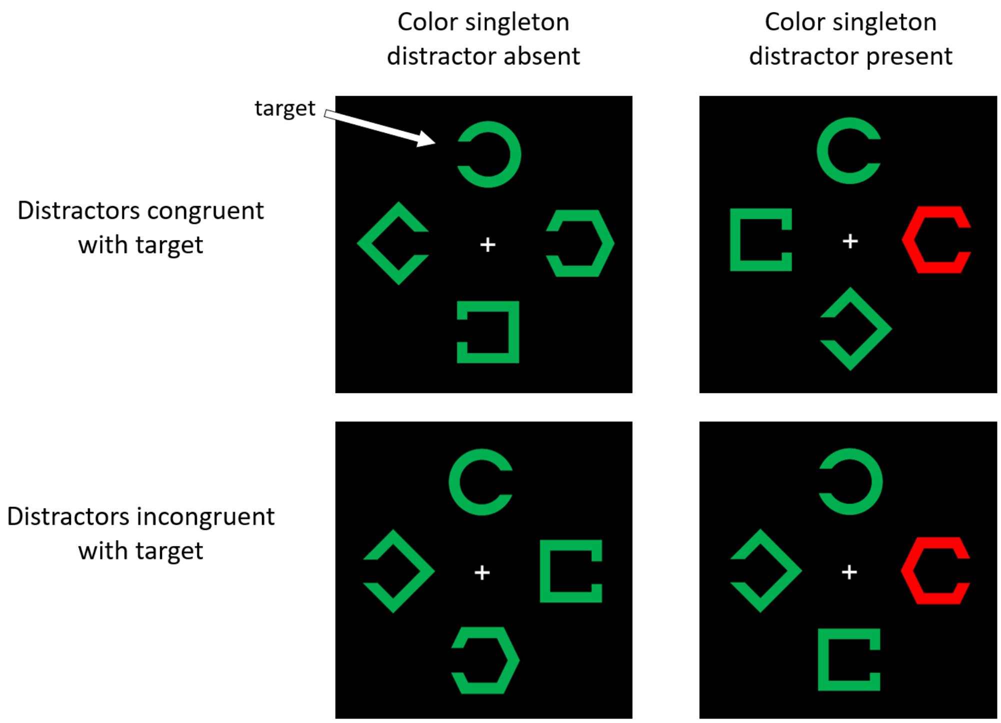

Figure 1. Examples of each different type of trial, from Experiment 1. The participant’s task was to report the location of the gap (left or right) on the prespecified target shape, a circle in these examples. Non-target shapes also contained gaps that were primarily either congruent or incongruent with that on the target. See text for additional details.

Design. The assignment of the target shape (circle or square) and the primary color of the search array elements (red or green) were counterbalanced across participants. A color-singleton distractor was present on one-half of the trials, randomly selected to be one of the three non-target shapes. The gap on the target shape was equally often on its left or right. On color-singleton distractor absent trials, either one or two of the non-target shapes (i.e., *neutral* *shapes*[1]) had a gap at a congruent location with that of the target, while the remaining two or one neutral shape(s) had a gap at an incongruent location. The more common gap direction determined whether a color-singleton distractor absent trial was deemed to be a congruent or an incongruent one, which occurred equally often. On color-singleton distractor present trials, one neutral shape contained a target-congruent gap and the other contained a target-incongruent gap; the gap on the color-singleton distractor was equally often congruent or incongruent with that of the target. Thus, when a singleton distractor was present, the location of its gap was the “tie breaker” that determined the overall congruence of the trial. Color-singleton distractor presence, the location of the gap on the target, and the congruency between the target and the color-singleton distractor, were fully crossed with each other, with the different types of trials presented in a random order. The locations of the four shapes were randomly determined on every trial. Following a practice block of 24 trials, participants completed three blocks of 96 trials each.

Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study, and the study follows JARS (Appelbaum et al., 2018). All data and analysis code has been made publicly available at https://osf.io/j8zq4. Data were analyzed using R, version 4.0.0 (R Core Team, 2020) and the Bayesian analyses were conducted in JASP (JASP Team, 2020). This study was not preregistered.

[1] We refer to the target-colored distractors as neutral shapes because they are neither the target nor are they salient. However, it is important to note that, since they are the same color as the target, they may benefit from target-color enhancement and hence may not be truly neutral. More about this issue appears in the General Discussion.

Results

All participants had an overall accuracy of 80% or greater, and were included in the analysis. For each individual, trials with incorrect or missing responses (1.2% of total trials) or reaction times (RTs) more than 2 standard deviations away from the mean in each condition were not included in RT analysis (4.2% of total trials).

Reaction times and error rates are shown in Figure 2. A 2 (distractor presence: present vs. absent) x 2 (congruency: congruent vs. incongruent) repeated measures ANOVA revealed a singleton presence benefit: Reaction times were faster when a color-singleton distractor was present (562 ms) compared to absent (577 ms), $F(1, 23) = 20.33$, $p < .001$, $\eta_p^2 = .47$, showing effective avoidance of the singleton. There was also a significant main effect of congruency, $F(1, 23) = 24.36$, $p < .001$, $\eta_p^2 = .51$, with faster RTs in the congruent condition (562 ms) compared to the incongruent condition (577 ms), indicating that the gap location on the non-target shapes was processed to some extent. Numerically, the congruency effect induced by the color-singleton distractor (11 ms) was smaller than that for the neutral shapes (19 ms), however the interaction between distractor presence and congruency was not significant, $F(1, 23) = 1.41$, $p = .247$, $\eta_p^2 = .06$.

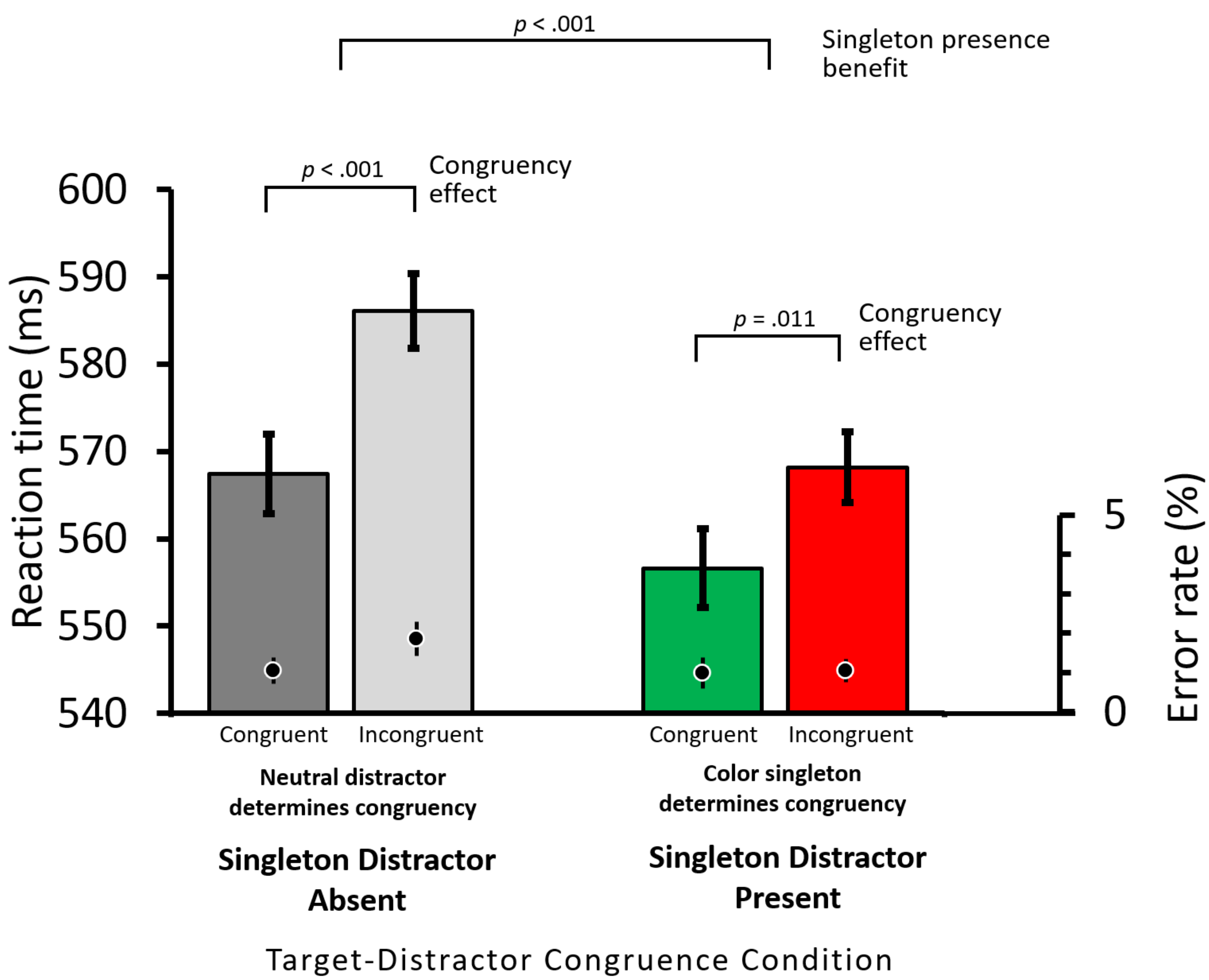

Figure 2. Reaction times (bars; left axis) and error rates (dots; right axis) from Experiment 1. Key comparisons (involving reaction time) are indicated in the figure; others are reported in the text. Error bars in all figures represent within-subject standard errors (Cousineau et al., 2021).

