The Role of Salience in the Suppression of Distracting Stimuli

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Researchers have long debated whether salient distractors have the power to automatically capture attention. Recent research has suggested a potential resolution, called the signal suppression hypothesis, whereby salient distractors produce a bottom-up salience signal, but can be suppressed to prevent visual distraction. This account, however, has been criticized on the grounds that previous studies may have used distractors that were only weakly salient. This claim has been difficult to empirically test because there are currently no well-established measures of salience. The current study addresses this by introducing a psychophysical technique to measure salience. First, we generated displays that aimed to manipulate the salience of two color singletons via color contrast. We then verified that this manipulation was successful using a psychophysical technique to determine the minimum exposure duration required to detect each color singleton. The key finding was that high-contrast singletons were detected at briefer exposure thresholds than low-contrast singletons, suggesting that high-contrast singletons were more salient. Next, we evaluated the participants' ability to ignore these singletons in a task in which they were task irrelevant. The results showed that, if anything, high-salience singletons were more strongly suppressed than low-salience singletons. These results generally support the signal suppression hypothesis and refute claims that highly salient singletons cannot be ignored.

Keywords: visual attention, attentional capture, suppression, salience, eye movements

Salient stimuli, such as brightly colored objects, are often used to signal important information on the assumption that they have inherent power to attract attention. However, formal research on *attentional capture* has painted a more complex picture. According to *stimulus-driven accounts*, the most salient stimulus in the scene will automatically capture attention even when it is task irrelevant (Theeuwes, 1992; Yantis & Jonides, 1984). According to *goal-driven accounts*, however, salient objects have no inherent power to capture attention; only objects matching the goals of the observer will capture attention (Folk et al., 1992). Although these accounts make opposing predictions, they are often fraught with additional assumptions that make them difficult to falsify and this has resulted in a longstanding debate about attentional control (for a review, see Luck et al., 2021).

The *signal suppression hypothesis* has been proposed as a potential resolution to this debate (Sawaki & Luck, 2010; see also Gaspelin & Luck, 2018b). It posits that salient stimuli produce an "attend-to-me" signal that competes for attention, consistent with stimulus-driven accounts. However, salient stimuli can be preemptively suppressed to prevent visual distraction when they are task irrelevant, consistent with goal-driven accounts. Support for this account has come from research employing a variety of techniques, including event-related potentials (Gaspar & McDonald, 2014; Gaspelin & Luck, 2018c; Sawaki & Luck, 2010), psychophysics (Chang & Egeth, 2019; Gaspelin et al., 2015; Gaspelin & Luck, 2018a; Lien et al., 2022; Ma & Abrams, 2022), eye movements (Adams et al., 2022; Gaspelin et al., 2017, 2019; Hamblin-Frohman et al., 2022; Won et al., 2019), computational models (Tam et al., 2022; Wyble et al., 2020), and even single-unit recording in monkeys (Cosman et al., 2018). Many of these studies have shown, in one manner or another, that salient distractors can be suppressed below baseline levels of other items in the search display.

One important line of evidence for suppression has come from studies of eye movements. For example, Gaspelin et al. (2017, Exp. 2) had participants search for a target shape (e.g., a green diamond) amongst heterogeneously shaped green distractors (e.g., as in Figure 1A). On some trials, a distractor was uniquely colored (a *color singleton*), and participants were instructed to ignore it. Shifts of gaze were used to evaluate attentional allocation. The key finding was that first eye movements were less likely to be directed to the singleton distractor than the baseline level of other nonsingleton distractors. This *oculomotor suppression effect* was taken to suggest that salient distractors were suppressed to prevent attentional capture, consistent with the predictions of the signal suppression hypothesis.

The signal suppression hypothesis, however, has been criticized on the grounds that the singletons used in previous studies may have been only weakly salient (Wang & Theeuwes, 2020; Theeuwes, 2004; see also Theeuwes in Luck et al., 2021, pp. 13-17). According to this *low salience account*, many previous studies of suppression used relatively small set sizes (e.g., 4 items), creating singletons with relatively low salience. If their salience were improved (e.g., by increasing the number of items to contrast with the color singleton), the singletons would overpower suppression and capture attention. Support for this viewpoint largely comes from Wang and Theeuwes (2020) who found that increasing the set size from 4 to 10 items in a modified probe paradigm produced evidence of suppression by the salient item at set size 4, replicating previous evidence of suppression (Gaspelin et al., 2015), but the salient item resulted in capture at set size 10. They reasoned that if a singleton is salient enough, it will automatically capture attention, consistent with stimulus-driven accounts of attention.

