Psychonomic Bulletin & Review
https://doi.org/10.3758/s13423-025-02736-z

THEORETICAL/REVIEW

Signal suppression 2.0: An updated account of attentional capture and suppression

Nicholas Gaspelin[1] · Xiaojin Ma[1] · Steven J. Luck[2]

Accepted: 28 June 2025

Abstract
The signal suppression account of attentional capture was proposed in 2010 to resolve a longstanding debate between bottom-up and top-down theories of capture by proposing that a top-down suppressive mechanism can eliminate bottom-up capture of attention. Since its original proposal, the signal suppression account has garnered much support and has also been challenged in important ways. The current article reviews how the signal suppression account has survived several challenges but has also been updated to account for new findings. The primary updates are that (a) suppression operates on specific feature values and locations rather than squashing a generalized "attend-to-me" signal produced by salient distractors, and (b) suppression reflects implicit learning that is triggered when attention is captured. This revised hypothesis predicts that initial instances of attentional capture are needed to drive the implicit learning processes that lead to distractor suppression. Because high-salience distractors are more likely to capture attention than low-salience distractors prior to this implicit learning process, the revised hypothesis predicts that it will be easier to learn to suppress high-salience distractors than low-salience distractors. It also predicts that explicit attempts to override capture may (ironically) lead to increased rather than decreased distraction.

Keywords Visual attention · Attentional capture · Distraction · Suppression · Salience

Introduction

Do salient stimuli have an automatic ability to distract us? For example, consider the leftmost image in Fig. 1A. The first thing that you will probably notice are the brightly colored flowers. A common explanation for this phenomenological experience proposes that salient stimuli such as uniquely colored objects have an inherent ability to attract attention (Itti & Koch, 2001). Indeed, salient stimuli such as traffic signs or cautionary labels (Fig. 1A middle and right) are often used to attract attention in applied settings. But if attention is automatically biased toward salient objects, how can we control our attention so that it can focus on objects that are relevant to our immediate goals without constant interruption by salient stimuli? This seemingly simple question has led to several decades of debate, with some researchers arguing that salient stimuli inevitably capture attention (e.g., Theeuwes, 1992; Theeuwes et al., 2022; Yantis & Jonides, 1984) and others arguing that salience impacts attention only insofar as it is related to task goals (e.g., Folk et al., 1992, 2002).

The *signal suppression account* was proposed to help resolve this debate by suggesting that salient stimuli produce an automatic "attend-to-me" signal that will ordinarily attract attention, but that this signal can be suppressed by top-down control mechanisms before attention is actually captured (Sawaki & Luck, 2010). This hypothesis provided a rapprochement between prior theories, agreeing with bottom-up theories that salient stimuli do have an intrinsic ability to attract attention, but agreeing with top-down theories that capture can be prevented. Moreover, this hypothesis led to the new prediction that salient items may be suppressed below the baseline of nonsalient distractors, which has since been verified in many studies. Although this account has garnered much support, it has also been challenged in important ways, leading to significant revisions of the theory. The current article aims to summarize some of this research and update the signal suppression account to explain recent

✉ Nicholas Gaspelin
ngaspelin@missouri.edu

[1] Department of Psychological Sciences, University of Missouri, Columbia, MO, USA

[2] Center for Mind & Brain and Department of Psychology, University of California, Davis, CA, USA

Published online: 29 July 2025

Fig. 1 Examples of salient stimuli in the real world and the laboratory. (**A**) Salient stimuli often seem to have an inherent power to attract attention and are often used as visual warning signals in applied settings. (**B**) In laboratory tasks of attentional capture, participants are typically asked to search for a target and are asked to ignore a salient distractor that is a color singleton (adapted from Theeuwes, 1992)

findings and outline new predictions that can be tested by future research.

The attentional capture debate

Traditionally, research on attentional capture was divided into two competing viewpoints (see review by Luck et al., 2021). *Stimulus-driven* (bottom-up) accounts proposed that salient stimuli have an automatic power to attract attention, even when task irrelevant (e.g., Theeuwes, 1992; Yantis & Jonides, 1984). For instance, Theeuwes (1992) had participants search for a target and attempt to ignore a salient distractor that was a uniquely colored object (a *color singleton*; see Fig. 1B). The target was found more slowly when the salient distractor was present in the display, suggesting that it captured attention (see also Theeuwes, 1994). Other studies suggested that suddenly appearing objects (*abrupt onsets*) also automatically attract attention (Franconeri & Simons, 2003; Jonides & Yantis, 1988; Yantis & Jonides, 1984).

Goal-driven (top-down) accounts, in contrast, proposed that capture by salient objects is largely dependent on the distractor's relevance to the viewer's goals (Folk et al., 1992). Initial studies supporting this account showed that salient stimuli captured attention much more powerfully if they matched one or more features of the search target (called the *target template* or *attentional set*[1]). For example, if an observer was searching for a red letter, a red square would capture attention whereas a green square would not. This was taken as evidence that salient objects capture attention more strongly when they match the observer's target template (see also Becker et al., 2010; Folk et al., 1994; Folk & Remington, 1998, 2006). To explain previous observations of stimulus-driven capture, Bacon and Egeth (1994) suggested that the paradigm used by Theeuwes (1992) encouraged an attentional set for salience. That is, because the target was a shape singleton, participants may have looked for singletons in general, and this *singleton-detection mode* may have caused the color singleton to capture attention. To test this explanation, researchers have discouraged the use of singleton-detection mode by using displays of heterogeneous shapes that forced participants to look for the specific target shape (called *feature-search mode*), which eliminated attentional capture by color singletons (Bacon & Egeth, 1994; see also Folk & Anderson, 2010; Folk & Remington, 2008; Lamy et al., 2003; Lamy & Tsal, 1999; Leber & Egeth, 2006; Lamy & Egeth, 2003).[2]

The signal suppression account

The stimulus-driven and goal-driven accounts competed for decades, with no obvious resolution in sight. The signal suppression account was developed to resolve this debate (Sawaki & Luck, 2010). The original version of the signal suppression account contended that salient stimuli produce an "attend-to-me" signal that will ordinarily elicit a shift of attention whether or not it matches the target template, but top-down control processes can squash this signal before attention is captured. By proposing that salient stimuli produce an automatic attend-to-me signal, this new theory

[1] Some research has used the phrase *attentional set* or *attentional control settings* to describe the features that control attention (Folk et al., 1992), whereas other researchers have used the phrase *target template* (e.g., Duncan & Humphreys, 1989). We will use these two phrases interchangeably.

[2] It has also been proposed that heterogeneous displays may constrain the attentional window in a manner that prevents capture (Theeuwes, 2023), but this explanation has been challenged (Gaspelin et al., 2023a; Leber & Egeth, 2006).

could explain the phenomenological experience of capture (as most people experience for the examples in Fig. 1A) and the finding that singletons automatically capture attention in many experiments. However, because it contained a suppressive mechanism, this theory could also explain the lack of automatic capture in other experiments.

The initial support for the signal suppression account came from event-related potential (ERP) studies (see review by Gaspelin et al., 2023b). These studies measured the *N2pc component*, which is observed when attention is focused on an object, and the *distractor positivity (P_D) component*, which is associated with the suppression of an object (Hickey et al., 2009; Luck, 2012). Many initial studies supporting the signal suppression account showed that salient distractors did not elicit an N2pc component, as would be expected if they captured attention, but instead elicited the suppression-related P_D component (Gaspar & McDonald, 2014; Jannati et al., 2013; Sawaki & Luck, 2010).

Later behavioral studies provided further evidence that salient distractors were actually suppressed relative to nonsalient objects and did not simply fail to capture attention. For example, Gaspelin and colleagues (2015) had participants search arrays of objects while trying to ignore a salient distractor (Fig. 2B). On a subset of trials, probe letters were superimposed over each object in the display and then disappeared. Participants were asked to report as many probe letters as possible, using the probability that a given letter was reported as an index of processing for the object at the location of that letter. This study found that letters were less likely to be reported if they appeared at the location of a singleton distractor than if they appeared at the location of the nonsingleton distractor objects (a *probe suppression effect*). In addition to demonstrating suppression of the salient distractors, this result also implied that the salient distractor "needed" to be suppressed (i.e., to prevent it from capturing attention). If the salient distractor did not generate an attend-to-me signal, why would it be suppressed? Evidence for the suppression of salient distractors was also obtained in studies using eye movements (Fig. 2C): Under conditions that promoted top-down control, gaze was less likely to be directed to salient distractors than to nonsalient distractors (Gaspelin et al., 2017, 2019; Gaspelin & Luck, 2018a; Ipata et al., 2006).