The results from the ANOVA reveal an overall congruency effect. To facilitate comparison with the following experiments, we report here the results of *t*-tests that examined the magnitude of the congruency effect separately for the two types of distractors. Paired-samples *t*-tests showed a significant congruency effect when the congruency was determined by the color-singleton distractor $t(23) = 2.77$, $p = .011$, $d_z = .57$, as well as when the congruency was determined by the neutral distractors, $t(23) = 4.24$, $p < .001$, $d_z = .87$.

A repeated measures ANOVA between distractor presence and congruency was also conducted on error rates. Neither the main effect of distractor presence nor the main effect of congruency was significant, $F(1, 23) = 2.93$, $p = .100$, $\eta_p^2 = .11$ and $F(1, 23) = 1.90$, $p = .182$, $\eta_p^2 = .08$, respectively. The interaction between the two variables was marginally significant, $F(1, 23) = 3.38$, $p = .079$, $\eta_p^2 = .13$, due to higher errors in the incongruent condition when the color-singleton distractor was absent (the slowest condition).

Discussion

The present experiment assessed the processing of non-target elements during visual search (specifically searches permitting distractor avoidance) in a manner that is not susceptible to the influence of decision-level (or other) biases against reporting about some of the search array elements. Here, processing of non-targets, including the color-singleton distractor, was inferred on the basis of the congruence between the gap location on the target and the location of the gaps on the non-targets. The results showed that both the neutral distractors and the color-singleton distractor were processed to some extent. This occurred at the same time that processing of the color-singleton distractor was reduced, as evidenced by a singleton presence benefit. Although the magnitude of the congruency effect for the color-singleton distractor was not significantly different from that of the neutral distractors, it was numerically smaller. The following experiments examine processing of the color-singleton more closely.

Experiment 2

Experiment 1 established the basic effectiveness of our approach. However, because there were gaps on all of the stimuli, each trial contained two non-target shapes with congruent (or incongruent) gaps competing with one non-target shape that had an incongruent (or congruent) gap. As a result, the congruency effect on each trial may have been contaminated by trial-to-trial variations in the specific shapes that were attended. In the present experiment, we conducted an improved and simplified version of Experiment 1 in which we presented a gap on only one non-target shape in the display on each trial. The gap could be either congruent or incongruent with that on the target, and could appear on either a neutral distractor or the color-singleton distractor (when present). The rationale is the same as before: the influence of the congruence of the distractor gap serves as an index of processing of the distractor. Because only one non-target shape contained a gap on each trial, this experiment provided a better opportunity to separately assess the processing of the neutral and the color-singleton distractors in the display. In addition, the method allowed us to manipulate the compatibility of a neutral distractor on trials that contained a color-singleton distractor (which was not possible in Experiment 1), permitting a more direct assessment of the processing of the different types of distractors.

Method

Participants. A new group of 24 undergraduate students (15 females, 9 males) participated in the experiment for course credit. Each participant was screened for normal visual acuity and normal color vision, and provided informed consent.

Stimuli, procedure, and design. Examples of the different trial types are shown in Figure 3. Experiment 2 was identical to Experiment 1 except that on each trial only one of the three non-target shapes contained a gap. On color-singleton distractor absent trials, one randomly selected neutral shape of the three had a gap. On color-singleton distractor present trials, the gap was equally often on the color-singleton distractor or a randomly selected neutral distractor. For both the color-singleton distractor and the neutral distractor, the gap was equally often congruent or incongruent with that on the target. The gap on each shape was equally often on the left or right.

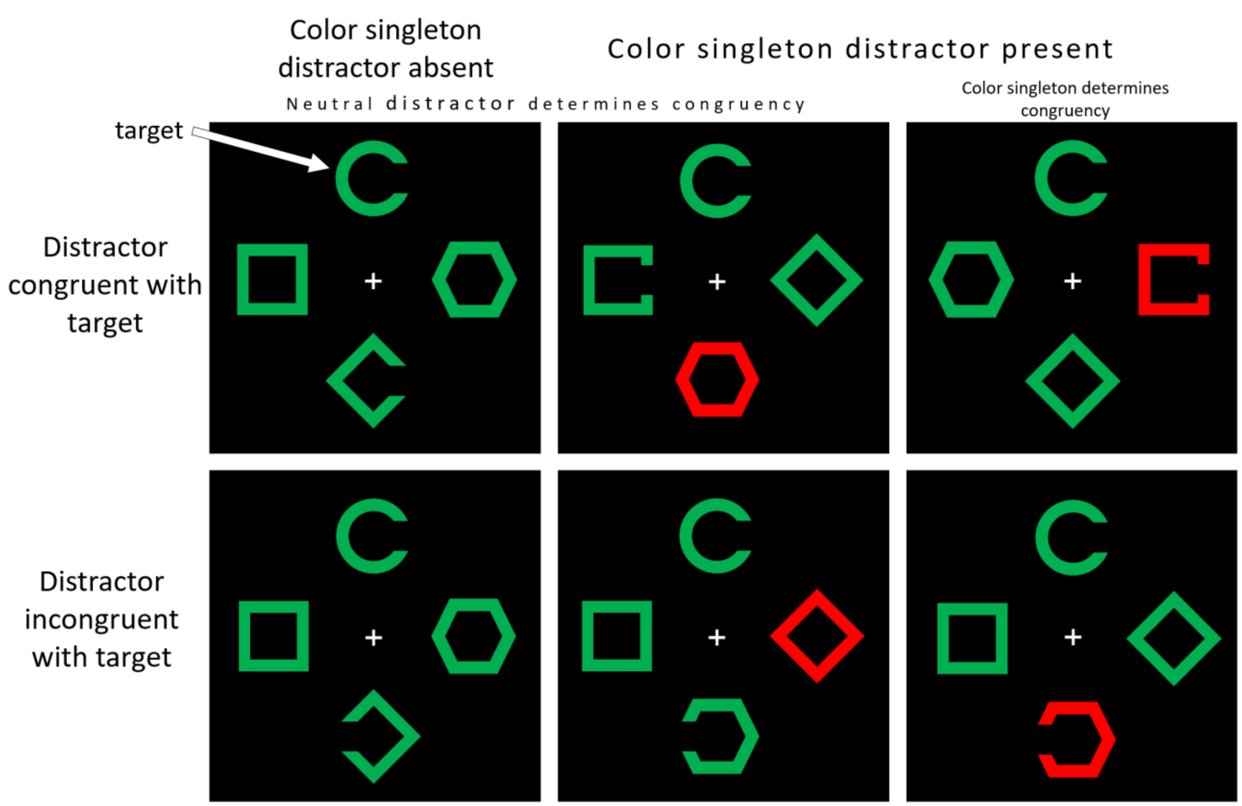

Figure 3. Examples of each different type of trial, from Experiment 2. The participant's task was to report the location of the gap (left or right) on the prespecified target shape, which is a circle in these examples. One non-target shape also contained a gap that was either congruent or incongruent with that on the target. The non-target shape with the gap could be a neutral distractor, or the color-singleton distractor, if present. See text for additional details.

Results

All participants had an overall accuracy of 80% or greater and were included in the analysis. For each individual, trials with incorrect or missing responses (3.2% of total trials) or RTs more than 2 standard deviations from the mean of each condition were not included in the analysis (4.0% of total trials).

Reaction times and error rates are shown in Figure 4. A paired-samples *t*-test showed that RTs on color-singleton distractor present trials (479 ms) were significantly faster overall than those on color-singleton distractor absent trials (495 ms), $t(23) = 5.83$, $p < .001$, $d_z = 1.19$. This singleton presence benefit reveals effective avoidance of the singleton distractor.