Several studies have since challenged the claim that highly salient stimuli cannot be suppressed. For example, Stilwell and Gaspelin (2021) provided evidence that the results of Wang and Theeuwes (2020) were due to a design flaw that encourages a floor effect, and once corrected, attentional suppression was found even at extremely high set sizes (e.g., 30-item displays). In addition, Stilwell et al. (2022) found that singleton distractors elicited a P_D component, indicative of suppression, at high set sizes (see also Gaspar & McDonald, 2014). Others have suggested that salience is unnecessary to observe suppression, by demonstrating that nonsalient triplets are just as easy to suppress as color singletons (e.g., Hauck et al., 2022; Lien et al., 2022). By this view, salience has nothing to do with suppression; both nonsalient and highly salient distractors are equally suppressible.

As can be seen, there is a lack of consensus about whether and how salience influences attentional capture. A major challenge in resolving this issue is that there are no established methods for measuring salience. Most previous studies have manipulated salience based upon intuition, by increasing the set size or the color contrast, which should theoretically enhance the "popout" generated by the color singleton (Duncan & Humphreys, 1989; Nothdurft, 1993). But without an independent measure of salience, it is difficult to evaluate how strong the manipulation was, or to compare relative salience across studies. Furthermore, the lack of an independent measure of salience makes it impossible to definitively resolve whether salient objects capture attention. If a salient object is successfully ignored, a low-salience account can be leveraged to suggest that the distractor was not salient enough, which is essentially unfalsifiable without a technique to measure salience (e.g., see Rule #1 in Wöstmann et al., 2022). Although some studies have attempted to use computational models to measure the salience of distractors in laboratory displays (Chang et al., 2021; Stilwell et al., 2022; Stilwell & Gaspelin, 2021), this approach is limited by the veridicality of the computational model, which often fail to perform like human observers (Kotseruba et al., 2020).

The present study aims to resolve this by introducing a psychophysical technique to estimate the relative salience of a distractor.[1] The experiment consisted of two separate tasks. First, we designed what we assumed would be low- and high-salience color singletons by manipulating the color contrast between the singleton distractor and the other items in the display (Figure 1A). An *oddball detection task* was used to verify this salience manipulation (Figure 1B; see Wöstmann et al., 2022). In this task, participants attempted to detect color singletons in briefly presented displays that were immediately masked. A staircase procedure was used to estimate the minimum exposure duration needed to accurately detect the color singleton. These detection thresholds were then compared for both singleton types. If the high-salience singleton is more perceptually salient than the low-salience singleton, it should be easier to detect and therefore produce a lower exposure threshold. To preview the results, our approach suggested that our manipulation of salience was successful.

Next, an *attentional capture task* was used to determine whether low- and high-salience singletons could be ignored (Figure 1C). This task used displays that were identical to the ones used in the previous task, but the color singleton was made task-irrelevant and participants were instructed to ignore it. Shifts of gaze were then used to determine if the singletons captured attention. This task creates competing predictions for different models of attentional capture. According to the low-salience account (Theeuwes, 1992; Wang & Theeuwes, 2020), high-salience singletons should capture attention, and do so more strongly than low-salience singletons.

[1] Although we refer to the salience of a distractor, to state the obvious, this salience is with respect to the context provided by a display. For example, a red item might be salient in an otherwise all-blue display but might not be in an otherwise all-pink display.

According to the signal suppression hypothesis (Gaspelin & Luck, 2018b), however, even salient distractors can be suppressed to prevent attentional capture. Therefore, neither low- nor high-salience singletons should capture attention.

Method

Participants

A sample size of 32 was determined based upon a previous study (Gaspelin et al., 2017, Exp. 2). Based upon the effect size of oculomotor suppression in that study (d_z = 1.58), 8 participants would be needed to obtain 95% power. The participants were students from State University of New York at Binghamton who participated for course credit (21 women, 10 men, 1 nonbinary; mean age = 18.4 years). All participants had normal color vision as indicated by an Ishihara test and had normal or corrected-to-normal visual acuity as evaluated by a Snellen chart.

Apparatus

Stimuli were presented using PsychToolbox for Linux (Kleiner et al., 2007). An Asus VG248QG LED monitor presented stimuli at a viewing distance of 100 cm and a refresh rate of 60 Hz in a dimly lit room. A photosensor was used to measure the timing delay of the video system (12 ms) and this delay was subtracted from all latency values in the paper. An SR Research Eye Link 1000+ desk-mounted eye tracker measured gaze position from the right eye at 500 Hz. The Eye Link Toolbox was used to interface the stimulus presentation and eye-tracking systems (Cornelissen et al., 2002).

Search Stimuli

For both tasks, the search displays were identical. As depicted in Figure 1A, search displays contained six shapes arranged in a notional circle at eccentricity of 4.3° from the center of the screen. Each search display contained one diamond (1.7° by 1.7°) and one circle (1.7° diameter). The remaining items could be hexagons (1.7° by 1.7°), triangles (1.7° height and 1.7° base width), and ovals (2.0° by 1.4°). These distractors shapes were selected at random with the exception that no distractor shape could repeat more than once (e.g., there were never more than two hexagons). Each shape contained a small black line (0.2° long by 0.1° wide), that was tilted either 45° to the left or right. The tilt of each line was selected at random with an equal number of each tilt in the display. Each search display contained an empirically optimized fixation cross which was presented in the center of the screen (Thaler et al., 2013), which consisted of a gray (30.3 cd/m^2, x = .301, y = .346) circle (0.5° diameter) that had a black crosshair with a gray dot in the center (0.1° diameter).