Other studies have shown that the P_D component – which inspired the initial theory – is related to behavioral measures of distractor suppression (Feldmann-Wüstefeld et al., 2020; Gaspelin & Luck, 2018b; Weaver et al., 2017). Moreover, a neurophysiological study in monkeys found that successful suppression of a salient distractor (as evidenced by decreased neural firing rates for neurons coding the distractor) co-occurred with a monkey homologue of the P_D component (Cosman et al., 2018). Finally, computational models of visual

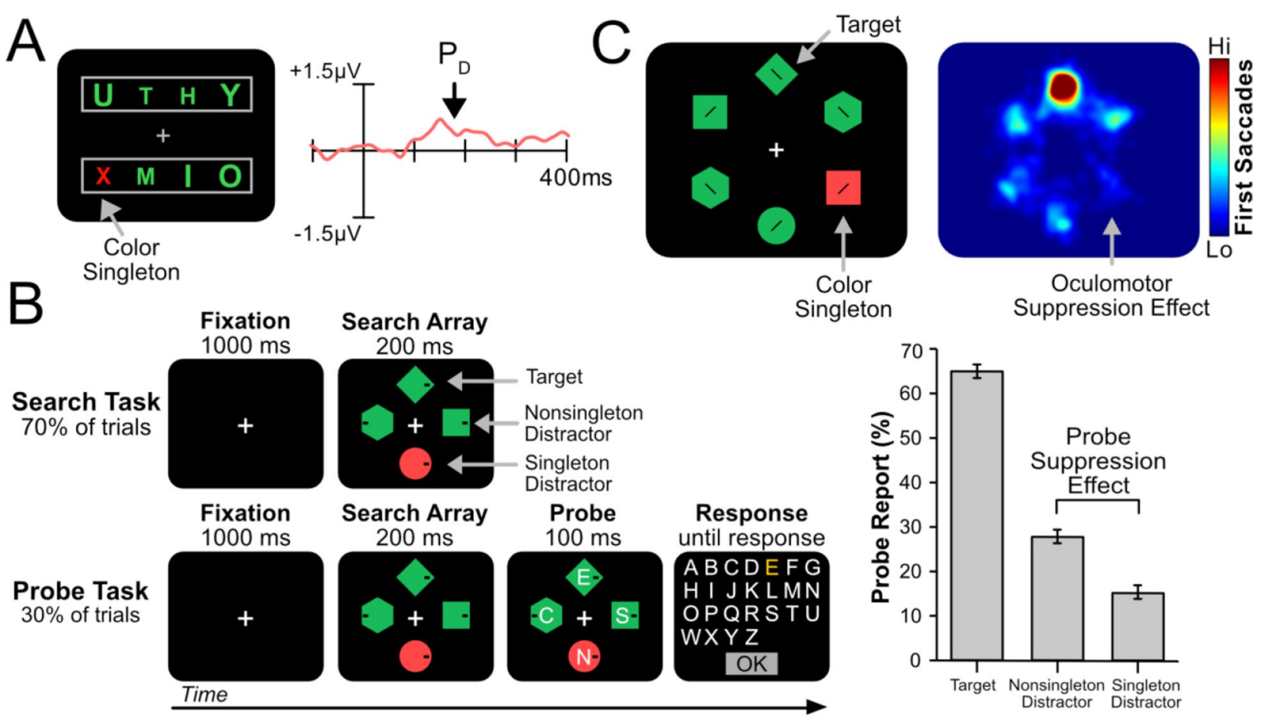

Fig. 2 Initial evidence supporting the signal suppression account. *Note.* (**A**) Sawaki and Luck (2010) found that color singletons did not elicit an N2pc component and instead elicited a P_D component indicating the salient distractor was suppressed, (**B**) Gaspelin et al. (2015) used a letter-probe paradigm and found that probe report at the location of a singleton distractor was suppressed below baseline levels. (**C**) Gaspelin et al. (2017) used an eye-tracking task to show that shifts of gaze to color singletons were suppressed.

attention with an inhibitory component were able to simulate a P_D component, consistent with the idea that suppression is necessary for a P_D component (Tam et al., 2022).

In sum, the original signal suppression account led to several new predictions that were subsequently verified by empirical research. Whether right or wrong, it has certainly generated many interesting new results.

Challenges and solutions

There have been some important challenges to the signal suppression account. Some of these challenges have turned out not to be real problems, but others will require a significant revision to the theory. In this section, we briefly review some of these challenges and potential solutions. This will motivate the updated version of the signal suppression account that we describe later in the paper.

Challenge #1: Highly salient distractors

An initial challenge to the signal suppression account was the argument that the salient distractors that were suppressed in prior studies were not actually very salient because the set size was relatively small (e.g., one color singleton amongst three nonsingleton objects). According to this *low-salience account*, the salient distractors would have captured attention in the prior studies if they had been more salient. Some initial evidence for this claim was provided by Wang and Theeuwes (2020), who used the letter-probe paradigm shown in Fig. 2B but with set sizes of 4, 6, and 10 items. At set size 4, singletons were suppressed, consistent with previous studies, but capture rather than suppression was reported at set size 10 (i.e., a greater probability of reporting letters on the salient distractor than on the nonsalient distractors). This was taken to suggest that sufficiently salient distractors cannot be suppressed.

The low-salience account has not been supported by subsequent research. First, Stilwell and Gaspelin (2021) found that the probe task used by Wang and Theeuwes (2020) suffered from a floor effect at larger set sizes (Fig. 3A). That is, when a display contains ten objects (and therefore ten probe letters), performance will be very low for a letter on a given nonsingleton distractor, making it difficult to see even lower performance for a letter on the singleton distractor. To avoid floor effects, Stilwell and Gaspelin presented probe