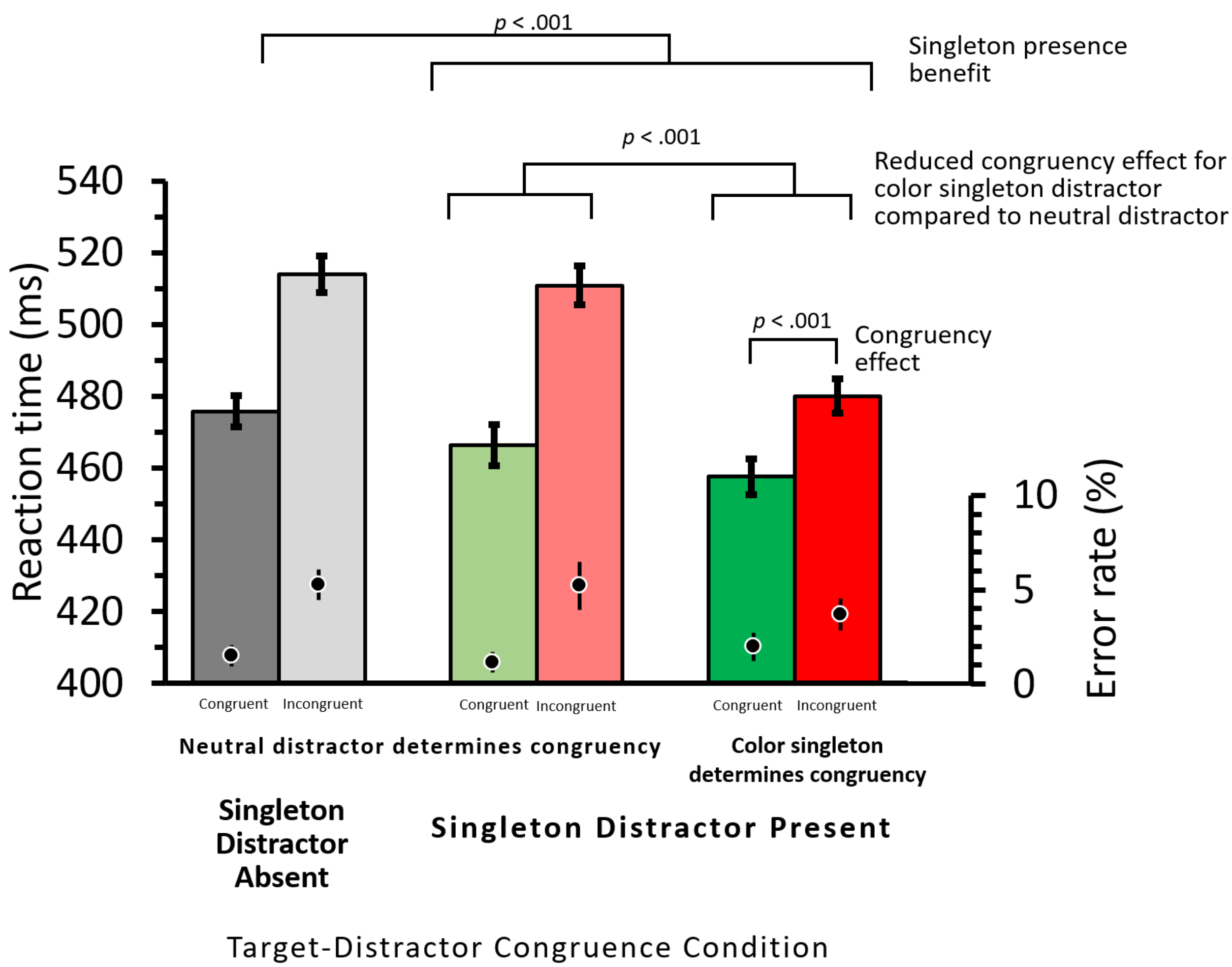

Figure 4. Reaction times (bars; left axis) and error rates (dots; right axis) from Experiment 2. Key comparisons (involving reaction time) are indicated in the figure; others are reported in the text.

To further evaluate the strength of processing of the avoided color-singleton distractor, the congruency effect caused by it was compared to that of a neutral shape. In Experiment 2, the neutral shapes could determine congruency both when a color-singleton was present and when a color-singleton was absent. Here we specifically considered only those trials containing a color-singleton distractor, and conducted a 2 (congruency determining shape: color-singleton distractor vs. neutral) x 2 (congruency: congruent vs. incongruent) repeated measures ANOVA on those trials (this corresponds to the rightmost 4 bars in Figure 4). There was a significant main effect of congruency on RT, $F(1, 23) = 47.48$, $p < .001$, $\eta_p^2 = .67$. Congruent gaps (462 ms) led to faster RTs than incongruent ones (495 ms), revealing processing of the (irrelevant) gap location on the distractor. There was also a significant main effect of congruency-determining-shape, $F(1, 23) = 33.79$, $p < .001$, $\eta_p^2 = .60$, with RTs faster overall when the gap determining congruency was on the color-singleton distractor (469 ms) compared to the neutral shape (489 ms). Importantly, the interaction between congruency and congruency-determining-shape was significant, $F(1, 23) = 16.31$, $p < .001$, $\eta_p^2 = .42$. The magnitude of the congruency effect induced by the color-singleton distractor (22 ms) was less than that of the neutral shape (45 ms), implying that the color-singleton distractor was processed to a lesser extent than the neutral distractors, as would be expected if participants were downweighting the color-singleton distractor and/or upweighting the target-colored non-salient distractors.

The same set of analyses were conducted on error rates and yielded consistent results. A paired-samples *t*-test did not find a significant difference in errors between the color-singleton distractor present (3.0%) and absent (3.4%) conditions overall, $t(23) = .96$, $p = .345$, $d_z = .20$. A repeated measures ANOVA between congruency-determining shape and congruency was conducted on the errors. The main effect of congruency-determining shape was not significant, $F(1, 23) = .28$, $p = .601$, $\eta_p^2 = .01$. The main effect of congruency was significant, with fewer errors on congruent trials, $F(1, 23) = 15.37$, $p < .001$, $\eta_p^2 = .40$. More importantly, the interaction between the two variables was significant, $F(1, 23) = 4.39$, $p = .047$, $\eta_p^2 = .16$. Consistent with the RT results, the size of the congruency effect in accuracy induced by the color-singleton distractor was smaller than that of the neutral shape, suggesting the participants processed the color-singleton distractor to a lesser extent than the neutral distractors.

Discussion

The present results confirm and clarify the findings from Experiment 1. As in Experiment 1, the congruence of both the neutral distractor shapes and the color-singleton distractor (relative to the target) influenced target identification, revealing that both types of distractors were processed to an extent. Importantly, here the magnitude of the congruency effect for the color-singleton distractor was significantly less than that for the neutral distractors (in Experiment 1 the magnitude was numerically, but not significantly, smaller) showing that the salient color-singleton distractor was processed to a lesser extent than a target-colored item even when assessed using a bias-free measure. It is worth noting that one possible concern regarding the presentation of gaps on only a subset of the shapes is that the gaps themselves may have stood out, perhaps invoking a gap-oriented search strategy. However, such a strategy would not be expected to render the color-singleton distractor less distracting. As a result, our findings can still be interpreted to reflect the relative downweighting of the color-singleton compared to the non-salient distractor.

Experiment 3

In the experiments reported thus far, the color-singleton distractor was processed to a lesser extent than the non-singleton distractors. That result is consistent with the interpretation that attention to the distractor was reduced proactively, at a relatively early perceptual or attentional stage. However, the results are also consistent with another interpretation. In particular, it is possible that the reduced congruency effect observed for the singleton distractor arose from reduced activity at a later stage of processing such as one associated with response selection. This interpretation is possible because stimuli and their associated responses were completely confounded in Experiments 1 and 2: If two stimuli had identical gaps, the responses associated with them were also identical, and when the gaps on two stimuli differed, so too did their responses. In the present experiment we disentangled stimuli and responses with the goal of determining whether the reduced congruency effect observed in Experiments 1 and 2 reflects distractor avoidance at the level of perceptual processing, or inhibition at some later (possibly response selection) stage. To do that, we had search array shapes contain a line in one of four possible orientations (vertical, horizontal, and tilted diagonally to the left or right). Each pair of orthogonally oriented lines was associated with the same key response. Thus, it was possible for two stimuli to be physically different yet activate the same response, permitting an assessment of the stage(s) of processing influenced by distractor avoidance. Similar methods that associate physically different stimuli with the same response have been used to effectively isolate perceptual processing and response generation in many earlier studies (e.g., C. W. Eriksen & Hoffman, 1973; Maxwell et al., 2021).