The colors of the shapes were either red (30.0 cd/m^2, x = .646, y = .324), blue (30.0 cd/m^2, x = .189, y = .252), pink (30.0 cd/m^2, x = .610, y = .305), or teal (30.0 cd/m^2, x = .215, y = .368). These colors were predetermined by selecting a portion of CIE color space (L = 30.0, radius = 90), and then adjusted to be photometrically isoluminant on the display monitors. On singleton-absent trials, all items were the same color. On singleton-present trials, one item was uniquely colored from the other items. This color singleton could either be low or high salience (Figure 1A). High-salience singletons were a color 180° in CIE color space from the nonsingleton color. This yielded four potential display configurations: a red singleton amongst blue items, a blue singleton amongst red items, a teal singleton amongst pink items, or a pink singleton amongst teal items. Low-salience distractors were drawn in a color that was 27° from the target color. This yielded four potential display configurations: a blue singleton

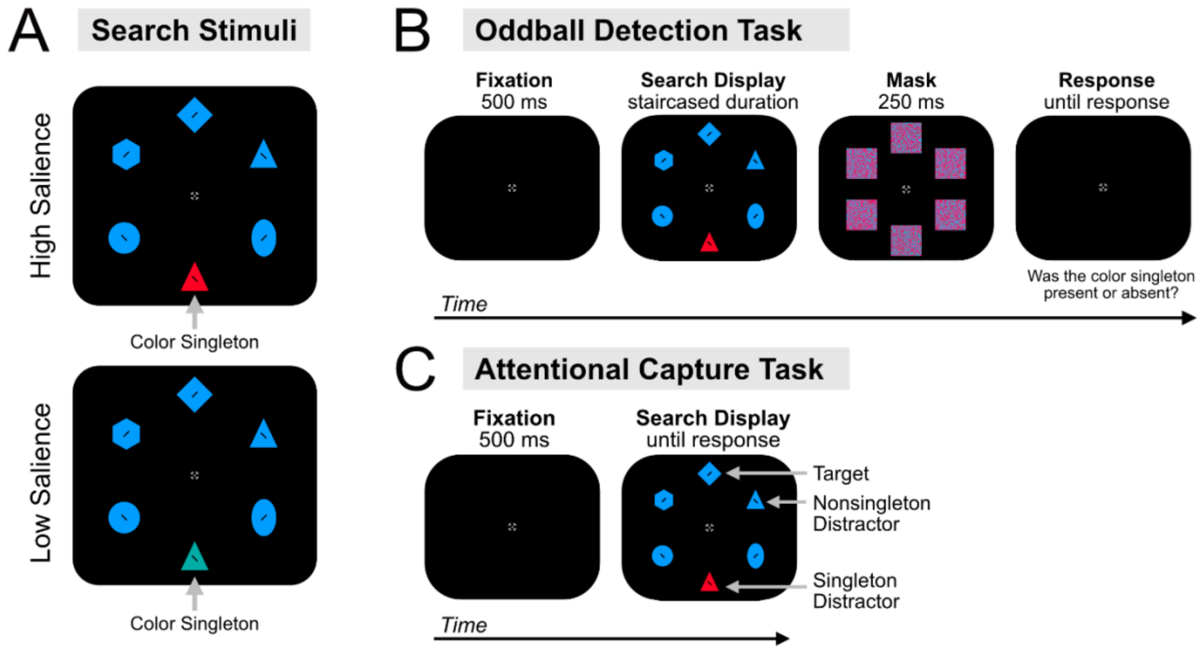

Figure 1. Stimuli and tasks for the current experiment. (A) Low- and high-salience singletons were created by manipulating the color contrast between singleton and other items. (B) In the oddball detection task, participants attempted to detect the presence of a color singleton that was briefly presented and then immediately masked. A staircase procedure was used to determine minimum exposure duration needed to detect the singleton. (C) In the attentional capture task, participants searched for a specific target shape (e.g., blue diamond) and attempted to ignore the singleton.

amongst teal, teal singleton amongst blue, pink singleton amongst red, or red singleton amongst pink. Although the colors shown on each trial were randomized, salience was blocked, as described later.

Mask displays consisted of random-color dot-patterns that were generated for each of the six stimuli positions on every trial. Each location's pattern-mask was 150% larger (2.6° by 2.6°) than the masked-stimulus and appeared for 250 ms, ensuring each stimulus was completely masked (Loftus et al., 1985). Each mask contained a random array of (0.03° by 0.03°) colored squares and an equal number of pixels in each of the four colors.