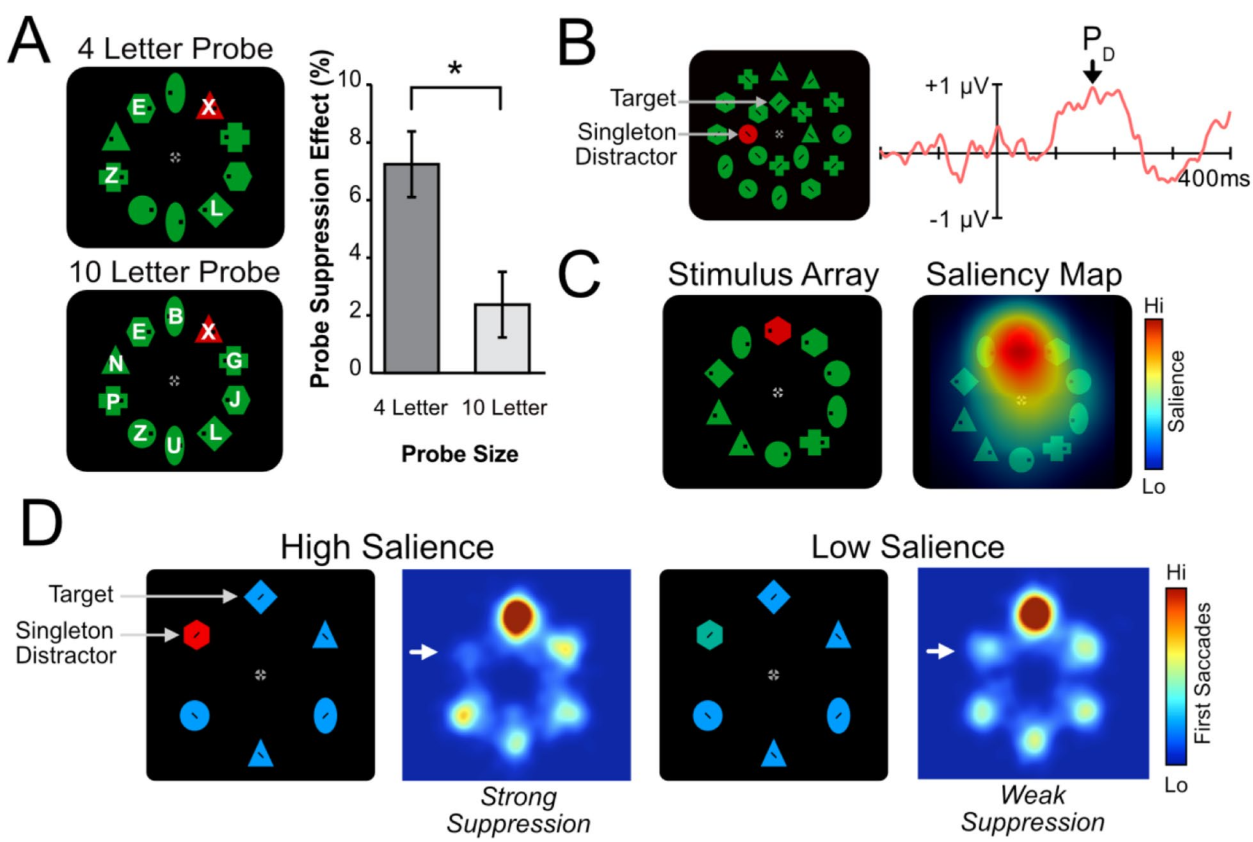

Fig. 3 Evidence that highly salient distractors can be suppressed. (**A**) Stilwell and Gaspelin (2021) found evidence of suppression at large set sizes as long as probe size was kept low to prevent floor effects. (**B**) Stilwell et al. (2022) found that salient distractors elicited a P_D component even at high displays sizes. (**C**) A computational model of salience seemed to indicate the distractors in both studies were truly salient (Stilwell & Gaspelin, 2021; see also Chang et al., 2021). (**D**) Stillwell et al. (2023) found that high-salience distractors were better suppressed than low-salience distractors (data adapted from Zhang & Gaspelin, 2024)

letters on only four items no matter how many items were in the display, yielding performance that was well above chance at all set sizes. This made it possible to see that performance was indeed reduced for probe letters presented on the singleton distractor even at high set sizes (see also Hamblin-Frohman et al., 2025). Other evidence against the low-salience account has come from ERP studies showing that salient distractors elicit a P_D component even at high set sizes, which further suggests that they can be suppressed even when highly salient (Fig. 3B; Stilwell et al., 2022; see also Gaspar & McDonald, 2014; Sawaki & Luck, 2010). Thus, suppression does not seem to be limited to low set sizes or weakly salient objects.

A major difficulty in resolving the debate about salience is that there are currently no well-established independent measures of salience. This has made it difficult to verify whether purported manipulations of salience were truly effective or to compare salience across studies. It can also make a purely stimulus-driven account unfalsifiable: any evidence that a salient distractor could be ignored could simply be attributed to "weak salience." Many researchers have used computational models of salience to provide evidence that the color singletons were truly salient (Fig. 3C; Stilwell & Gaspelin, 2021; see also Chang et al., 2021; Stilwell et al., 2022). However, these models may not accurately quantify salience, especially with artificial laboratory displays (Jeck et al., 2019; Kotseruba et al., 2020).

To address this, Stilwell et al. (2023) developed a psychophysical measure of salience, which was originally suggested by Theeuwes (in Wöstmann et al., 2022). In this approach, participants performed an *oddball detection task* in which they attempted to detect a color singleton in briefly presented displays that were immediately masked. Importantly, the specific color of the singleton was unknown to the participant (e.g., it could be either red among blue or blue among red, randomly intermixed), so the singleton had to be detected on the basis of popout, per se. There were two levels of degree of color difference between the singleton and the other display objects (Fig. 3D). A staircase procedure was used to determine the exposure duration needed to obtain a target detection accuracy of 75% (the *exposure threshold*). Exposure thresholds were much lower when the color difference between the singleton and nonsingleton items was high, confirming that the salience was indeed improved (see also Stilwell et al., 2024). □□□□This independent assessment of salience made it possible to determine whether singletons with high salience (as verified by their low exposure thresholds) can be suppressed. When the low- and high-salience singletons were used in an oculomotor suppression task, the high-salience singletons were indeed suppressed, demonstrating that suppression is possible for stimuli with empirically verified high salience. Moreover, the high-salience distractors were actually *easier* to suppress than the low-salience distractors, which would be very difficult for stimulus-driven theories of capture to explain. This basic pattern of greater suppression for more salient stimuli has now been shown by many studies (Drisdelle & Eimer, 2023; Gaspar & McDonald, 2014; Moher et al., 2015; Xie et al., in press; Zhang et al., 2025a, b, c; Zhang & Gaspelin, 2024).

In sum, there has not been much evidence to support the claim that suppression is possible only for low-salience objects, so the challenge provided by Wang and Theeuwes (2020) did not necessitate a change to the signal suppression account. However, this challenge did make it clear that independent metrics of salience are essential in this area of research.

Challenge #2: Rapid disengagement hypothesis

A classic challenge to evidence that salient distractors can be suppressed is the *rapid disengagement hypothesis* (Theeuwes, 2010; Theeuwes et al., 2000). This hypothesis proposes that attention is initially captured by the salient distractor in a bottom-up manner, but that attention can quickly reject the salient distractor and reorient to another location. This quick reorienting will lead to no observable capture effect, even though the salient distractor actually attracted attention. This explanation was originally developed to explain why irrelevant distractors do not capture attention in the spatial cueing paradigm (e.g., Folk et al., 1992), but it can also be used to explain findings of suppression: If attention is initially captured by a salient object but is rapidly disengaged, this may appear as reduced processing of the salient distractor compared to the nonsalient distractors.

Initial studies provided evidence against a rapid disengagement explanation. As reviewed above, Gaspelin et al. (2017) showed that initial eye movements were preferentially directed away from salient distractors and these oculomotor suppression effects occurred even in the fastest quartile of saccades (ca. 175 ms), which would leave little time for the salient distractor to be attended and then suppressed as predicted by rapid disengagement (see also Stilwell et al., 2023; Zhang & Gaspelin, 2024). Similarly, in probe tasks, suppression effects occurred even when the probe letters appeared simultaneously with the search array and were visible for only 100 ms (Gaspelin et al., 2015; Stilwell & Gaspelin, 2021). Assuming that covert attentional shifts take 35–100 ms (Horowitz et al., 2009; Tsal, 1983), this would leave little time for attention to shift to the singleton ditractor, identify it as a nontarget, and then suppress it prior to the offset of the probe letters. In ERP studies, rapid disengagement should produce an N2pc component followed a P_D component. Such a pattern is observed when the task encourages singleton-detection mode (e.g., as in Hickey et al., 2006; see also Chang et al., 2023), but salient distractors elicit a P_D component without a preceding N2pc component when the task does not encourage attending to

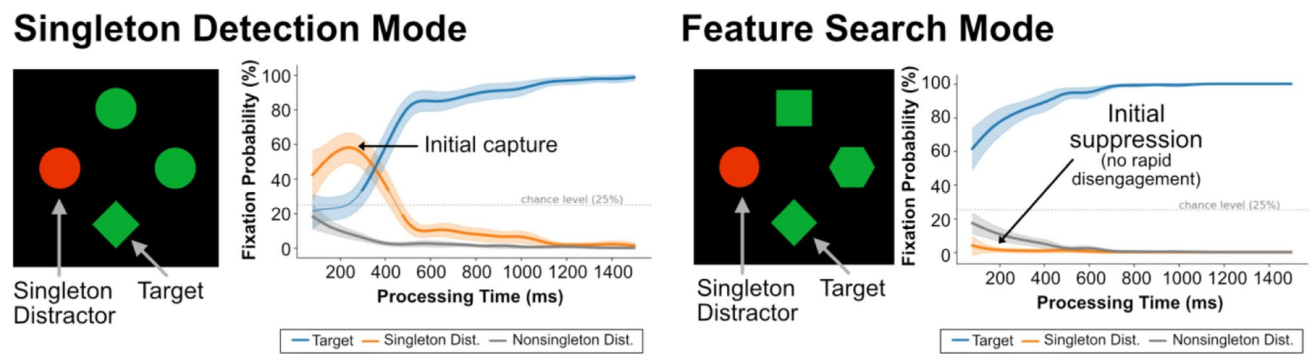

Fig. 4 Results from the forced response method. Zhang and colleagues (2024) used a modified response-deadline procedure to study the timecourse of distractor suppression. In singleton-detection mode, there was initial capture by the salient distractor. In feature search mode (where signal suppression is typically observed), there was no evidence of initial capture by singleton distractor, which is inconsistent with a rapid disengagement explanation. This figure was recreated by generating new illustrations of stimuli and new figures of the data with permission from the original authors

the singleton (Gaspar & McDonald, 2014; Gaspelin & Luck, 2018b; Sawaki & Luck, 2010; Stilwell et al., 2022).