Method

Participants. A new group of 24 undergraduate students (17 females, 7 males) participated in the experiment for course credit. Each participant was screened for normal visual acuity and normal color vision, and provided informed consent.

Stimuli, procedure, and design. Examples of the stimuli used in the present experiment are shown in Figure 5. The stimuli consisted of the same geometric shapes used in the earlier experiments (circle, square, diamond, and hexagon), however here the shapes all had solid fill colors of red or green. The target shape and one other shape on each trial contained a solid black line (0.18° in width) crossing through it. The lines were either horizontal, vertical, or tilted 45° to the left or right. Participants were asked to report the categorical orientation of the line inside the target shape, which was either a circle or a square for different participants, and to ignore the line in any other shape. A horizontal or vertical target line required a “M” key response, while the tilted orientations required a “Z” key response on the computer keyboard. The line inside the target shape appeared equally often in each of the four possible orientations. The line in the distractor could bear one of three relations to the target line: On some trials the distractor line was a physical match to the target line (and thus, would be associated with the response required by the target; *physical match* condition); on some trials the distractor line was physically distinct from the target line yet still evoked the same response (e.g., the target line could be vertical and the distractor line could be horizontal; *same response* condition); and on some trials the distractor line was physically different from the target line and evoked a different response (e.g., the target line could be vertical and the distractor line could be oblique; *incongruent* condition). As in Experiment 2, on each trial only one of the three non-target shapes contained a feature that might match the target. On trials with a color-singleton distractor present, the distractor line would sometimes appear on the color singleton, and sometimes on a neutral distractor. The color-singleton distractor presence, the orientation of the target line, and the congruency between the target line and distractor line were manipulated to vary independently, with different types of trials presented in random order.

After a practice block of 24 trials, participants completed 3 blocks of 128 trials each.

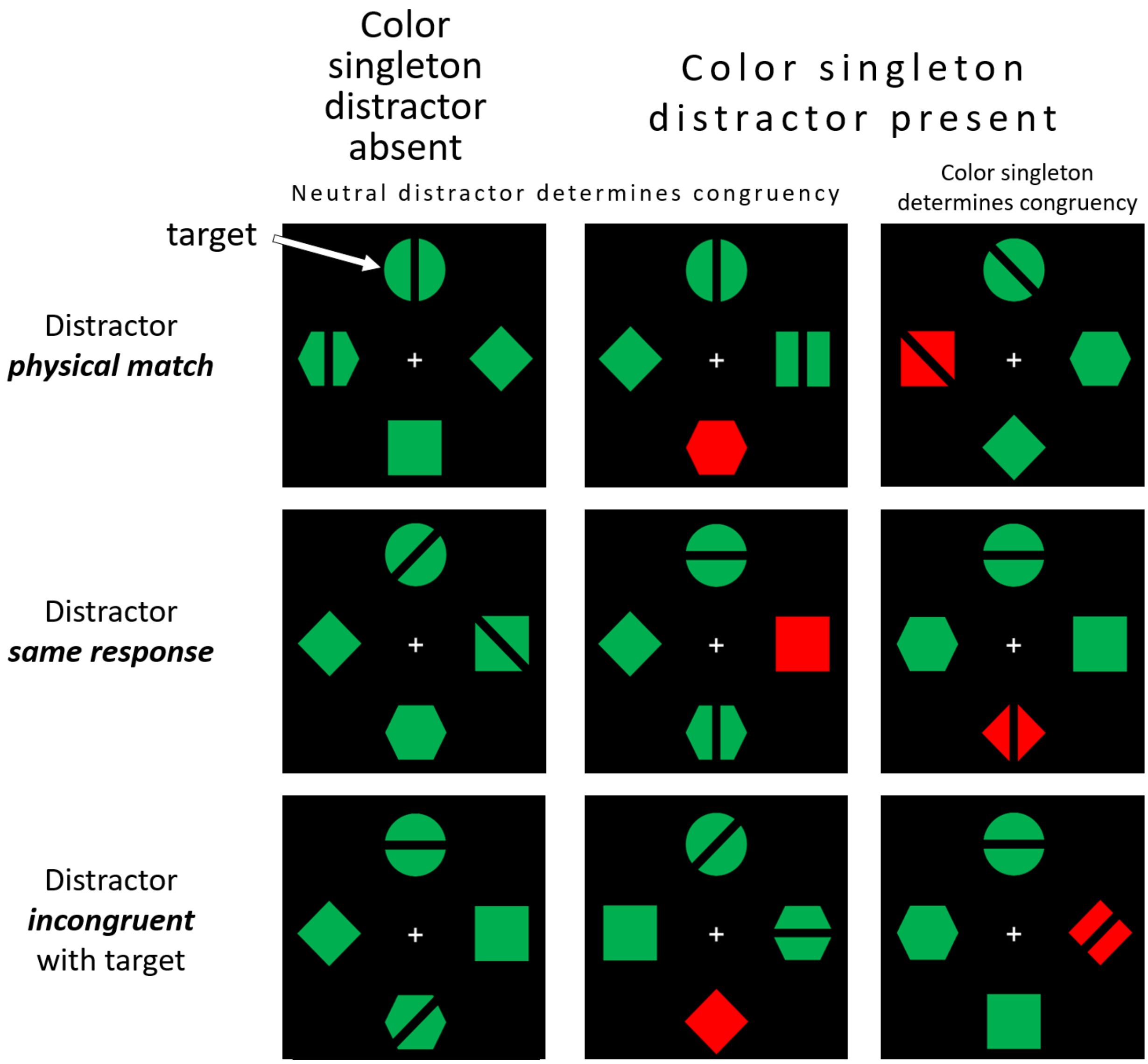

Figure 5. Examples of each different type of trial, from Experiment 3. The participants' task was to report the categorical orientation of the line on the prespecified target shape, which is a circle in these examples. Vertical and horizontal orientations required one response, while oblique orientations required another. One non-target shape also contained a line that was either (a) a ***physical match*** to the line in the target [top row], (b) calling for the ***same response*** to the target but physically distinct [middle row], or (c) ***incongruent*** with the target line and its response [bottom row]. The non-target shape with

the line could be a neutral distractor, or the color-singleton distractor, if present. See text for additional details.

Results

One participant failed to meet the overall accuracy criterion of 80% or greater, and was excluded from analysis. For each individual, trials with incorrect or missing responses (4.9% of total trials) or RTs beyond 2SD from the mean of each cell condition were not included in RT analysis (4.9% of total trials).

Reaction times and error rates are shown in Figure 6. A paired-samples *t*-test showed that RTs on color-singleton distractor present trials (605 ms) were significantly faster than those on color-singleton distractor absent trials (636 ms), $t(22) = 6.87$, $p < .001$, $d_z = 1.43$. This singleton presence benefit demonstrates effective avoidance of the singleton distractor.