Oddball Detection Task

Participants first completed an oddball detection task (Figure 1B), in which they attempted to detect a color singleton that was briefly presented and then immediately masked. A staircase procedure was then used to determine the exposure threshold needed to detect low- and high-salience color singletons. This allowed us to empirically compare the salience of our two singletons.

The color singleton was present on half of trials and, when present, it was equally likely to appear at any of the six search locations. To prevent an attentional set for the specific singleton color, the singleton-nonsingleton color pairings were randomly selected on each trial. For example, one trial might have a pink singleton amongst teal items and the next trial might have a blue singleton amongst red items.

Each trial began with a fixation cross for 500 ms, followed by the stimulus array which appeared for a variable duration (see next paragraph), followed immediately by a pattern mask for 250 ms. After the mask disappeared, participants made an unspeeded response to the absence or presence of the color singleton via a gamepad, using the left- and right-shoulder buttons, respectively. Accurate trials were classified as either correctly detecting the color singleton when present (i.e., hits) or correctly rejecting the singleton when it was absent (i.e., correct rejections). If participants failed to detect the singleton (i.e., misses) or detected a singleton when it was absent (i.e., false alarms), the trial was scored as incorrect.

A 3-up/1-down staircase procedure was used to adjust the exposure duration of the search display (e.g., Greene & Oliva, 2009). If the participant responded incorrectly on the current trial, the next trial's exposure duration was 50 ms *slower* (i.e., 3-up), with a maximum of 300 ms. If the participant responded correctly, the next trial's exposure duration was 16.67 ms *faster* (i.e., 1-down), with a minimum duration of 16.67 ms. This 3-up/1-down staircase procedure ensures that accuracy asymptotes at approximately 75% correct (Kaernbach, 1990). The exposure duration began at 50 ms for the first trial of each experimental half.

The oddball-detection task consisted of two halves: low- and high-salience. The order of singleton salience was counterbalanced across participants. At the beginning of each half, participants were instructed of which type of singletons they would be detecting (low- or high-salience). This included an example search display to illustrate the salience-level of the upcoming block (e.g., a blue singleton amongst red items for easy blocks or a teal singleton amongst blue items for difficult blocks). In each half, participants first performed 1 practice block of 48 trials followed by 4 regular blocks of 48 trials. This yielded 192 trials for each salience condition, of which 96 were singleton-present trials and 96 were singleton-absent trials. Participants received block-by-block feedback on mean accuracy.

At analysis, a logarithmic function was used to express the relation between each participant's mean accuracy level and exposure duration (Figure 2A). Mean accuracy asymptotes at approximately 75% due to the staircase procedure (Kaernbach, 1990). The exposure duration of the stimulus array needed to reach this asymptotic accuracy performance can be estimated by extracting the exposure duration where the logarithmic function achieved a mean accuracy of 75%. This was done separately for both low- and high-salience color singletons (see black and gray lines in Figure 2A). We term this derived critical duration the *exposure threshold*. An exposure threshold was calculated for each salience condition and each participant, which then served as our primary dependent measure. If the high-salience singleton is more salient than the low-salience singleton, it should be detected more easily. This should result in a lower exposure threshold for the high-salience distractor than the low-salience singleton.

Attentional Capture Task

Next, we evaluated whether the low- and high-salience singletons captured attention or could instead be suppressed. The same participants performed a search task with identical displays to the oddball detection task (except for some slight differences in the trial structure as discussed in the next paragraph). The task was changed to find a shape-defined target and *ignore* the salient color singleton (Figure 1C). The destination of first eye movements were used to evaluate whether the singleton captured attention or was instead suppressed (Gaspelin et al., 2017). Note that, the ordering of tasks could increase attentional capture by the singleton because participants first search for the singleton in the oddball-detection task before being told to ignore it in the attentional capture task. However, since this ordering bias should only make the singleton distractors *more likely* to capture attention in the attentional capture task, any evidence of suppression should be all the more compelling.

Each participant was assigned to search for a target of a specific shape and color (e.g., blue diamond). The target color and shape remained constant for the entire task. A color singleton distractor was present on 75% of trials. When present, the singleton distractor appeared at a random location, with the exception that it could never appear at the target location. Participants were informed of this and were instructed to ignore the singleton distractor to the best of their ability. The attentional capture task was divided into two halves, one for each level of salience (low- vs. high-salience). For example, for a participant searching for the blue diamond, if the low salience condition came first, the singleton distractor was teal (low-salience) for the first half and then red (high-salience) for the second half. The order of halves was counterbalanced across participants.