Particularly compelling evidence against a rapid disengagment explanation comes from a study using the *forced response method* (Zhang et al., 2025a, b, c). As illustrated in Fig. 4, participants in this study searched for a target (e.g., green diamond) while ignoring a singleton distractor. On each trial, a tone indicated when participants should initiate an eye movement to the target, and the stimulus onset asynchrony (SOA) of this "go" signal varied randomly across trials. This allowed the researchers to investigate the probability of fixating a given search item as a function of *processing time* (the time between search display onset and the saccade). In search displays that encouraged singleton-detection mode, the singleton distractor captured overt attention above baseline levels, and this was particularly pronounced at brief processing times (Fig. 4). In search displays that encouraged feature-search mode, however, there was no evidence of an initial boost for the salient distractor at early processing times. That is, the singleton distractor was suppressed even at the fastest processing times. This directly challenges a rapid disengagement explanation (see also Chen & Mordkoff, 2007; Niu et al., 2025).

In sum, although the rapid disengagement hypothesis initially seemed like a plausible explanation for observations of singleton suppression, this hypothesis has been disconfirmed by multiple sources of evidence. Thus, there was no need to update the signal suppression account in response to this challenge.

Challenge #3: Downweighting, upweighting, or both?

Another alternative explanation is that apparent suppression effects might reflect upweighting of the target features rather than downweighting of the salient distractors. That is, when the singleton distractor is one color and the target/nonsingleton distractors are another color, increasing the attentional priority of the target color (*upweighting*) could masquerade as a decrease in the attentional priority of the singleton color (*downweighting*). Some evidence in favor of this *upweighting account* has been reported (Kerzel et al., 2021; Kerzel & Huynh Cong, 2023; Oxner et al., 2023; van Moorselaar et al., 2023).

Chang and Egeth (2019) teased apart the separate contributions of upweighting and downweighting using a modified probe task (Fig. 5). On most trials, participants performed the same task as in Gaspelin et al. (2015), in which they searched for a target of a specific shape (e.g., a diamond) and ignored a color singleton. On probe trials, four colored disks appeared that were superimposed with letters, and participants searched for a target letter (A or B). On target-color present trials, one of the disks was a target color and the remaining disks were neutral colors that were not used in the search displays. On singleton-color present trials, one of the disks was the salient distractor color and the remaining disks were neutral colors. The target letter could appear on any of the disks. Response times (RTs) were speeded when the probe letter appeared on a target color (*target enhancement effect*) compared to a neutral color. In addition, RTs were slowed when the probe letter appeared on the salient-distractor color (*distractor suppression effect*). This suggests that both target enhancement and distractor suppression simultaneously guide attention (see also Chang & Egeth, 2021; Hamblin-Frohman et al., 2025). Similarly, an eye-tracking study (Hamblin-Frohman et al., 2022) found that shifts of gaze were more likely to be directed to the target color than the neutral baseline and were less likely to be directed to the distractor color than the neutral baseline.

A pure upweighting account also struggles to explain learning effects that were specific to the singleton color and not to the target color (Gaspelin & Luck, 2018a, Experiment 4; Ramgir

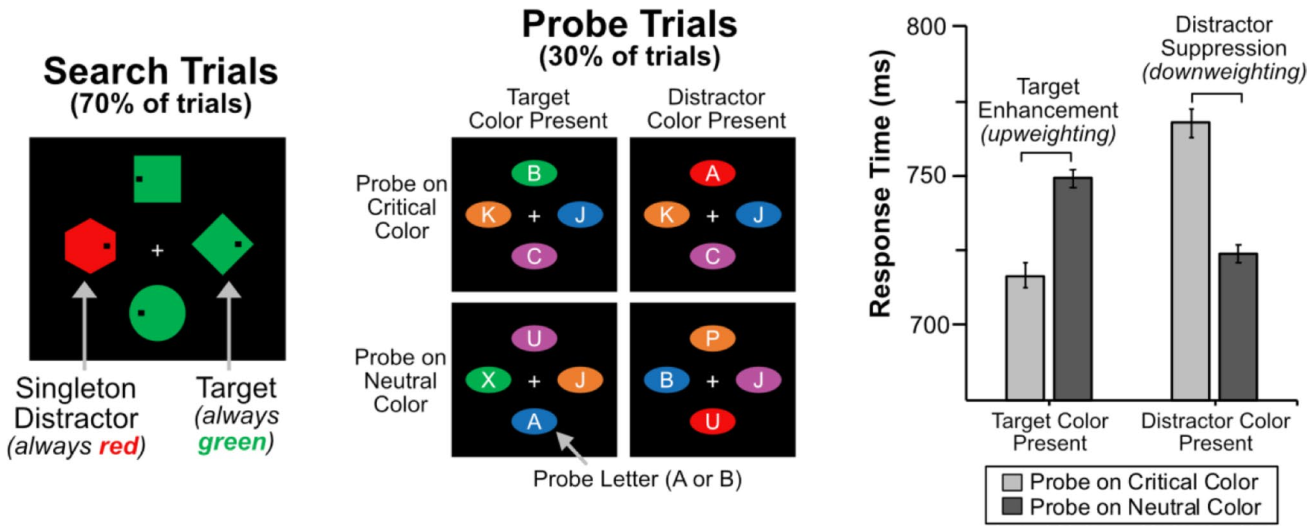

Fig. 5 Evidence of simultaneous upweighting and downweighting. Chang and Egeth (2019) adapted the probe task of Gaspelin et al. (2015) to separately evaluate upweighting of the target color and suppression of the distractor color. The results showed that both target enhancement and distractor suppression simultaneously guided attention. This figure was recreated by generating new illustrations of stimuli and figures of the data with permission from the original authors

& Lamy, 2023; Savelson et al., 2025; Savelson & Leber, 2024; Vatterott & Vecera, 2012). For example, Gaspelin and Luck (2018a, Experiment 4) had participants look for a target of a specific color and shape that was constant throughout the entire experiment. Every two blocks, the singleton color changed to a new color. Singletons captured attention at the beginning of a block with a new color but were suppressed by the end of the block. If the ability to ignore distractors is entirely determined by an attentional set toward the target color, why did changing the singleton to a new color lead to distraction even when the target color was the same as in previous blocks? In fact, recent evidence suggests that the representation of distractor-specific features is reduced once participants learn to suppress them (Narhi-Martinez et al., 2024; Won et al., 2022; see also Chen et al., 2019). Finally, several studies have used comparisons with various neutral conditions to rule out the upweighting-only hypothesis in terms of nonsalient distractors, suggesting that attention can operate by inhibiting distractor objects (Addleman & Störmer, 2023, under review; Carlisle, 2023; Stilwell & Vecera, 2020. 2022; Zhang et al., 2019).

In sum, the current evidence suggests that *both* distractor downweighting and target upweighting contribute to the ability to ignore salient distractors. As described below, our updated account now includes both upweighting and downweighting.

Challenge #4: Second-order suppression

The original signal suppression account proposed that salient objects are suppressed based upon a generalized salience signal that is independent of the specific features of salient distractor (Sawaki & Luck, 2010). However, several studies failed to confirm these accounts, showing instead that observers must learn the specific features of a salient distractor for suppression to occur (e.g., Gaspelin et al., 2019; Gaspelin & Luck, 2018a; Ramgir & Lamy, 2023; Stilwell et al., 2019; Vatterott & Vecera, 2012). These *first-order suppression* accounts suggest that attention uses stimulus features (e.g., color) to suppress salient objects.