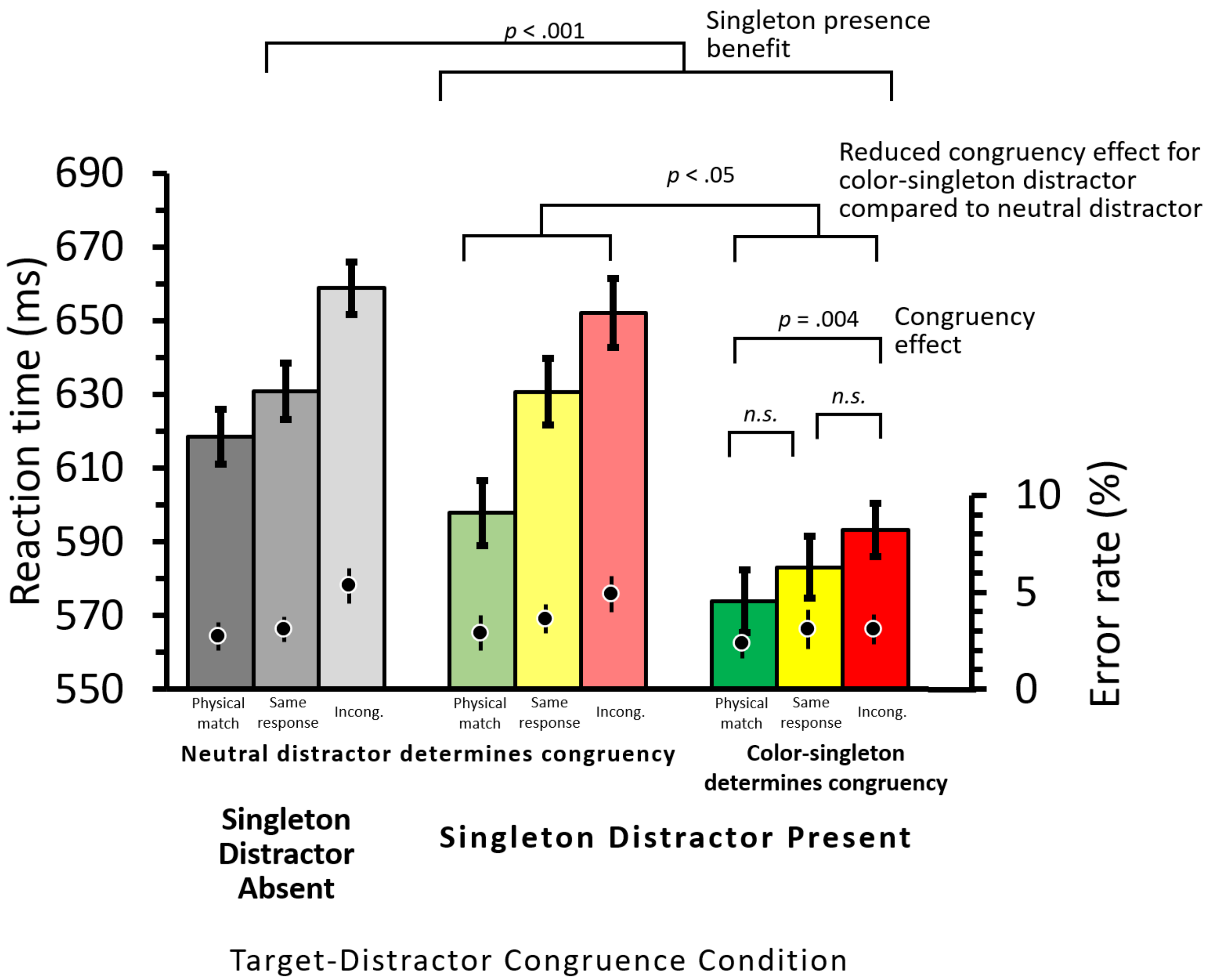

Figure 6. Reaction times (bars; left axis) and error rates (dots; right axis) from Experiment 3. Key comparisons (involving reaction time) are indicated in the figure; others are reported in the text. Note: Incong. = incongruent.

To further evaluate the strength of processing of the color-singleton distractor, the congruency effect caused by it was compared to that of a neutral shape. In this analysis, as in Experiment 2, we specifically considered only those trials containing a color-singleton distractor, and conducted a 2 (congruency determining shape: color-singleton distractor vs. neutral) x 3 (congruency: physical match, same response, incongruent) repeated measures ANOVA on those trials (this corresponds to the rightmost 6 bars in Figure 6). In RT, there was a significant main effect of congruency determining shape, $F(1, 22) = 51.45$, $p < .001$, $\eta_p^2 = .70$. RTs were faster overall when the line determining congruency was on the color-singleton distractor (583 ms) compared to the neutral shape (627 ms). There was also a significant main effect of congruency, $F(2, 44) = 26.93$, $p < .001$, $\eta_p^2 = .55$. Physical matches of the non-target line led to the fastest RTs (586 ms), physically distinct lines that called for the same response as that in the target had intermediate RTs (607 ms), and incongruent lines led to the slowest RTs (623 ms). Importantly, the interaction between congruency determining shape and congruency was significant, $F(2, 44) = 4.17$, $p = .022$, $\eta_p^2 = .16$. As seen in Figure 6, the congruency manipulation had a bigger effect when the neutral shape determined congruency compared to when the color-singleton distractor determined congruency, consistent with the results showing that participants processed the salient color-singleton distractor to a lesser extent than the target-colored items.

To further examine the reduced processing of the color singleton, we computed the congruency effect induced when the target and distractor only shared the same response (the difference between the incongruent and same response conditions) and the additional effect induced by a physical match of target and distractor (the difference between the same response and the physical match conditions; referred to as *match increment*) separately for the neutral and color-singleton distractors, and we subjected the values to a 2 (congruence type: response only vs. match increment) x 2 (distractor type: neutral vs. color singleton) ANOVA. As would be expected, the mean of the two congruence effects was smaller for the color-singleton distractor (9.6 ms) compared to the neutral distractor (27.2 ms), $F(1, 22) = 9.98$, $p = .005$, $\eta_p^2 = .31$, revealing the effects of relative distractor avoidance. The congruence effects also were approximately equal in size (response only = 15.8 ms, match increment = 21.0 ms), producing no effect of congruence type, $F(1, 22) = .36$, $p = .552$, $\eta_p^2 = .02$. Importantly, the two factors did not interact, showing that the effect of distractor type was the same for the two types of congruence, $F(1, 22) = .29$, $p = .595$, $\eta_p^2 = .01$. This suggests that distractor avoidance affected the two types of congruence equally.

In order to assess the extent to which the color-singleton distractor was processed, we conducted additional *t*-tests to compare the different congruency effects when the color-singleton distractor determined congruency. The physical match distractor was significantly faster than the incongruent distractor, $t(22) = 3.26$, $p = .004$, $d_z = .68$, revealing that the color-singleton distractor was indeed processed to some extent. Although RTs for the same response condition were numerically intermediate between the physical match distractors and the incongruent distractors, they did not differ significantly from either of the latter two conditions, $t(22) = 1.09$, $p = .286$, $d_z = .23$, and $t(22) = 1.47$, $p = .156$, $d_z = .31$, respectively. Bayesian analyses were conducted to further evaluate the non-significant results. Bayesian paired samples *t*-tests produced Bayes factors $BF_{10} = 0.373$ for the same response compared to the physical match condition, and $BF_{10} = 0.560$ for the same response compared to the incongruent condition. Both indicate anecdotal evidence supporting an absence of difference between the conditions, consistent with the non-significant results.

The same sets of analyses were performed on error rates. A paired-samples *t*-test showed that error rates on color-singleton distractor present trials did not differ from those on color-singleton distractor absent trials, $t(22) = 1.62$, $p = .120$, $d_z = .34$. A 2 (congruency determining shape: color-singleton distractor vs. neutral) x 3 (congruency: physical match, same response, incongruent) repeated measures ANOVA showed a marginally significant main effect of congruency determining shape, $F(1, 22) = 3.56$, $p = .073$, $\eta_p^2 = .14$. Neutral distractors led to slightly higher error rates than the color singleton. There was also a marginally significant main effect of congruency, $F(2, 44) = 2.96$, $p = .062$, $\eta_p^2 = .12$. The perceptual match condition had the lowest error rate, followed by the same response, and the incongruent condition. The interaction between the two was not significant, $F(2, 44) = .60$, $p = .552$, $\eta_p^2 = .03$. To further compare the congruence effect induced due to response match and that due to additional perceptual match, a 2 (congruence type: response only vs. match increment) x 2 (distractor type: neutral vs. color singleton) ANOVA was conducted on error rates. The main effect of congruence type, the main effect of distractor type, and the interaction between the two were all non-significant, $F(1, 22) = .01$, $p = .928$, $\eta_p^2 = .00$; $F(1, 22) = 1.43$, $p = .245$, $\eta_p^2 = .06$; $F(1, 22) = .22$, $p = .644$, $\eta_p^2 = .01$, respectively.

Discussion

The results of the present experiment again provide a bias-free index of the avoidance of a color-singleton distractor because the effects of target-distractor congruency were smaller for the color-singleton distractor compared to a target-colored distractor. The results also provide some insight into the nature of the processes that are affected by distractor avoidance. In particular, distractor avoidance appeared to affect both (a) the benefit or cost associated with the distractor and target having the same response yet being physically different, and (b) the additional benefit or cost associated with the distractor and target being physically identical. The former effect may reflect the operation of distractor avoidance at a relatively late stage of processing, such as one involved in response selection, whereas the latter effect seems likely to involve a relatively early perceptual or attentional stage of processing. Importantly, theories of attentional suppression assume, either implicitly or explicitly, that at least some of the effect should occur at a relatively early stage of processing (Gaspelin & Luck, 2019).

In the present experiment, while it is clear that some processing of the color singleton distractor occurred, the estimates of the individual components (attributable to either relatively early or relatively late processes), were both not different from zero. The next experiment was designed to clarify the situation by dissociating responses from the physical features of the search stimuli, allowing better isolation and assessment of the early perceptual processing of the color-singleton distractor.

Experiment 4

The first three experiments showed that the magnitude of the congruency effect caused by color-singleton distractors was in all cases less than that caused by neutral distractors, revealing relatively reduced processing of the color-singleton distractor. Experiment 3 separately assessed avoidance of the distractor during early perceptual and attentional processes as opposed to avoidance during later response selection processes. The result of that test showed that distractor avoidance appeared to occur at both stages of processing—and, importantly, at least some of the avoidance effect occurred at relatively early processing stages, as assumed by theories of suppression.