Each trial began with the fixation cross. To initiate a trial, participants had to maintain gaze within a circular region of 1.5° centered around the center of the screen for 500 ms. Once this fixation requirement was met, the search array appeared until response was made or until a 2000 ms timeout. If the participant responded inaccurately or exceeded the 2000 ms search timeout, a 200 Hz tone sounded for 300 ms. Feedback on mean accuracy and RT was provided at the end of each block. These block breaks also warned participants whose accuracy fell below 90%. If a trial could not be initiated (due to a failure to fixate the center of the screen), the eye tracker was recalibrated before attempting to initiate trial again.

The attentional capture task consisted of 12 blocks of 60 trials (720 trials total). As stated above, the task was divided into two halves for low- and high-salience singletons. Each half consisted of 1 practice block (60 trials) followed by 5 regular blocks (60 trials), totaling 300 experimental trials per salience condition. At the end of each block, participants received feedback about mean response time and accuracy. The eye tracker camera was recalibrated using a nine-point calibration at the beginning of each block.

First eye movements were measured to evaluate whether the singleton captured attention or was instead suppressed as in Gaspelin et al. (2017; see also Adams et al., 2022; Adams & Gaspelin, 2021; Gaspelin et al., 2019; Gaspelin & Luck, 2018a; Hamblin-Frohman et al., 2022; Leonard & Luck, 2011). Saccades were defined by a minimum acceleration threshold of 9500°/sec^2 and a minimal eye velocity threshold of 30° per second. First saccade destinations were defined using an annulus around the search array, with an inner radius of 1.5° from fixation and an outer radius of 7.0° from fixation. The first eye movement landing within the annulus was classified as the first saccade and the nearest search item was then selected as the first saccade destination. This effectively creates wedge-shaped interest areas around each search item (Leonard & Luck, 2011). Saccadic latency was measured as the start time of the first saccade that landed within the annulus.

The first block from each half of the experiment was excluded as practice. Trials with RTs less than 200 ms or greater than 2000 ms (search timeout) were removed from analysis (0.3% of trials). Trials in which participants did not move their eyes from central fixation (0.1%) and trials with abnormal saccade latencies (less than 50 ms or greater than 1000 ms, comprising 1.8% of trials) were also removed. Trials with incorrect responses (3.9%) were omitted from analyses. In total, 5.6% of trials were excluded.

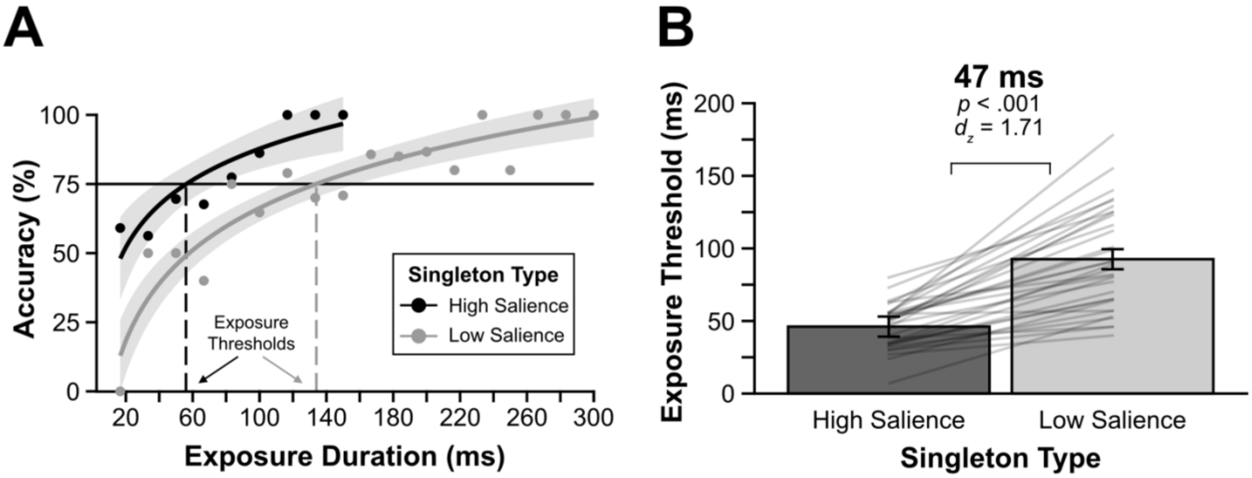

Figure 2. Results from the oddball detection task. (A) An example of an individual participant's exposure threshold estimation. Shading depicts the standard error of the mean. (B) Grand averaged exposure thresholds for low- and high-salience singletons. Each participant's score is shown as a whisker plot. Error bars represent within-subject 95% confidence intervals (Cousineau, 2005; Morey, 2008).

