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OBSERVATION

Ignoring the Unknown: Attentional Suppression of Unpredictable Visual Distraction

Xiaojin Ma and Richard A. Abrams
Department of Psychological and Brain Sciences, Washington University in St. Louis

Recent findings have shown that people are capable of proactively inhibiting salient visual distractors in a scene when they know the color of the distractor, enhancing efficient search. Investigations of this *suppression effect* have concluded that it is not possible to suppress a distractor of an unknown color, implying a mechanism that operates only on a first-order, feature-specific level. However, with a modification to the search task, we show here for the first time that people can indeed suppress salient uniquely colored distractors even when not knowing their color in advance. The task requires participants to search for the most prevalent of several shapes in the display. In two experiments the presence of an unpredictable-color singleton facilitated search. An experiment with briefly presented probes confirmed proactive prevention of capture by the distractor. The results reveal a second-order or global-salience-based suppressive mechanism that facilitates visual processing.

Public Significance Statement
Natural visual scenes contain more information than can be processed at once, so the visual system must select portions of a scene for further processing. One way in which that selection occurs is by suppressing elements known to be irrelevant to one's current goals. Previous research has suggested that this suppression is possible only if specific features of the unwanted elements (e.g., their color) are known in advance; however, we show here, with a simple change to the experimental task, that people are indeed capable of suppressing distractors even without advance knowledge of their specific features. The results reveal a new mechanism that enhances efficient visual selection from the environment.

Keywords: visual attention, visual search, attentional suppression, attentional capture

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Most natural scenes contain more information than we can fully process. As a result, brain mechanisms of attention must prioritize the elements in a scene. Considerable research has been devoted to identifying properties of those selective attention mechanisms. A common finding is that salient, uniquely colored items (color singletons) can capture attention even when they are known to be irrelevant to the observer's goals (Theeuwes, 2004). Recently, it has been discovered that people are also capable of inhibiting or suppressing salient but irrelevant color singletons–devoting fewer resources to them than to nonsalient items–under certain circumstances. For example, participants are faster to report the location of the black dot on the green diamond in a display if one of the elements is a red color singleton, as in Figure 1a, compared with when all are the same green color, as in Figure 1c (Gaspelin et al., 2015). Such suppression has revealed a previously unknown manner in which attentional prioritization within a scene is achieved by actively inhibiting parts of the scene.

Suppression of irrelevant features has been characterized as being *proactive* in nature—that is, inhibitory control is generated in advance, preventing attentional capture by the salient distractor (Gaspelin & Luck, 2019).[1] Proactive suppression has only been

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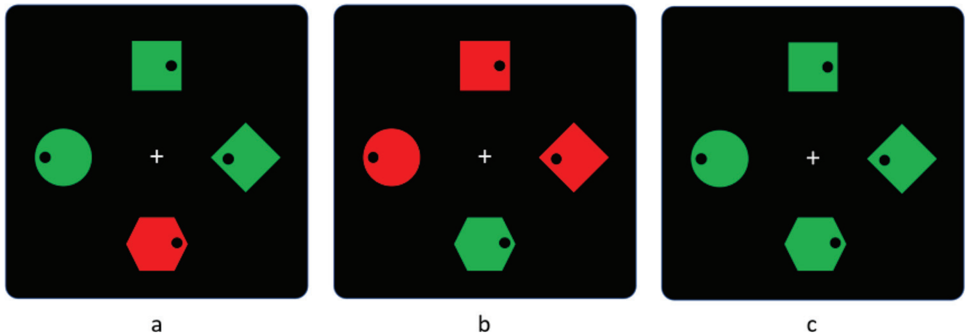
Xiaojin Ma https://orcid.org/0000-0003-4592-6408
The data and analysis code of both experiments of this study are available at https://osf.io/r52db. This study's design and hypotheses were not preregistered.
Correspondence concerning this article should be addressed to Xiaojin Ma, Department of Psychological and Brain Sciences, Washington University in St. Louis, 1 Brookings Drive, St. Louis, MO 63130, United States. Email: xiaojinma@wustl.edu

[1] Indeed, Gaspelin and Luck (2019) suggest that the suppressive mechanisms are engaged not merely before allocation of attention to the distractor, but before stimulus onset. Because little is known about the specific mechanisms underlying suppression, we take the less extreme view that the suppression is put in place before attentional allocation, and we use the term "proactive" to refer to that characteristic of the suppression. Note that some studies of inhibition of likely distractor *locations* (as opposed to likely distractor features) may have more solid ground upon which to base a claim of suppression before stimulus onset (e.g., Huang et al., 2022).