For instance, Vatterott and Vecera (2012) had participants search for a target while attempting to ignore a color singleton (Fig. 6A). The color of the singleton distractor was constant within a block of trials but changed to a new color at the beginning of each block. The singleton was found to capture attention at the beginning of a block, and observers learned to ignore it later in the block (see also De Tommaso & Turatto, 2019; Ramgir & Lamy, 2023; Savelson et al., 2025; Savelson & Leber, 2024). A similar pattern of results was found in a paradigm adapted for eye tracking: color singletons drawn in new colors initially captured the eyes, but they were suppressed below baseline after multiple repetitions (Fig. 6B; Gaspelin & Luck, 2018a, Experiment 4). All of these results suggest that suppression operates on specific features of salient distractors rather than a generalized salience signal.

Learned feature suppression has some important properties. First, the learning seems to be rapid. Initial experiments suggested that learning may take only 10–20 trials to ignore singletons of a particular color (Gaspelin & Luck, 2018a; Ramgir & Lamy, 2021; Vatterott & Vecera, 2012). This is effectively half of a practice block in many experiments. Some recent experiments have even suggested that

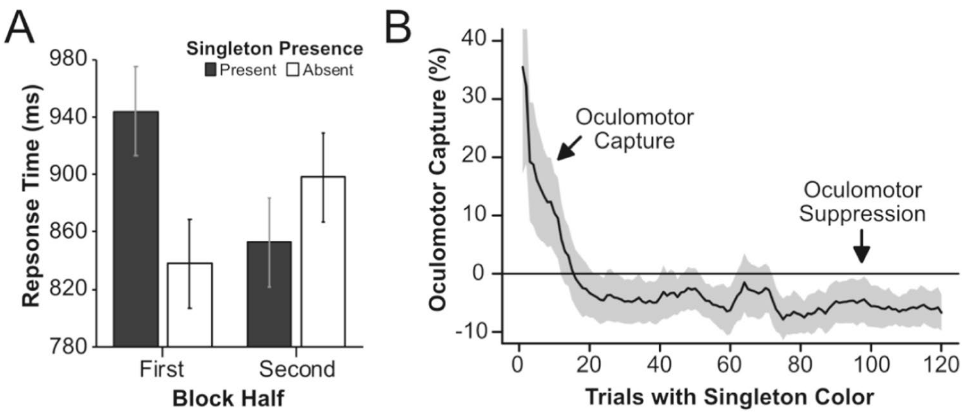

Fig. 6 Examples of feature-based learning. (**A**) Vatterott and Vecera (2012) blocked the singleton color and found capture in the first half of blocks but not the second. (**B**) Gaspelin and Luck (2018a, b) used a similar approach of blocking the singleton color but measured eye movements. Oculomotor capture was observed for the initial few trials but was suppressed below baseline

learning can occur within a few exposures to the color singleton (Gaspelin et al., 2019, Experiment 3; Savelson et al., 2025) and that massive decreases in attentional capture occur after only single exposure to a salient stimulus (e.g., Adam et al., 2024; Horstmann, 2002). Another important finding is that first-order suppression can occur even when the to-be-ignored distractors are nonsalient (e.g., Lien et al., 2022; Savelson & Leber, 2024; Won & Geng, 2018, 2020).

There has, however, been some evidence that salient distractors can be suppressed without knowledge of their specific features (Drisdelle et al., 2025; Ma & Abrams, 2023a, b; Sawaki & Luck, 2010; Vatterott et al., 2018; Won et al., 2019). This has sometimes been called *second-order suppression*, meaning that the salient distractors are suppressed with only knowledge of their feature dimension but without knowledge of their feature value (e.g., knowing a color singleton will appear without knowing its specific color). For example, Ma and Abrams (2023a) reasoned that the original task used by Gaspelin et al. (2015) might have discouraged participants from suppressing color singletons because the target was also a lone shape. They adapted the task to use a *majority search* procedure in which participants indicated which of two shapes was more prevalent in a search display (circles or squares). Importantly, the color of the search display could vary between two color assignments, preventing a first-order suppression. A singleton-presence benefit was found on search RT, suggesting the singleton could be suppressed even without knowledge of its specific color. Later studies used the letter-probe technique to provide additional evidence of second-order suppression using the same majority search technique (Ma & Abrams, 2023b; see also Drisdelle et al., 2025).

The above findings suggest that second-order suppression is possible under certain conditions, but it seems to require special conditions and may not indicate that suppression occurs after saliency has been computed. At the moment, it is unclear why certain paradigms produce evidence of second-order suppression, but here we will speculate about why this might occur. One observation is that many studies showing second-order suppression have used tasks that involve counting (or subitizing) the number of targets (e.g., Drisdelle et al., 2025; Ma & Abrams, 2023a, b). A counting task might influence the spatial distribution of attention in order to quickly count the number of targets. This type of counting task might allow attention to quickly detect color popouts using second-order features in addition to first-order features.

A second interesting observation is that some studies showing second-order suppression have used a large number of trials (Sawaki & Luck, 2010; Vatterott et al., 2018). It might also be possible that participants can learn to suppress second-order features with extensive practice, even though they begin by learning to suppress via first-order features. In such cases, it will be important to distinguish between learning true second-order suppression and first-order suppression of multiple features. That is, with practice, participants might learn to suppress multiple individual colors that are not the target, and a newly introduced distractor color might be suppressed because it is sufficiently close to one of the individual colors that participants have learned to suppress. This might look like second-order suppression but would just be an instance of first-order suppression of multiple colors.

In sum, the original idea that suppression operates on a generalized salience signal has not been supported by the evidence. In many cases, suppression is clearly based on specific feature values, not a generalized salience signal. In other cases, second-order suppression seems possible, which could be achieved by suppression of a generalized salience signal, but it might instead reflect suppression of a specific second-order feature (e.g., a *color* popout) rather than reflecting the suppression of a generic saliency signal. Thus, there is no compelling evidence that a generalized salience signal can be suppressed. The signal suppression account has therefore been updated to operate by changing the weights on specific feature values, not by squashing a generic "attend-to-me" signal. The account includes the possibility that second-order as well as first-order features can be subjected to this weighting.[3]

Challenge #5: Explicit goals versus implicit learning

The original version of the signal suppression account implied that suppression was a result of explicit goals, stating that it is, "presumably mediated by the prefrontal cortex and depends on the availability of working memory resources" (Sawaki & Luck, 2010, p. 1467). There is now, however, good reason to believe that suppression is largely a result of implicit learning and that explicit goals cannot readily be used to suppress salient distractors. Implicit learning in the context of visual search is often treated as a special case of *selection history,* which is a general term that refers to a broad set of cognitive processes whereby prior experience can influence attentional allocation (Anderson et al., 2021; Awh et al., 2012). Here, we explain why we think suppression is mostly the result of implicit learning.

There are multiple sources of evidence that implicit learning powerfully contributes to the suppression of salient distractors. As reviewed in Challenge #4: Second-order suppression, many studies have shown that several trials of experience with a given color singleton are needed before it can be suppressed (e.g., Failing et al., 2019; Gaspelin & Luck, 2018a, Exp. 4; Ramgir & Lamy, 2023; Savelson et al., 2025; Savelson & Leber, 2019; Stilwell et al., 2019; Vatterott & Vecera, 2012; Wang et al., 2019; Wang & Theeuwes, 2018). This shows that learning is involved, but it does not show that the learning is implicit or that the suppression does not also involve explicit goals. Evidence for these elements comes from other studies.

Evidence against the ability of observers to use explicit goals to suppress salient distractors comes from the study of Gaspelin et al. (2019), who had participants attempt to ignore a salient distractor. In an *alternating-colors* condition, the color of the singleton and target alternated on successive trials, meaning that the color of the target and singleton on one trial perfectly predicted the color of the target and singleton on the next trial. A cue also explicitly indicated the upcoming color configuration. This design pitted automatic priming (e.g., the fact that the target color on one trial became the singleton color on the next trial) against explicit goals. Although participants had foreknowledge of the upcoming distractor color and had the goal of suppressing it, the salient color singleton was not suppressed and instead captured attention. Other experiments have suggested that an explicit goal can lead to ironic capture by salient distractors matching those features (Cunningham & Egeth, 2016; Gaspelin et al., 2019, Experiment 4; Moher & Egeth, 2012). Other studies have shown that it is difficult for participants to proactively suppress nonsalient distractors using an explicit cue (Addleman & Störmer, 2022; Hauck et al., 2024). This might be because an explicit goal of suppressing a feature value might be implemented by holding that feature in working memory, and features being held in working memory tend to attract attention (Olivers, 2009; but see Carlisle, 2023).