Results

Oddball Detection Task

Overall accuracy was 76.9%, consistent with the 3-up/1-down staircase procedure (Kaernbach, 1990). As explained previously, a logarithmic function was used to estimate the exposure threshold for each participant (Figure 2A) and these exposure thresholds were then grand averaged for the low- and high-salience conditions (Figure 2B). If the high-salience singleton is more salient than the low-salience singleton, it should have a lower exposure threshold, which is exactly what was found. Exposure thresholds were lower for high-salience singletons (46 ms) than low-salience singletons (93 ms), $t(31) = 9.68$, $p < .001$, $d_z = 1.71$, and every participant showed this effect. This provides independent verification that the salience manipulation was successful at altering the detectability of the singletons.

Attentional Capture Task

Manual Responses

Table 1 depicts manual RTs by distractor salience and singleton presence. In both salience conditions, participants were faster on singleton-present trials than singleton-

Table 1
Mean Response Time (ms) and Error Rate (%) by Distractor Salience and Singleton Presence

Distractor Salience		Singleton Present	Singleton Absent	Singleton Presence Benefit
Low	RT	934 (16)	952 (17)	18
	Error Rate	3.7 (0.4)	3.6 (0.6)	-0.1
High	RT	937 (18)	956 (19)	19
	Error Rate	3.2 (0.3)	3.5 (0.5)	0.3

Note. Standard errors of the mean are provided within parentheses.

absent trials (a *singleton presence benefit*), which suggests that the singleton distractors were inhibited (e.g., see Gaspelin et al., 2015). One-sample t tests indicated that singleton presence benefits were significant for both low-salience distractors (18 ms), $t(31) = 2.90$, $p = .007$, $d_z = 0.51$, and high-salience distractors (19 ms), $t(31) = 3.79$, $p < .001$, $d_z = 0.67$. The difference in singleton presence benefits between singleton types was not significant, $t(31) = 0.26$, $p = .80$, $d_z = 0.05$. Mean error rates were generally low and revealed no significant singleton presence benefits or costs, p's > .10. These results suggest that salient distractors were effectively ignored, regardless of their salience. The following section will more directly evaluate to what extent these effects are due to attentional allocation, per se, using the destination of the first saccades.

First Saccade Destination

The primary aim of the attentional capture task was to evaluate how salience would influence oculomotor suppression of singleton distractors. Figure 3A depicts heat maps of first saccades for each potential target-singleton angular distance for each singleton type. Heat maps were plotted such that the target always appeared at the top position and the singleton location is indicated by a white arrow. For -60° and -120°, the x axis was inverted and then pooled with the positive angular distances. As can be seen, first saccades to the high-salience singletons were suppressed below the baseline level of saccades to nonsingleton distractors, replicating previous studies (Gaspelin et al., 2017). First saccades to low-salience singletons, however, were not strongly suppressed. This can be more clearly seen in Figure 3B, which depicts the percentage of first saccades to each search item for both salience conditions, collapsed across all singleton-target angular distances. The nonsingleton distractor has been divided by the number of nonsingleton distractors (i.e., four on singleton-present trials) to provide a per item estimate of being overtly attended.

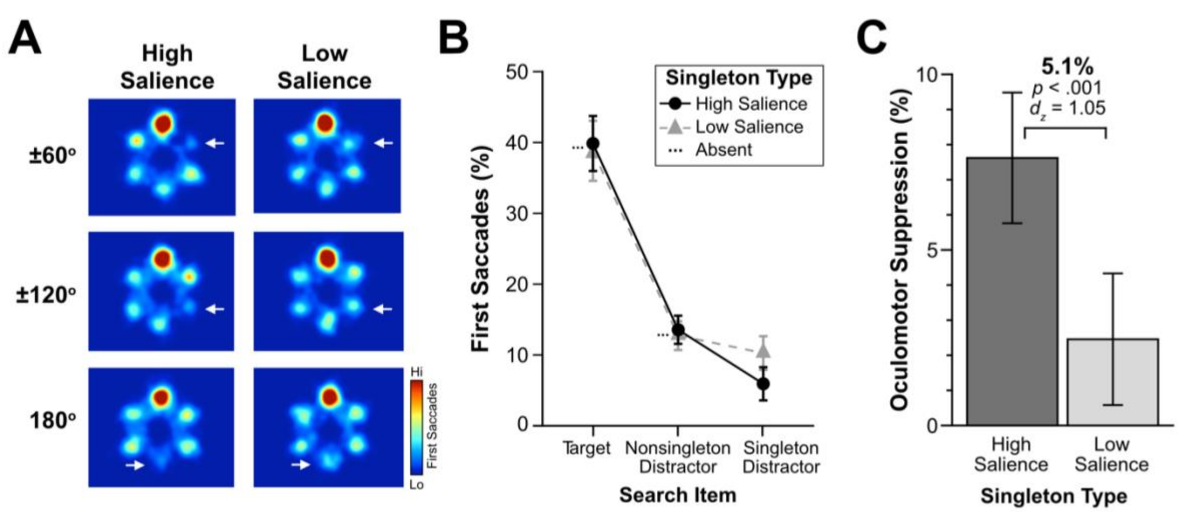

Figure 3. Saccade destination results in the attentional capture task. (A) Heat maps of first saccades as a function of singleton salience and angular distance between the target and singleton distractor. The heat maps were generated so that the target was always at the top position and the white arrow points to the singleton position. (B) The percentage of first saccades to each search item as a function of singleton salience. (C) Oculomotor suppression effects as a function of singleton salience. Error bars represent within-subject 95% confidence intervals.