Figure 1
Examples of Displays Used in Previous Studies of Attentional Suppression



Note. The task in each case would be to report the location of the dot on the prespecified target shape (e.g., diamond). If the color of the singleton distractor is known in advance, target identification is often faster when the singleton is present, as in (a), compared with when it is absent, as in (c). If trials like those in (a) and (b) are mixed in an experiment, the singleton color is uncertain and suppression of it will not occur. See the online article for the color version of this figure.

observed when the to-be-suppressed item is of known identity (e.g., red in color). If the target and distractor colors change from trial to trial, such as when displays like those in Figures 1a and 1b are intermixed in an experiment, people are unable to suppress capture by the color singleton (Gaspelin & Luck, 2018; Graves & Egeth, 2016; Vatterott & Vecera, 2012).[2] In other words, proactive inhibitory control can only be generated based on first-order information (a *specific* color), but not on second-order information (a *unique* color), or on global salience (a salient item). The inability to make use of second-order or global saliency information places important constraints on the mechanisms underlying attentional selection. For example, under circumstances in which it is critical to minimize distractions, ignoring distractors may be impossible if their precise identity is not known.

The present experiments explored the possibility of proactive suppression of items with unpredictable features by employing a novel search task that encouraged global spreading of attention, permitting participants to ignore any local visual uniqueness. In all prior studies of suppression, the search task required participants to locate one specific target shape among an array of heterogeneous shapes of the same color, sometimes in the presence of a different-colored singleton distractor (as in Figure 1a or 1b). However, its sole occurrence in the display on each trial made the target itself unique (in the sense that there was only a single occurrence of the target shape in the search array; the nontargets typically consisted of several heterogeneous shapes), and the search task may have been most expeditiously performed by adoption of an attentional control setting exploiting that uniqueness. Such a strategy may have prevented suppression of a uniquely colored singleton in the array. Under those circumstances it may only be possible to suppress capture by the singleton if its specific color is known, as has been demonstrated (Gaspelin & Luck, 2018). In other words, a strategy to suppress unique items in general (i.e., second-order or global-salience-based suppression), if possible, would have been counterproductive for identification of the sole target. To address that potential limitation, we used displays that contained multiple instances of different shapes and had subjects identify the shape that was most prevalent in the array—a *majority search*. With that change, the target of the search was no longer unique, permitting proactive suppression of unique salient distractors with unpredictable features.

Our approach is similar to that of Bacon and Egeth (1994, Experiment 2) in their study of capture by salient singletons. In that experiment, as in the present study, the displays included multiple instances of the sought-for shape, unlike previous experiments that had contained only one target instance (among homogeneous distractors in Bacon and Egeth's case; among heterogeneous distractors in the studies of suppression). The change was intended to alter participants' search strategies and to make it ineffective for participants to simply search for a unique item—instead they needed to search for a specific shape. With that change Bacon and Egeth found that color singletons no longer captured attention. Similarly, in the present study, our intent was that by including multiple instances of the target shapes, and by having subjects report the most numerous shape, they would not adopt a search strategy that prioritized singular elements in the display—a strategy that could have been used in earlier studies of suppression that contained only one instance of the target. With that change in strategy, we believed that suppression of unknown-color singletons might be possible. Note also that the Bacon and Egeth (1994) study did not explicitly address proactive suppression, and they in fact did not find any benefit of the presence of a color singleton (a hallmark of suppression). Additionally, the singleton distractors in their experiments were always a known

[2] A few studies have shown that unpredictable-color singletons can elicit an event-related potential component thought to reflect suppression, but in those studies there was no behavioral evidence that the singleton had been suppressed relative to nonsingleton distractors (Burra & Kerzel, 2013; Sawaki & Luck, 2010). An additional behavioral study found that attentional capture did not depend on whether the color of the distractor was predictable, but that study also did not find actual suppression (Won et al., 2019).

color, so any conclusions reached would not apply to other than first-order suppression.