One aspect of the results from Experiment 3 deserves further scrutiny: Despite the fact that an overall congruency effect remained for the avoided color-singleton distractor, the estimates of the two individual components of distractor processing (i.e., that due to shared responses between target and distractor and that due to a physical match) were not significantly different from zero. However, it is possible to devise an experiment that can directly provide a sensitive measure of the magnitude of any perceptual-level interference or facilitation caused by the congruency of the color-singleton distractor with the target, as well as the effect of distractor avoidance on that interference or facilitation. We report that experiment next.

In the present experiment, the participant's task was not to explicitly respond to a feature of the target, but instead to indicate whether a probe shape presented at the end of the trial did or did not match the target. Because the responses to the probe ("yes" or "no") were not associated with specific targets, any effect of target-distractor congruency in this task must be an effect that occurred at an early attentional or perceptual stage, and not at a later response selection stage. As a result, any reduction in the effect of target-distractor congruency can also be attributed to reduced processing of the distractor at an early attentional or perceptual stage. The experiment was very similar to Experiment 2 except that here the search array was presented briefly and then masked--and instead of reporting about features of the target, participants indicated whether a shape presented at the end of the trial did or did not match the target.

Method

Participants. A new group of 24 undergraduate students (15 females, 9 males) participated in the experiment for course credit. Each participant was screened for normal visual acuity and normal color vision, and provided informed consent.

Stimuli, procedure, and design. This experiment was very similar to Experiment 2. The same conditions and search arrays were used (as shown in Figure 3), and the design was the same. The only difference involved the procedure on each trial, which is shown in Figure 7. As shown in Figure 7, the search array was displayed only briefly and then masked. Instead of immediately responding to the location of the gap on the target, participants were a short time later presented with a probe image, and were asked to report whether the gap on the probe matched that on the target. The probe was always the same shape as the target (i.e., a circle or a square, for different participants), but equally often contained a gap that did or did not match that on the target. To prevent ceiling effects in accuracy, the duration of the search array was dynamically adjusted using a staircase method based on each participant's performance. Starting with an initial display duration of 150 ms, a correct response would shorten the duration of the following trial by 8 ms, while an incorrect response would lengthen the duration by 42 ms. The lower and upper boundaries of the adjustment were restricted to be 83 ms and 200 ms, respectively. Four pattern masks (2°×2° each) were presented after the search array for 500 ms, followed by the probe image (the same size as the target, centered on the screen) that remained on the screen until a response was entered. Participants were encouraged to respond as quickly and accurately as possible. As in Experiment 2, on each trial only one of the three non-target shapes contained a gap. On trials with a color-singleton distractor present, the distractor gap would sometimes appear on the color singleton, and sometimes on a neutral distractor. The color-singleton distractor presence, the location of the target gap, the congruency between the target gap and distractor gap, and the congruency between the target gap and probe gap were manipulated to vary independently, with different types of trials presented in random order. After a practice block of 24 trials, participants completed 3 blocks of 128 trials each.

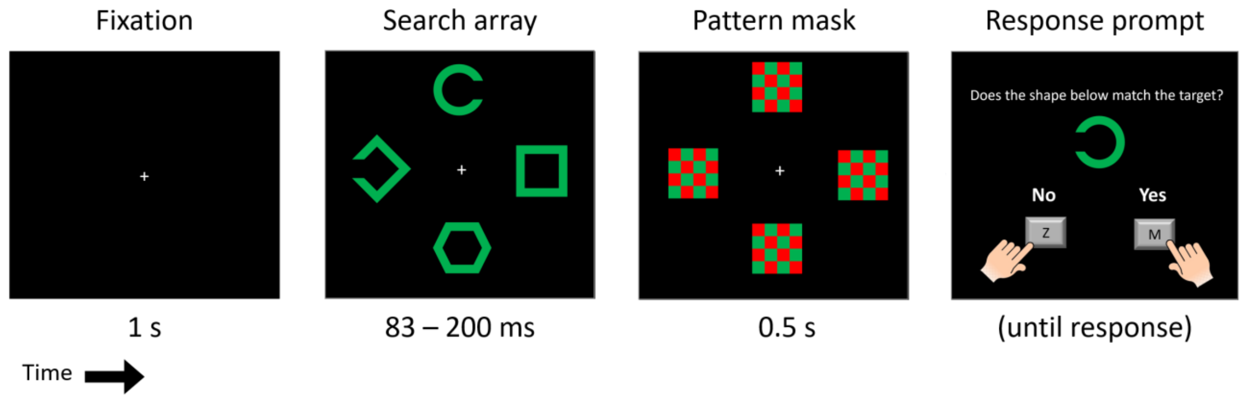

Figure 7. Sequence of events on a trial of Experiment 4. Participants reported whether a probe stimulus contained a gap that matched the location of the gap on the search target (a circle in this example). The duration of the search array was adjusted based on each participant's performance. The trial types presented were the same as those from Experiment 2 (see Figure 3). See text for additional information.

Results

Because the stimulus duration here was adjusted to prevent ceiling effects in accuracy, and because responses were delayed until the probe display, we expected the primary dependent measure to be error rate and not reaction time. With an overall mean accuracy of 87.7% (SD = 7.81%) across participants as a result of the calibration, we correspondingly lowered the accuracy criterion to 70%. All subjects met this criterion and were included in the analysis. Reaction time analyses excluded trials with incorrect or missing responses (12.3% of total trials) or RTs beyond 2SD from the mean of each cell condition (3.8% of total trials).

Mean error rates for each condition are shown in Figure 8. Overall, when a color-singleton distractor was present (11.4%), error rates were significantly lower than when one was absent (13.7%), $t(23) = 2.54$, $p = .018$, $d_z = .52$, revealing a singleton presence benefit. Next, as in Experiment 2, we compared the magnitude of the congruency effect for trials containing a color-singleton distractor between those trials on which the neutral distractor determined the congruency and the trials on which the color-singleton distractor determined the congruency by conducting a 2 (congruency-determining-shape: color-singleton distractor vs. neutral) x 2 (congruency: congruent vs. incongruent) repeated measures ANOVA (this corresponds to the rightmost 4 bars in Figure 8). The analysis revealed a significant congruency effect, with congruent trials (7.3%) less error prone than incongruent ones (15.5%), $F(1,23) = 46.25$, $p < .001$, $\eta_p^2 = .67$, and a main effect of congruency determining shape, with error rates lower when congruency was determined by the color-singleton distractor (9.2%) compared to a neutral distractor (13.7%), $F(1,23) = 30.23$, $p < .001$, $\eta_p^2 = .57$. Importantly, the magnitude of the congruency effect was significantly less for the color-singleton distractor (4.4%) compared to the neutral distractor (12.1%), as revealed by an interaction between the two factors, $F(1,23) = 11.98$, $p = .002$, $\eta_p^2 = .34$. When considered alone, there was a significant congruency effect for the color-singleton distractor, $t(23) = 2.98$, $p = .007$, $d_z = .61$.