The key question was whether singleton distractors were suppressed or instead captured attention. To evaluate this, we computed an oculomotor suppression effect, which is a difference score between the percentage of first saccades to the salient distractor and the average nonsingleton distractor (Figure 3C; Gaspelin et al., 2017, 2019). A positive score indicates that the salient distractor was *suppressed*. High-salience singletons were clearly suppressed (7.5%), $t(31) = 8.18$, $p < .001$, $d_s = 1.45$, similar to previous studies (Adams et al., 2022; Gaspelin et al., 2017, 2019; Gaspelin & Luck, 2018a). Low-salience singletons were also suppressed (2.4%), albeit only weakly, $t(31) = 2.61$, $p = .014$, $d_s = 0.46$. Oculomotor suppression effects were larger for high-salience singletons than low-salience singletons, $t(31) = 5.94$, $p < .001$, $d_z = 1.05$.

For completeness, we also compared first fixations for each search item as a function of salience in the Supplemental Material. Although we had no a priori predictions, we did find that participants were less likely to fixate the singleton distractor in the high-salience condition than the low-salience condition, $p < .001$. This provides further evidence that they can be suppressed.

Oculomotor Suppression Effects by Saccadic Latency

We also assessed the time course of the oculomotor suppression effects to evaluate the possibility that some these effects were due to reactive processes that occur after initial covert attentional capture (Theeuwes, 2010). If this were the case, there should be some evidence of an oculomotor bias toward the singleton at fast saccadic latencies (van Zoest et al., 2004). First saccade destinations were separated into quartiles based upon saccadic latency for each participant and oculomotor suppression effects were computed for each quartile (Figure 4). As can be seen, high-salience singletons were suppressed across all saccadic latencies (p's $< .01$), including the fastest quartile ($M = 155$ ms). Low-salience singletons, however, were suppressed only for the slower quartiles and suppression effects increased in later quartiles only (e.g., $M = 212$ ms). This is consistent with the idea that high-salience singletons were rapidly suppressed, whereas low-salience singletons were only successfully suppressed during relatively slow saccades.

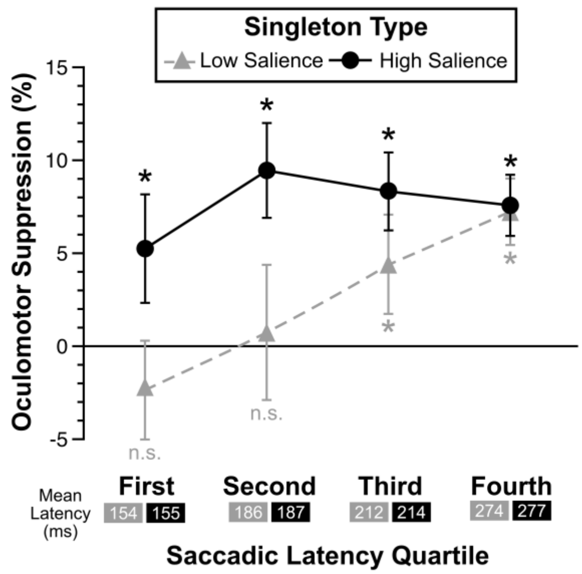

Figure 4. Oculomotor suppression effects as a function saccadic latency quartile for low- and high-salience singletons. Mean saccadic latency for each quartile (low salience/high salience) are provided below the x-axis labels. Error bars represent within-subject 95% confidence intervals. * $p < .01$.

Discussion

Previous research has suggested that salient distractors can be suppressed when they are task-irrelevant (Gaspelin & Luck, 2018b, 2019). But this research has been challenged on the grounds that previous studies may have used distractors that were weakly salient (Wang & Theeuwes, 2020). This criticism has been difficult to definitively resolve. Although several subsequent studies have evaluated the role of salience in suppression (Lien et al., 2022; Ramgir & Lamy, in press; Stilwell et al., 2022; Stilwell & Gaspelin, 2021), none of them included an independent measure of salience, making it difficult to evaluate whether the attempt to boost salience was truly successful.

The current study addressed this by introducing a psychophysical technique to measure salience. We designed displays with low- and high-salience color singletons via a manipulation of color contrast. Participants then performed an unspeeded oddball detection task in which they attempted to determine whether a color singleton appeared in a briefly presented display, and the minimum exposure threshold needed to detect the singleton was determined. If a high-salience singleton is more salient than a low-salience singleton, it should be more rapidly detected in the oddball detection task. Indeed, detection thresholds were briefer for our high-salience singletons (46 ms) than low-salience singletons (93 ms).