Experiment 1

Experiment 1 tested the possibility that multiple instances of the target shape in a search display might invoke a top-down goal specifically for items with repeated occurrences, possibly permitting suppression of salient and unique singletons of unknown color. Search arrays like the ones in Figure 2a were used, containing, in addition to a nontarget distractor, five shapes that consisted of either three circles and two squares or two circles and three squares. Participants were asked to indicate whether circles or squares were more prevalent in the display. Note that this task differs from traditional search tasks in which participants must localize a singular item and identify a specific feature of it (such as the location of a dot, as in Figure 1).

In the experiment, the elements of the search array were displayed in either red or green, and the singleton distractor, when present, was displayed in the alternate color—making it a highly salient color singleton. Because a unique item (i.e., a color singleton) is not relevant to the task of the majority search, it might be possible for participants to suppress salient singletons in a feature-blind manner.

Method

Participants

Similar experiments (Gaspelin et al., 2015, Experiments 2–4) yielded a d_z = .78 for the effect of singleton presence on reaction time (RT). A sample size of 20 would be sufficient to detect such an effect with power = .9 (Erdfelder et al., 1996). Allowing for potential participant exclusion, we tested 24 undergraduate students (16 females).[3] All participants reported normal color vision and provided informed consent. Both experiments were run in 2022.

Stimuli

As shown in Figure 2a, the search array consisted of six shapes, with their centers spaced equally along the circumference of an invisible ring (r = 2°). Each array contained either three circles (1.4° × 1.4°) and two squares (1.2° × 1.2°), or two circles and three squares, plus one hexagon (1.5° × 1.5°). The circles and squares were always colored red or green (equally often), with the color singleton distractor, when present, appearing in the alternate color, as shown in Figure 2a. A fixation cross (.7° in height) appeared at the center of the display throughout each trial.

Procedure

Each trial began with a fixation cross for 1,000 ms, followed by the presentation of the search array until the participant made a response or 2,500 ms had elapsed. The task was to identify the most prevalent shape in the array—either circles or squares. Participants responded by pressing either the "Z" or "M" key on a computer keyboard. An incorrect or absent response was followed by an error message of "Incorrect!" or "Too slow!" The next trial began after a 1,000 ms blank screen.

Design

On one-third of the trials, all elements in the array were in the same color, either red or green (*color-singleton absent* condition); on two-thirds of the trials the hexagon shape was presented in the alternate color (*color-singleton present*). Participants were explicitly told that the shapes relevant to their task would always be homogeneously colored, and never uniquely colored and they should ignore the color singleton. After a practice block of 24 trials, participants completed two test blocks containing 96 trials each. Each test block included 32 color-singleton absent trials and 64 color-singleton present trials. The search array and the color-singleton were equally likely to be red or green. The majority target shape was equally often circles and squares, and was fully crossed with color singleton presence and color. The locations of all shapes were randomly selected on each trial; trial order was randomized within each block.

Transparency and Openness

For both experiments, we report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study, and we follow JARS (Kazak, 2018). All data, and analysis code are available at https://osf.io/r52db. Data were analyzed using R (R Core Team, 2020). This study's design and its analysis were not preregistered.