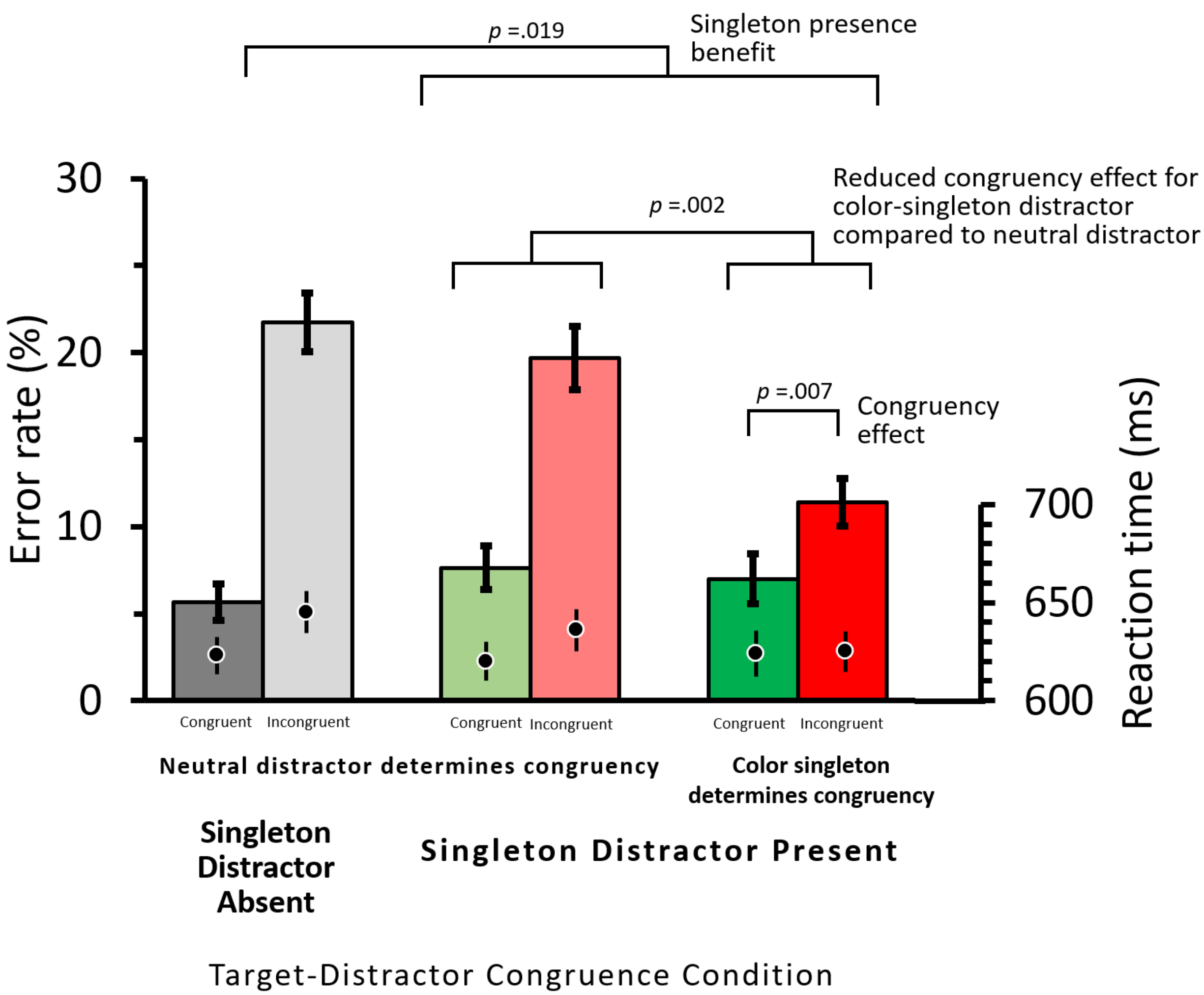

Figure 8. Error rates (bars; left axis) and reaction times (dots; right axis) from Experiment 4. Key comparisons (involving error rate) are indicated in the figure; others are reported in the text.

Similar analyses were conducted on the reaction times. RTs were marginally significantly faster when a color-singleton distractor was present compared to absent, consistent with avoidance of the color-singleton distractor, $t(23) = 1.87$, $p = .075$, $d_z = .38$. When considering the trials containing a color-singleton distractor, there was no main effect of congruency, $F(1,23) =$

.98, p = .332, η_p^2= .04, no main effect of congruency determining shape, F(1,23) = .16, p = .692, η_p^2= .01, nor did those two factors interact, F(1,23) = 1.99, p = .172, η_p^2= .08.

Discussion

We again found a singleton presence benefit indicating effective avoidance of the color-singleton distractor: participants were more accurate in identifying the target when a singleton distractor had been present in the search array. In addition, the congruency of the singleton distractor was less influential than the congruency of a neutral distractor, revealing again evidence of reduced processing of the salient distractor relative to target-colored items as assessed by a bias free measure.

More importantly, the present experiment revealed that the distractor avoidance must be operating at least in part at a relatively early perceptual or attentional stage of processing. The task in the present experiment required participants to indicate whether a post-search probe shape did or did not match the target presented during the search. As a result, the responses (“yes” or “no” keypresses) were not linked to specific target stimuli, and any effect of distractor-target congruency must reflect an effect that occurred during attentional or perceptual analysis and not during later response selection processes. Thus, a reduction in the effect of distractor-target congruency must reflect reduced processing of the distractor at a similar stage. Because the magnitude of the congruency effect caused by the color-singleton distractor was less than that caused by the neutral distractors, it was indeed the perceptual processing of the salient distractor that was reduced relative to a non-salient distractor.

It is worth considering an alternative interpretation of the present results. According to the alternative, early perceptual processing proceeded equally for the gap locations on the target-colored shapes and the singleton distractor—with no reduced perceptual analysis. Then, some post-perceptual stage would have been needed in order to determine which of the two gaps on a trial was on the target shape—and it is this stage of processing that might have been easier to complete when the distractor gap was on the color singleton (with greater low-level feature contrast to the target), compared to when it was on a target-colored neutral distractor. In other words, the reduction in processing might have occurred in some post-perceptual stage, rather than perceptual processing *per se*. However, in the present experiment, it would not have been possible for participants to begin any processing related to response selection before the appearance of the probe display. As a result, any "post-perceptual" processing involved in identifying the target gap location would still have involved a relatively early stage of processing and might reasonably be considered to be some form of (late) perceptual analysis. Hence, the reduced congruency effect observed for the color singleton distractor could still be characterized as having stemmed from reduced processing at a relatively early perceptual or attentional stage of processing.

Note that despite the use here of a post-trial "probe" display, the present experiment is considerably different in design from the earlier probe methods such as that used by Gaspelin et al. (2015). The earlier experiments involved a dual-task paradigm that included an unconstrained report of the letters from a probe display which had been presented as an alternative to the search array on a subset of trials. Perhaps in part due to the difficulty or impossibility of reporting *all* of the letters in the probe display and to the competing demands of the dual tasks, participants have been shown to bias their reports against the color-singleton item, as we have noted. In the present experiment the single task was to report whether a post-search-presented “probe” image did or did not match the sole target shape from the search array. The probe had only one correct answer and thus was not subject to biased decisions like those that affected the earlier studies. The use of a single task also prevents strategic changes in control settings across different tasks.

One additional feature of the present experiment is worth noting. The present experiment used only a brief exposure of the search array, in contrast to the search trials (as opposed to probe trials) from most, if not all, previous studies of distractor avoidance, in which the search array remained visible until the participant responded. Thus, it is theoretically possible that the long exposure used in other experiments might have permitted capture by the color-singleton distractor followed by rapid disengagement—and then perhaps inhibition of the information acquired from the color-singleton distractor. In other words, even the reduced congruency effects reported in our earlier experiments might not unambiguously rule-out the possibility that the color singleton distractor might have initially captured attention, followed by rapid disengagement. The present experiment, however, is not subject to that same concern, and the present results support our earlier conclusions.

General Discussion

In each of the reported experiments, participants searched for a specific shape of known color, sometimes in the presence of a salient color-singleton distractor. We found evidence of attentional avoidance of the distractor in each experiment in the form of a benefit to the search when the singleton distractor was present. Additionally, evidence of distractor avoidance was also obtained using an unbiased measure of the processing of the salient distractor based on the congruence between features of the target and features of the distractor. Finally, the relative reduction in processing was identified as occurring during early perceptual-level processing of the distractor, as assumed by theories of attentional suppression.

Unbiased measure of distractor processing

As noted earlier, many studies of distractor avoidance have offered evidence by conducting a search task in which occasional “probe” trials are included to specifically assess the processing of the various items in the display (e.g., Gaspelin et al., 2015; Ma & Abrams, 2023c, 2023b). On the probe trials, there are typically letters superimposed onto the search elements. Participants are instructed to abandon the search on such trials and instead report as many letters as possible. Common findings are that people report fewer letters on the color-singleton distractor compared to neutral distractors—consistent with avoidance of the color-singleton distractor. However, Kerzel and Renaud (2023) have shown that probe letter reports can be influenced at least in part by decision-level factors. In particular, because the search instructions require participants to ignore the color singleton, participants may also be somewhat reluctant to report the probe letters that appear on it, leading to a biased (overestimated) measurement of the magnitude of distractor avoidance. Also, because the probe reports follow the end of the trial, they are also potentially vulnerable to differential memory decay of the different types of items in the display.

In the present experiments we developed an unbiased measurement of distractor processing based on the rich history of the use of "flankers" in cognitive psychology (e.g., B. A. Eriksen & Eriksen, 1974). In each experiment, features of the target that determined the correct response were either congruent or incongruent with features of one or more of the distractors. We used the magnitude of the effect of target-distractor congruence as an index of the extent to which the distractor had been processed. This measure is unbiased in the sense that there is no explicit requirement for participants to report anything about any of the distractors in the display. If a distractor can be effectively avoided, then its congruence with the target should have no effect on target identification. Conversely, if the distractor-target congruence does influence target identification, then it can be concluded that the distractor was processed to some extent during the search—with the magnitude of the influence serving as an index of the extent of processing. Using this measure, we found in each experiment that the salient color-singleton distractor was processed to a lesser extent than the neutral distractors—consistent with the relatively reduced processing of the singleton distractor compared to target-colored items.