Evidence that the distractor suppression is based on implicit learning also comes from studies showing that observers seem to have relatively limited awareness of when attentional capture occurs and a lack of awareness of the processes involved in guiding attention. Several studies have shown that individuals have difficulty identifying trials where capture has occurred (Adams & Gaspelin, 2020, 2021), and that making individuals better aware that attentional capture is occurring does not seem to directly improve ignoring of salient distractors (Anderson & Mrkonja, 2021, 2022). Several studies have also shown that subliminal cues (i.e., salient cues below the threshold of perceptual awareness) can capture attention without awareness of the observer (Lamy et al., 2015). Finally, several studies have shown that learned suppression of salient distractors based upon an expected location or color is unrelated (or even negatively related) to awareness with end-of-experiment questionnaires (Golan & Lamy, 2022; Wang & Theeuwes, 2018; but see Giménez-Fernández et al., 2023).

In sum, we propose that suppression of salient distractors is largely a result of implicit learning, not an active goal to ignore salient distractors. Indeed, a goal of suppressing a distractor often leads to capture rather than suppression.

Challenge #6: Other kinds of salient stimuli

Most studies of distractor suppression have focused exclusively on color singletons, but capture is a much broader phenomenon. Many prior studies have suggested that dynamic stimuli such as the sudden appearance of an object (an *abrupt onset*) or the movement or looming of an object may automatically capture attention (Abrams & Christ, 2003; Franconeri & Simons, 2003; Franconeri et al., 2005; Gaspelin et al., 2016; Jonides & Yantis, 1988; Lamy

[3] A natural question might be whether our account is still a "signal" suppression account. However, the name is still appropriate with an update to the kind of signal being suppressed. That is, whereas the original account proposed the suppression of a salience signal, the revised account proposes the suppression of feature and location signals.

& Egeth, 2003; Yantis & Jonides, 1984; Zivony & Lamy, 2018; see review by Zhang et al., 2025c). A natural question is therefore whether the same suppressive mechanisms used for color singletons also apply to other salient features.

To address this question, Adams and Gaspelin (2024) compared oculomotor suppression across a wide variety of salient stimuli. Some distractors consisted of *static* salient features (e.g., color or size singletons) that remained unchanged for the duration of the search, and others consisted of *dynamic* salient features that involved some kind of motion. All the static distractors were suppressed, extending the original signal suppression account to a broader range of static features. The dynamic distractors were not suppressed, but they also did not capture attention (see also van Moorselaar et al., 2023). Other recent studies have also suggested that abrupt onsets may be difficult to suppress compared to color singletons and can persistently capture attention (Adams et al., 2023; Gaspelin et al., 2016; Ruthruff et al., 2019, 2020; Toledano et al., 2024; Zhang et al., 2025a, b, c; Zivony & Lamy, 2018). Altogether, the results suggest a key distinction between static and dynamic stimuli.

It is important to note that some studies have shown that capture by dynamic distractors can be reduced with extensive experience (e.g., Folk & Remington, 2015; Turatto et al., 2018). In many of these studies, frequently appearing abrupt onsets or motion stimuli are successfully ignored. However, the fact that capture was reduced but without suppression below a pre-established baseline may reflect habituation, as will be discussed later.

Why might dynamic features be more difficult to suppress than static singletons? An obvious possibility is that dynamic stimuli are simply more salient. However, studies combining salient motion stimuli with salient static features have provided a much more interesting explanation (Adams et al., 2023; Adams & Gaspelin, 2024; Goller et al., 2020; Zhang et al., 2025a, b, c). For instance, Adams and Gaspelin (2024) used singletons that differed from the background only in motion, only in color, or in both motion and color (Fig. 7). As in previous research, motion-only singletons could not be suppressed, but the color-only singletons could be suppressed. The key question was whether color+motion singletons could be suppressed. If motion singletons cannot be suppressed because they are simply too salient, then the color+motion singleton should have been at least as difficult to suppress as the motion-only singleton. However, the color+motion singleton was suppressed just as strongly as the color-only singleton. Similar effects have been found by combining abrupt onsets with an irrelevant feature (Adams et al., 2023; Goller et al., 2020; Zhang et al., 2025a, b, c). The fact that dynamic stimuli can be suppressed when combined with a static feature indicates that these stimuli are not simply too salient to suppress, dovetailing with the evidence described above that high-salience color singletons are no

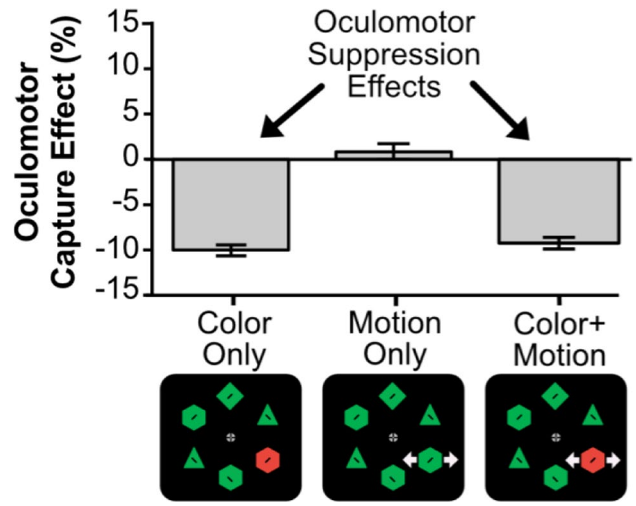

Fig. 7 Suppression of motion and color. Adams and Gaspelin (2024) compared oculomotor capture by motion-only, color-only, and motion+color distractors. Color-only singletons were suppressed, whereas motion-only singletons were not. Interestingly, combining motion and color (motion + color singletons) enabled suppression to occur

more difficult to suppress than low-salience color singletons (Stilwell et al., 2023; Stilwell & Gaspelin, 2021; Zhang & Gaspelin, 2024). Other evidence against a salience-based explanation of abrupt-onset capture comes from a study using an oddball detection task to show that abrupt onsets are perceived as less salient than color singletons (Zhang et al., 2025a, b, c). Altogether, this suggests that the problem seems to be in directing the suppression mechanism on the basis of the dynamic features.

Why might it be difficult to use dynamic features to direct the suppression mechanism? One possibility is that dynamic stimuli, by definition, change over time, and this might make it difficult to direct the suppressive mechanism to these stimuli. For instance, consider an abrupt onset. In order to suppress an abrupt onset, suppression would have to be engaged upon the feature of "onset-ness" at the precise moment that the salient distractor appeared. This may be too difficult for the suppressive mechanisms to do reliably. Similarly, with motion, much of the attention-capturing power seems to come from the initial onset of motion (Abrams & Christ, 2003). It might be challenging for the attentional system to engage a suppressive mechanism upon this onset of motion. The feature is so sudden and transient that it is gone by the time the suppressive system is ready to react. This could also explain why, for instance, adding a suppressible salient feature (e.g., color) can enable suppression of dynamic stimuli: The stable color feature can be used to direct the suppressive mechanism toward the salient distractor.