Results and Discussion

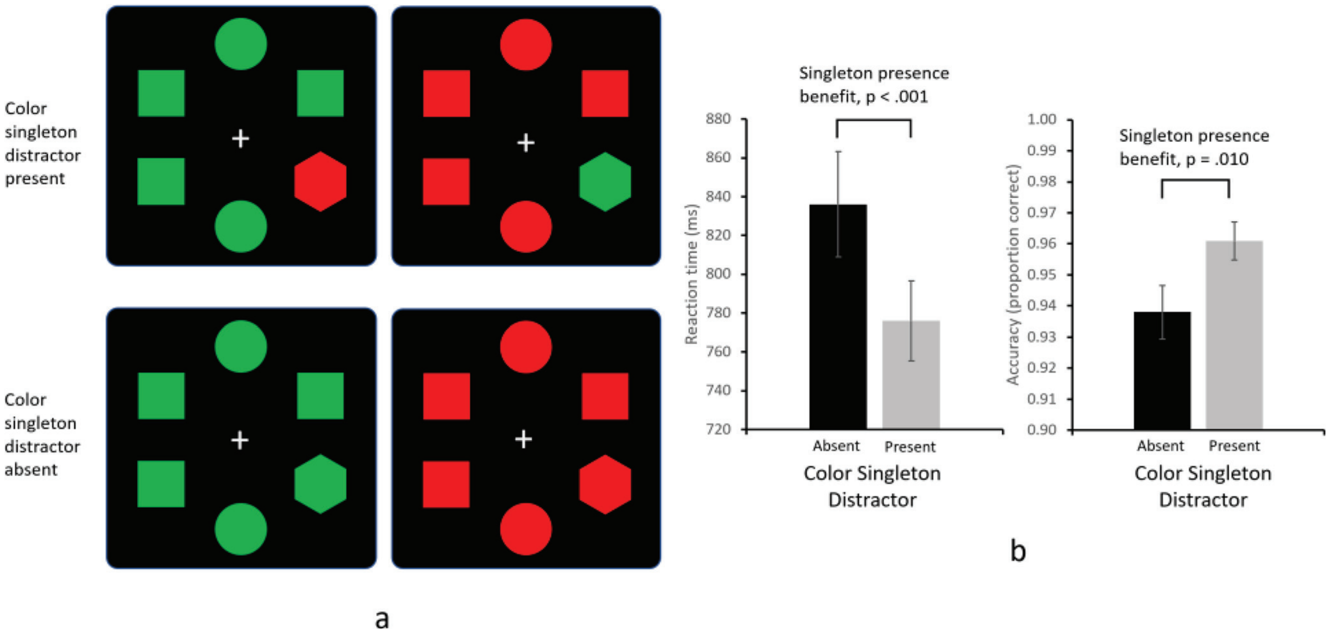
Trials with RTs more than 2 *SD*s from the mean of each participant's responses in each condition were removed (4.0% of trials), as were trials with incorrect responses (5.0%). All 24 participants met an overall accuracy criterion of 80% correct. As shown in Figure 2b, participants were faster and more accurate to identify the majority shape when a color singleton distractor was present (776 ms; 96.1%) compared with when it was absent (836 ms; 93.8%; for RT, $t(23)$ = 5.87, $p < .001$, d_z = 1.20; for accuracy, $t(23)$ = 2.82, p = .010, d_z = .57). Twenty-three of the 24 participants showed suppression based on RT ($p < .001$ by a sign-test). (Analyses in online supplemental materials show that the results were not caused by individual subjects each suppressing only one of the distractor colors.) Changing the search task so that the sought-for target was no longer unique revealed, for the first time, that people can suppress a salient singleton of unknown color on the basis of either a second-order color difference or global salience.

Experiment 2

The singleton presence benefit in Experiment 1 could be due to either *proactive* suppression of the distractor, or initial capture by the distractor followed by rapid disengagement (see Theeuwes, 2010). To examine that possibility, here we repeated Experiment 1 with the additional insertion of infrequent *probe trials* in which letter probes were briefly presented on the elements of the search array, as shown in Figure 3a. Such a task has been used often to test for, and confirm the absence of, attentional capture by a known-color singleton distractor (e.g., Gaspelin et al., 2015). If

[3] The use of undergraduate students was not deemed to constrain the generality of the present findings.

Figure 2
The Majority Search Task, From Experiment 1



Note. (a) Examples of the different search arrays. The relevant items were randomly all red or green whereas the distractor, when present, was the alternate color. (b) Presence of the color singleton distractor speeded responses and improved accuracy, indicating suppression. Error bars in all figures represent within-subject standard errors (Cousineau et al., 2021). See the online article for the color version of this figure.

suppression of an unknown-color singleton is proactive, probe letters on the color singleton distractor should be less likely to be reported compared with those on the distractor when it was not a color singleton.

Method

Participants

A new set of 24 participants was recruited (13 females). The critical comparison involves the probe letter report rates for the task-irrelevant distractor shape when it was a color singleton compared with when it was not. Based on an estimated effect size d_z = .75 from three similar experiments in Gaspelin et al. (2015; reported in Gaspelin & Luck, 2018), a sample size of 21 is needed to achieve a power of .90. Our sample of 24 participants ensures adequate power.

Procedure and Design

Frequent search trials (two-thirds of the trials) were interleaved with infrequent probe trials (one-third of the trials). The search trials were identical to those from Experiment 1. On probe trials, after a fixation display of 1,000 ms, a search array (generated by the same rules as on the search trials) was presented, except that a white letter (1.2° in height) was superimposed on each shape. On these trials, participants were to abandon the majority search and instead try to remember as many letters as possible. The letters were visible for 150 ms, and then were each replaced by a pound sign mask (1.2° in height) for 500 ms. After that, all stimuli disappeared, and an alphabetic response screen was displayed. Participants, using a mouse, were instructed to click on as many letters as they remembered seeing. A color singleton distractor was present on two thirds of the search trials and two-thirds of the probe trials. The six letters on every probe trial were randomly selected without replacement from the 26 letters in the alphabet. Before the main experiment, participants completed a 24-trial practice block of the majority search task, followed by a 28-trial practice block of interleaved search and probe trials. The main experiment consisted of three blocks of 108 trials, each including 72 search trials and 36 probe trials.