We then compared the ability of both high- and low-salience singletons to be suppressed in a task where the singleton should be ignored. Oculomotor suppression effects were significantly larger for high-salience singletons (7.5%) than low-salience singletons (2.4%), indicating that high-salience singletons were more strongly suppressed (for similar results with ERPs, see Gaspar & McDonald, 2014). Furthermore, suppression of high-salience singletons occurred even in the fastest quartile of eye movements (ca. 155 ms), whereas suppression of low-salience singletons occurred only in later quartiles (ca. 212 ms), indicating that high-salience singletons were more quickly suppressed. Together, this suggests that high-salience singletons were easier to suppress than low-salience singletons, although we do not have a direct measure of ease of suppression. This might be because high-salience singletons are easier to distinguish from other search items on a preattentive feature map, and this could then be used to inhibit the salient distractor location. Low-salient singletons, however, will be difficult to distinguish from other items on a preattentive feature map, and it will therefore be difficult to inhibit the singleton location.

The current findings refute the low-salience account of suppression (Wang & Theeuwes, 2020) and stimulus-driven accounts of attentional capture more generally (Theeuwes, 1992, 2004). These accounts predict that increasing the salience of an object should make it more likely to capture attention. If anything, the effect was in the wrong direction: the high-salience singletons were more strongly suppressed than low-salience singletons. One might be tempted to argue that the "high-salience" singletons in the current study were not truly salient (e.g., Wang & Theeuwes, 2020). But our new oddball detection paradigm provides clear evidence that the high-salience singletons were salient enough to be rapidly detected (ca. 46 ms). That being said, future studies might try to further enhance the salience of the singleton. It is worth pointing out, however, that increasing set size is not an advisable approach to improving salience, especially in the current eye-tracking paradigm, because it could result in a floor effect problem (see Stilwell & Gaspelin, 2021).[2]

In the current study, an oddball detection task was used to compare saliencies of two stimuli, on the underlying assumption that a

[2] The floor effect problem refers to the inflation of the per-unit average derived for the nonsingleton distractor condition at higher set sizes. To calculate the per-item average, the total is divided by the number of nonsingleton distractors. Thus, increasing the number of nonsingleton distractors will artificially decrease the per-item average. This makes it difficult to observe suppression below the level of the nonsingleton distractor.

high-salience singleton should be more readily detected than a low-salience singleton. This assumption seems reasonable, as our intuitive manipulation of salience produced large differences in detectability of the singletons, suggesting the oddball task is sensitive to changes in salience. Future research is needed to test the generalizability of the oddball detection paradigm with other types of salient stimuli.

Our psychophysical task yields a sensible result, and this method (or perhaps a simplified version) can be used to assess the salience of stimuli in other experiments. In our task, singletons produced an "attend-to-me" signal that was greater with stronger color contrast. This allowed a singleton with greater color contrast to be detected more quickly when the singleton was task relevant. One potential explanation for this is that the high-salience singleton garnered more attention than the low-salience singleton. Although our displays were brief and masked, the fact that even subliminal stimuli can capture attention makes this seem plausible (e.g., Lamy et al., 2015). In any case, whether the oddball task did or did not measure attentional allocation, the most striking new finding is that strong capture by a relevant stimulus (in the oddball detection task) leads to strong suppression when it is made irrelevant (in the attentional capture task).

In sum, the role of salience in the ability to suppress distracting stimuli seems to be that high-salience distractors are more strongly suppressed than low-salience distractors. These results directly challenge the idea that increasing the salience of distractors will make them harder to suppress; if anything, increasing salience made them easier to suppress. Generally speaking, the oddball detection task could be used to broadly test claims about salience and compare salience of items across experimental conditions and studies.

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Supplemental Material

First Saccade Destination

Although we had no a priori predictions, for completeness, pairwise comparisons assessed the percentage of first saccades to each search item as a function of singleton type. First saccades were more likely to be directed to the singleton distractor in the high-salience condition than low-salience condition, $t(31) = 5.65$, $p < .001$, $d_z = 1.00$. First saccades were more likely to be directed to nonsingleton distractors in the high-salience condition than low-salience condition, $t(31) = 2.28$, $p = .030$, $d_z = 0.40$. First saccades were numerically more likely to be directed to the target in the high-salience singleton than low-salience condition, although this effect was not significant, $t(31) = 0.79$, $p = .44$, $d_z = 0.14$. Together, these data suggest that high salience singletons were suppressed more so than low salience singletons. When gaze successfully avoided the singleton distractor, it was instead more likely to land either on a nonsingleton distractor or the target, which was more pronounced in the presence of the high salience than low salience singleton distractor. In other words, the eyes were more likely to avoid high salience than low salience singleton distractors, which complements the oculomotor suppression effects.