In sum, there is evidence that static features other than color singletons can be suppressed (e.g., size singletons

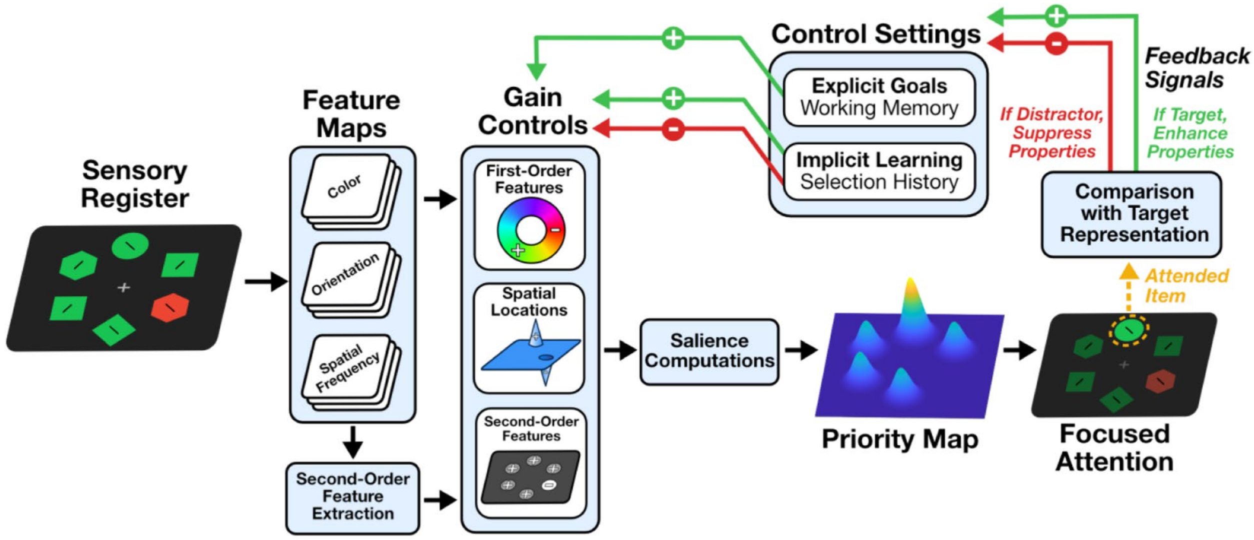

Fig. 8 An updated signal suppression account. This new version shows that most proactive control of spatial attention occurs via gain modulations of feature signals and location signals that occur via implicit learning. Mechanisms for second-order gain control and feedback signals have also been added

or fill singletons). Although initial evidence indicated that dynamic features such as motion and abrupt onsets are difficult to suppress, this appears to reflect a difficulty in determining which object to suppress on the basis of dynamic features rather than a difficulty in suppressing objects that contain dynamic features. The signal suppression account has been updated to reflect this important distinction.

Bringing it all together: Signal suppression version 2.0

This section provides an integrated description of the updated signal suppression account. Note that, although many details of the hypothesis have changed, we retain the core ideas that (a) physically salient stimuli will automatically generate a priority signal and capture attention in the absence of countervailing attentional control, and (b) attentional control can suppress signals arising from a salient distractor and thereby prevent the capture of attention.

The updated account is depicted in Fig. 8 and is a refinement of the account of attentional capture described by Luck et al. (2021). The updated account begins with an initial sensory register (the retinal representation of the search display). The sensory register is then parsed into feature maps that represent the locations of basic features such as color and orientation, just as in many classic accounts of visual attention (e.g., Desimone, 1999; Treisman & Gelade, 1980; Wolfe, 1994). As in other theories, attention operates to enhance or suppress specific features or locations by means of gain control mechanisms (Eldar et al., 2013; Herrmann et al., 2012; Hillyard et al., 1998; Itthipuripat et al., 2014; Reynolds & Heeger, 2009). A given feature value can be upweighted either by explicit goals, which are stored in working memory, or by implicit learning. However, an unusual feature of our model is that downweighting of the gain for a nonspatial feature is possible only on the basis of implicit learning. For both upweighting and downweighting, gain control operates before the priority map is generated, meaning that the priority of a given object can be reduced without a prior shift of spatial attention. Although it is not explicitly shown in Fig. 8, another important addition to the updated account is that suppressive feature gain control is limited to static features (as reviewed under Challenge #6: Other kinds of salient stimuli).

Next, second-order features are extracted. We propose that second-order features are extracted prior to salience computations and can be upweighted either by explicit goals or implicit learning. We tentatively propose that second-order features can also be downweighted by means of implicit learning, just like first-order features, which could explain some observations of second-order suppression effects (as reviewed under Challenge #4: Second-order suppression). However, this proposal is tentative because some studies have failed to find suppression of second-order features (Gaspelin & Luck, 2018a). One possibility is that, because second-order features involve an extra stage of feature extraction, this type of attentional control is more time-consuming or effortful than using first-order features to guide attention (e.g., see Lee et al., 2024).

After gain controls have been implemented, salience computations occur in which items are assigned values based upon their contrasts with other objects. We remain agnostic to exactly how salience computations are implemented, which has been explored in detail by other researchers (Itti & Koch, 2001; Jeck et al., 2019). The important part is that the salience computation occurs *after* gain controls have been implemented, which reduce any influence of the feature singleton if it is suppressed via its first-order features, spatial location, or second-order features. This could explain why, for example, learning effects have been reported to influence salience computations in early visual cortex (Adam & Serences, 2021). It is also important to highlight that there may be unique salience computations for different kinds of features (Thayer & Sprague, 2023). The salience computations produce a priority map which controls the subsequent allocation of spatial attention. The item with the highest priority has the highest probability of becoming the next shift of focused attention.

After attention has shifted to an item, the attended item is compared with the target representation to determine if the attended object is indeed the target. We have chosen to separate the control settings (i.e., the processes that influence guidance of attention) from the comparison with the target representation (i.e., a decision about whether the attended object is a target) for two reasons. First, several studies have shown that the attentional guidance is much coarser than the target representation used to make a decision about whether the current item is a target (Yu et al., 2022a, b, 2023). Second, a target-comparison process would allow for reactive control of attention. Indeed, there is considerable evidence that salient distractors which mismatch the target representation are quickly rejected after initial capture, and this rapid rejection can reduce RT-based capture effects even though the underlying probability of capture was unchanged (e.g., Gaspelin et al., 2016; Geng & Diquattro, 2010; Rigsby et al., 2023; Ruthruff et al., 2020).

The comparison of the attended item to the target representation plays two distinct roles. First, it allows the observer to decide whether the target has been found, which is necessary for making the behavioral response. Second, it allows the system to evaluate whether the current attentional control settings are appropriate for guiding attention to the target. That is, if the attended item is the target, that provides evidence that the control settings are effective; if the attended item is not the target, that provides evidence that the control settings should be updated.

Thus, after attention has been focused on an item, our account proposes that a *feedback signal* is sent to the control settings, updating the weights of the features that will control future shifts of attention (i.e., updating the search template). If the attended item is the target, a positive feedback signal will be sent that increases the weight of *all* features of the currently attended item, including incidental properties. These properties might include, for example, the currently attended item's color, shape, and/or location. However, if the comparison process indicates that the attended item is not the target, a negative feedback signal will be sent that decreases the weight of all features of the attended item in the target template (including incidental properties, such as the item's location). This will then influence the guidance of attention on subsequent trials by affecting the control settings that influence gain controls. We will discuss this iterative learning process in greater detail in the next section.

We assume that this learning process is largely unconscious, changing the search template implicitly rather than changing the observer's explicit goals. However, it is possible that observers might sometimes consciously notice statistical regularities in the task, such as whether the target tends to appear more frequently in one location than in another. This could then lead to changes in explicit goals in parallel with any implicit changes in the attentional control settings.

Keeping score: How might implicit learning work?

In this section, we provide an illustrative example of how implicit learning might unfold across an experimental session. Note that Signal Suppression 2.0 is not yet a formal mathematical model, and the goal of this section is to provide a concrete but informal example of how the attentional control settings *might* vary across trials. In this informal example, we use the analogy of a score-keeping system to illustrate how implicit learning might update the weights of features and location signals in the target template.

Figure 9 depicts a simplified version of an implicitly learned bias accumulating across several shifts of covert attention during a typical attentional capture experiment. In this imaginary experiment, the target is a green diamond, and a red color singleton is presented at a random nontarget location on each trial. At the beginning of the session, the observer is told the features that define the target, which leads to an explicit goal of finding green diamonds that is represented in working memory. Thus, the "green diamond" will be the target definition that is used for determining whether an attended object is the target. Over time, the features from the explicit goal will become represented in the implicitly learned template and no longer need to be present in working memory (Carlisle et al., 2011; Reinhart & Woodman, 2014).