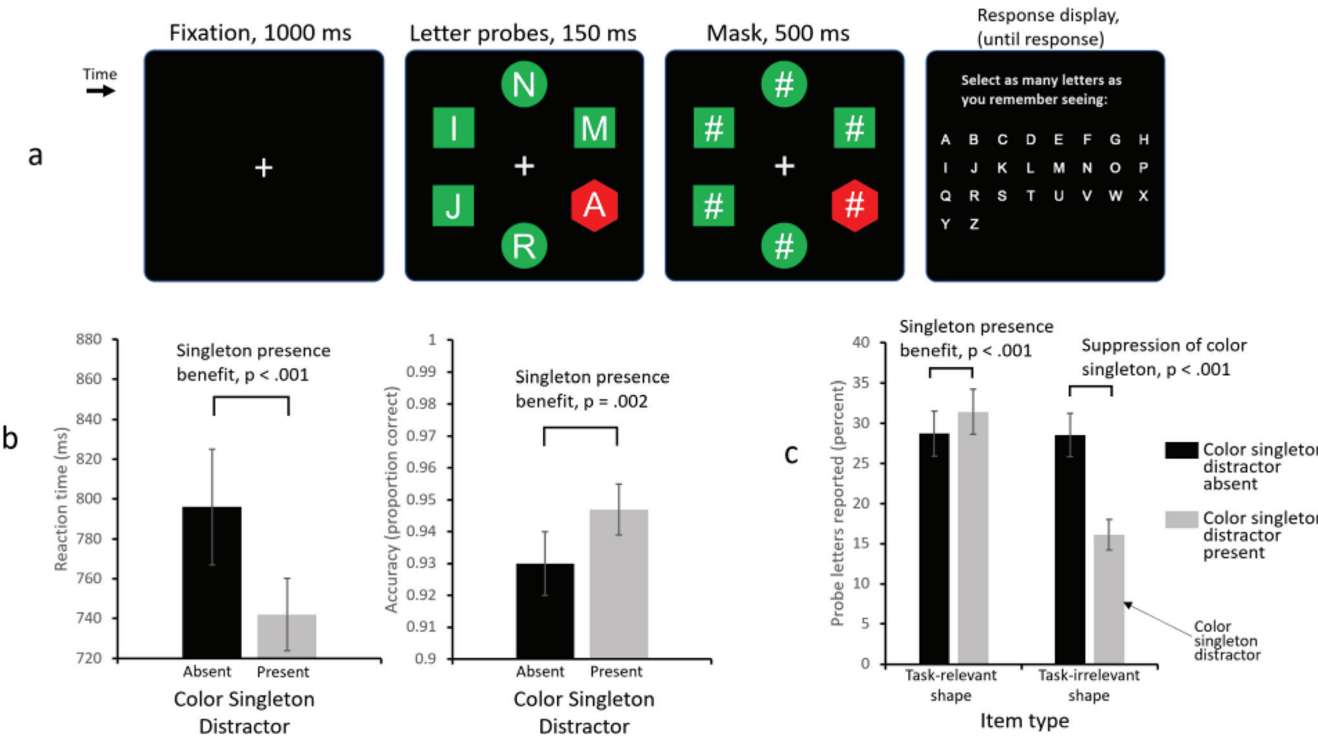
Results and Discussion

Four participants were removed for failing to meet the search task accuracy criterion used earlier (minimum 80% correct), or for reporting fewer than .8 correct letters per probe trial, leaving 20 participants in the analysis. As in Experiment 1, trials with extreme RTs (4.6% of trials) and incorrect responses (6.1% of trials) were removed.

Majority Search Task

The search task results mirror those from Experiment 1. As shown in Figure 3b, when a color singleton distractor was present (742 ms; 94.7%), participants were faster and more accurate to identify the majority shape compared with when it was absent (796 ms; 93.0%; for RT: $t(19) = 4.16$, $p < .001$, $d_z = .93$; for accuracy: $t(19) = 3.60$, $p = .002$, $d_z = .80$). The singleton presence benefit reveals suppression of the color distractor. Seventeen of the 20 participants showed suppression ($p = .003$ by a sign-test).