Relation to existing evidence of distractor avoidance

Using a novel bias-free measure of distractor avoidance, the present study showed reduced processing of a salient distractor compared to neutral, non-salient distractors. Processing of the salient distractor, however, was not completely eliminated as indicated by a significant congruency effect for the color singleton distractor in each of our experiments. This finding of reduced, but not fully eliminated, attentional allocation to the distractor is consistent with existing evidence of distractor avoidance. For example, in the earlier probe report experiments, letters on the singleton probe were reported at a lower rate than those on target-colored distractor shapes, but were nevertheless consistently reported with a probability of around 10-15% in several studies (Gaspelin et al., 2015; Ma & Abrams, 2023c; Stilwell & Gaspelin, 2021). Additionally, oculomotor studies that reported reduced saccades to the salient distractor also still found incidental saccades to the distractor on approximately 5% of trials (Gaspelin et al., 2017, 2019). Thus, the distractor avoidance that has been reported is typically incomplete—nevertheless, the distractor downweighting and target upweighting mechanisms appear powerful enough to eliminate what, in many cases, would be a substantial advantage conferred to the salient distractor.

Previous researchers who also examined effects of distractor compatibility often attributed congruence effects to attentional capture by the distractor. For example, Theeuwes and Burger (1998) found, in several experiments, when the colors of the distractor and target were not predictable, that the presence of a color singleton distractor not only slowed search times, but incongruent distractors had an even greater effect than congruent ones. They concluded that the distractor had captured attention (see also Theeuwes, 1996, for similar findings and conclusions). In contrast, we have suggested that the congruence effects observed in the present experiments do not reflect capture of spatial attention by the distractor. There are several reasons for this. First, attentional capture by the distractor would be expected to slow search (as it did in Theeuwes & Burger, 1998 and Theeuwes, 1996), yet in the present experiments we observed a singleton presence advantage. Next, the diagnostic target feature in the present experiments was a highly salient gap or tilted line. Such features may become available in an early, preattentive, stage of processing during which the entire display is inspected prior to attentional selection of relevant elements for detailed inspection (as in the "rapidly extracted attributes" of Wolfe, 2021). Hence, the identity of the distractor could affect behavior without the distractor having been selected. Finally, our participants were explicitly searching for gaps and tilted lines. Thus, such features might have been intentionally prioritized for selection as a result of the participants' top-down goals—and not due to bottom-up exogenous capture.

Given the variety of factors just noted that could influence processing of a distractor, one advantage of the present method is that it relies not on the absolute magnitude of the distractor compatibility effect, but instead on a comparison between the singleton distractor and a neutral shape. Such a comparison was not available in some earlier studies that manipulated stimulus compatibility to assess capture (e.g., Theeuwes & Burger, 1998).

Distractor avoidance affects attentional processing

An implicit assumption of proponents of signal suppression is that the suppression affects early attentional processing. For example, Gaspelin and Luck (2018c) proposed that attentional suppression influences activity in a putative attentional priority map which is used to guide attentional selection. Similarly, attentional guidance by target features is also thought to shape the priority map and subsequently prioritizes selection of goal-relevant items (Wolfe, 2021). Nevertheless, in previous behavioral studies of distractor avoidance, the observed effects do not permit any inferences about the stage or stages of processing that are affected by distractor avoidance. The present Experiment 4 did provide an opportunity to learn more about the locus of distractor avoidance effects. The experiment employed a yes/no matching task in which participants reported whether a shape presented at the end of the trial did or did not match the target that had been presented earlier. Because the required response in that task was unassociated with any specific target stimulus, distractor avoidance can influence performance only through activity at relatively early attentional or perceptual stages[2]. The results showed that the processing of the distractor was indeed reduced, consistent with the interpretation that distractor avoidance operates at least in part at an early stage of processing.

Target feature enhancement

In the present experiments, the color of the target was specified in advance, and we compared the processing of color singleton distractors to the processing of distractors that were the same color as the target. As a result, the relative deprioritization of the color singleton—that is, what we have called distractor avoidance here—includes the combined influence of suppression of the color singleton distractor as well as potential enhancement (or "upweighting") of the target-colored distractors. Indeed, it has been shown that, in some search tasks, processing of target-colored items is enhanced relative to the processing of novel-colored items (Chang & Egeth, 2019, 2021; Oxner et al., 2023). It is worth noting that these conclusions are based on dual-task experiments that used infrequent probe trials to assess attentional allocation to items of different colors. As a result, it is possible that the results may have been

[2] It is worth considering one additional possibility here. Because responses in this experiment were withheld until after the probe stimulus was presented, it is possible, in theory, that distractor avoidance may have exerted an influence on the *memory* of the items from the display, and not perceptual processing per se. Because the effects of avoidance were similar to the effects in other experiments in which memory was not involved, this possibility seems unlikely.

influenced by the same decision-level biases that have been shown to play a role in other dual-task probe paradigms (Kerzel & Renaud, 2023).

For tasks in which object color is the feature that defines the target (such as the tasks used in the present experiments), in order to more definitively distinguish between color-singleton suppression and target-color enhancement researchers have typically included a subset of trials in which novel-colored distractors are sometimes present (e.g., Chang & Egeth, 2019, 2021; Oxner et al., 2023). Doing so, however, may complicate the interpretation of the results because the presence of additional novel colors could potentially alter the search behavior throughout the task. For example, when the distractor singleton color and the target color randomly switch with each other from trial to trial, people are unable to suppress either singleton color (e.g., Gaspelin & Luck, 2018b; but see Ma & Abrams, 2023b). Distinguishing between target-color enhancement and distractor-color suppression remains an important endeavor for future research.

Dissociating spatial attention and perceptual processing

Our results also have implications for studies that have reported a dissociation between the cuing of spatial attention to a location and attentional processing (or "engagement") of the item at that location. For example, Zivony and Lamy (2018) showed, in a search for an item of a specific color, that a salient cue in a task-irrelevant color attracted attention to its location yet did not result in the processing of the item at its location. Maxwell et al. (2021) found similar results. In contrast, each of our experiments here obtained evidence that seems to be inconsistent with those findings: In every experiment reported, a salient cue in an irrelevant color (the color-singleton distractor) was processed to an extent that its congruence with the target influenced target identification (the same measures used by Zivony & Lamy, 2018, and Maxwell et al., 2021). Furthermore, this occurred despite the fact that the distractor in the present experiments appeared *not* to have captured spatial attention (based on the singleton presence advantage in search performance). One potential explanation for the different pattern of results is that the earlier researchers used a sudden onset stimulus to capture attention whereas here a salient color-singleton was used. Additionally, in the earlier studies, the stimuli that carried the features that were either congruent or incongruent with the target appeared as separate items from the onset cue that was salient, whereas in our experiments the salient singleton per se contained the congruence features, possibly facilitating better processing of the features. Despite the differences, both the present study and the earlier ones show an apparent dissociation between spatial capture of attention and the processing of a salient item. More work will be needed to learn about the circumstances that lead to a dissociation between spatial attention and visual processing.

Additional advantages of the present method

In addition to providing a bias-free measure of the processing of the elements in the search array, the present method has several advantages over the probe techniques that have been used in the past to study distractor avoidance. In particular the probe method is a dual task paradigm: participants are required to learn two sets of instructions, and to be prepared to abandon the search task in order to perform the probe task when necessary. With the present method, participants receive only one set of instructions, they have only one task to perform on all trials, and they are always engaged in visual search. Thus, not only is the present task more straightforward, but there is no concern that participants might alter their search strategy in order to be more prepared for occasional probe trials. In addition, the present method provides information about the magnitude of distractor processing on every trial compared to the probe task in which information is available only from the relatively infrequent probe trials, permitting briefer experiment sessions.

One potential limitation of the experiments that contained only a single distractor with a response-relevant feature (Experiments 2 – 4) involves the trials on which that feature (either a gap or line) was identical on the target and on the distractor. In those cases, it would have been possible for participants to respond correctly without deciding which shape was the target. If that occurred, it might have had the effect of reducing reaction times in the congruent or physical match conditions of the experiments, and consequently inflating any estimate of distractor processing. However, because the strategy would be equally likely to occur regardless of the type of distractor, this possibility does not change the conclusions that we have offered.

Conclusion

The present experiments assessed avoidance of salient distractors in visual search using an unbiased measurement of distractor processing. The results confirm that the processing of salient distractors is reduced at early perceptual or attentional stages of processing.

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