Figure 3
Method and Results from Experiment 2



Note. (a) Sequence of events on the probe trials from experiment 2, which were interspersed among search trials identical to those from Experiment 1. The task on probe trials was to identify as many letters as possible. The example shows a trial with a color singleton distractor; other trials had no color singleton. (b) Results from the search task and (c) the probe task revealing proactive suppression of the color singleton distractor. See the online article for the color version of this figure.

Probe Task

On average, participants reported 1.99 letters per trial, 87.0% of which were present in the array. Overall, the number of letters reported (including erroneous reports) did not depend on whether the color singleton was present (1.98) or absent (2.00; $t(19) = .77$, $p = .450$, $d_z = .17$), indicating equivalent motivation to report letters regardless of color singleton presence.

We separately computed the number of letters correctly reported on each of the task-relevant shapes (circles and squares), and the task-irrelevant shape (both when it was a color singleton distractor and when it was not), with the results shown in Figure 3c. A 2 (item type: task-relevant shapes, task-irrelevant shape) × 2 (color singleton distractor presence: present, absent) repeated measures analysis of variance showed that letters on a task-relevant shape (30.1%) were significantly more likely to be reported than letters on a task-irrelevant shape (22.3%; $F(1, 19) = 24.80$, $p < .001$, $\eta_p^2 = .57$). This confirms the effectiveness of the probe task in measuring attentional allocation to individual array items. Color singleton distractor presence had a significant effect on letter report rate overall, with fewer letters reported correctly when the color singleton distractor was present (23.8%) than absent (28.6%; $F(1, 19) = 26.47$, $p < .001$, $\eta_p^2 = .58$). However, the influence of color singleton distractor presence was different for the task-relevant shapes and the task-irrelevant shape, as revealed by a significant interaction, $F(1, 19) = 44.12$, $p < .001$, $\eta_p^2 = .70$. As seen in the figure, many fewer letters were reported from the task-irrelevant shape when it was the color singleton distractor (16.1%) compared with when it was not a color singleton (28.5%; $t(19) = 6.23$, $p < .001$, $d_z = 1.39$). This reduction in the letter report rate for the color singleton distractor during a very brief viewing after stimulus onset suggests that the distractor was proactively suppressed, ruling out the possibility of capture followed by rapid disengagement. (Analyses reported in online supplemental materials show that the effect was not driven by suppression of only one of the distractor colors.) Additionally, the correct letter report rate for the task-relevant shapes benefited from the presence of a color singleton distractor (31.4% when present vs. 28.7% when absent; $t(19) = 4.26$, $p < .001$, $d_z = .95$). This singleton presence benefit is consistent with the search task performance, also implying proactive suppression of the distractor.

General Discussion

The present experiments have revealed for the first time that it is possible for people to proactively suppress salient color singletons even when their color (and the color of the relevant items) cannot be predicted. That occurred here and not in earlier studies because the majority search task encouraged global analysis of the search displays, discouraging a strategy of searching for a unique item. The goal of searching for multiple-instance targets permitted suppression of a unique single-instance item in the display, even with an unpredictable color.[4] The present results show the existence of a suppressive mechanism operating at the level of either a discontinuity in one feature (e.g., color; a second-order attribute), or on a global saliency map of the scene, and not exclusively at the level of specific feature values (i.e., a specific color). The findings reveal a previously unknown way in which selective attention mechanisms can flexibly prioritize aspects of visual scenes.

[4] It is worth noting that the unique demands of the majority search task raise the possibility of an alternative explanation for the singleton presence benefit that we reported. In particular, the present task required directing attention to multiple circles and squares and distinguishing between them, unlike the search tasks used previously to study suppression (e.g., Gaspelin & Luck, 2018). Our task may have been impeded by the presence of a hexagon distractor because it is perceptually similar to both circles and squares, but when the hexagon was a color singleton it may have actually been easier to exclude from the items to be scrutinized. We note, however, that in other studies with unpredictable-color hexagon distractors, the presence of a color singleton did not facilitate the search (e.g., Gaspelin & Luck, 2018), but in those cases the participants were searching only for a single target instance and were not required to distinguish multiple circles from multiple squares. Additional experiments will be needed to definitively rule out this possibility.

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