In this example, the scorecard represents the weights in the attentional template that are developed via implicit

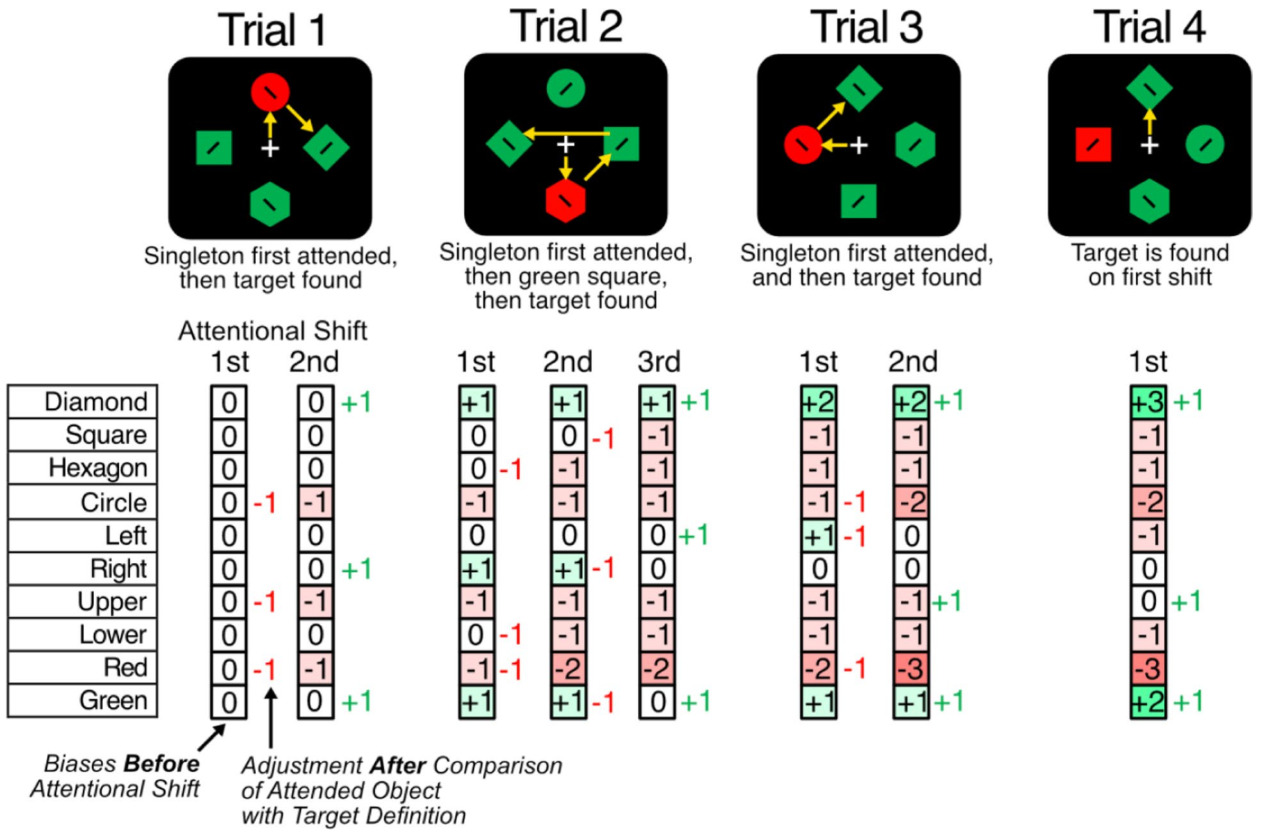

Fig. 9 An illustrative example of accumulating implicit biases. In this illustrative example, the target is the green diamond, and the color singleton is never the target. Below each trial, attentional tuning properties are demonstrated in a "scorecard" format and increment with each shift of attention made during the trial. For example, the columns below "1st" and "2nd" refers to the attentional tunings before the first and second attentional shift. The +1 and −1 values to the right of the box indicate the change in weight that occurs after attention has shifted as the result of the comparison of the now-attended item with the target definition

learning. The scorecard does not represent the values of individual objects or features on the priority map (and therefore includes no values for salience and values for individual types of display objects). On trial 1, there are no implicitly learned biases to suppress or attend to any features, which causes all the implicit biases to begin at zero (far left of Fig. 9). This will allow the intrinsic salience of the color singleton to have a strong signal in the priority map. As a result, the singleton captures attention. Because the singleton has captured attention, it will be compared with the target definition but will not match. As a result, all the features of the singleton (e.g., its color, its shape, its location) will be downweighted, indicated by the −1 values next to the leftmost column of weights in Fig. 9. The weights in the template are then updated, and attention shifts again in a manner biased by these updated weights. Visual search continues, with each shift of attention leading to a comparison with the target definition and an updating of the weights. When attention finally shifts to the target, and the actual target is compared with the target definition, the weights are boosted for all features of the target, even if they are incidental. For example, the weight for the "right" location is increased (indicated by the *+1* next to *Right* in the second column for Trial 1 in Fig. 9) because the target happened to be in this location, even though location is randomized and not a target-defining feature. These updated weights are then carried forward to the next trial, where they determine the template at the beginning of that trial.

In this example, we suppose that the first shift of attention on trial 2 goes to the singleton distractor because, even though the weight for red has been reduced slightly on the previous trial, the salience of the singleton is great enough to overcome this small weight reduction. By trial 4, however, the red feature has been downweighted substantially, and the green and diamond features have been upweighted, so the first shift of attention goes directly to the target. This then further upweights the green and diamond features. On subsequent trials, the singleton might still occasionally capture attention, but this would cause further downweighting of red.

We would like to emphasize that this is just an informal example of how the principles of Signal Suppression

2.0 might lead to updating of the attentional template and shifts of attention in this imaginary experiment. A formal mathematical model would require additional elements, such as assumptions about the magnitude of upweighting, decay of weights over time, and the similarity of different feature values within a given dimension. However, this informal example does illustrate some key points. For example, it shows that the template is being updated after each shift of attention rather than at the end of each trial. This is important, because real-world visual tasks are not typically divided into discrete trials.

The illustrative example also shows that the color of the singleton is not downweighted until after attention has been captured by the singleton; in other words, capture is needed for suppression to occur on subsequent trials. This predicts that distractors with a high attention-capturing power will more successfully drive changes to the template due to their initial ability to attract attention. After enough learning has occurred, people will (ironically) suppress them more strongly than items with low attention-capturing power (e.g., as observed in Stilwell et al., 2023; Zhang & Gaspelin, 2024). Note that changes in the template can occur even for items that are not particularly salient (as observed by Lien et al., 2022). As long as a nontarget object attracts attention, the features of that object will be downweighted in the template.

Another key point is that features contained in attended items will be upweighted (when the attended item matches the target description) or downweighted (when the attended item mismatches the target description) even if they are task irrelevant. This could potentially explain previously observed intertrial priming effects in visual search. For example, the target location is task irrelevant in the example shown in Fig. 9, and there is no rational reason to increase the priority of the target location from the previous trial. However, because Signal Suppression 2.0 proposes that *all* features of the attended item will be upweighted when that item matches the target, the location of the target on a given trial will be boosted in the template, increasing the likelihood that this location will be attended on the next trial. This is consistent with previous studies showing priming from the previous-trial target location (e.g., Maljkovic & Nakayama, 1996; Talcott et al., 2022; Talcott & Gaspelin, 2020; Toledano et al., 2024). The same kind of priming would occur for nonspatial features, consistent with previous research (e.g., Chun & Nakayama, 2000; Maljkovic & Nakayama, 1994, 2000; Ramgir & Lamy, 2022), or perhaps even entire feature dimensions (Found & Müller, 1996; Liesefeld & Müller, 2019; Müller et al., 1995, 2003). Moreover, if the weights accumulate over trials rather than rapidly decaying, this simple learning mechanism could also explain statistical learning of to-be-ignored features or locations (Golan et al., 2024; Wang & Theeuwes, 2018). Similarly, if explicit rewards or punishment occur, this could cause larger weight changes, providing a potential explanation of value-driven biases (Anderson, 2024; Anderson et al., 2011; Anderson & Yantis, 2012). Note that Signal Suppression 2.0 predicts that these kinds of learning will be limited to items that are at least occasionally attended, although additional mechanisms may be available for learning about unattended information.

Relationship to habituation

The concept of distractor suppression in the signal suppression account has some resemblance to the concept of *habituation*, as has been very nicely reviewed by Turatto (2023) (see also Bonetti & Turatto, 2019; Cowan, 1988; De Tommaso & Turatto, 2019; Folk & Remington, 2015; Turatto et al., 2018). Habituation refers to a general learning principle in which an organism's response to a stimulus decreases with repeated exposure. For instance, if you move into a house near the airport, the sound of an airplane flying overhead might initially attract your attention, but after enough time, you will habituate, and the sound will become less distracting. Indeed, habituation has long been proposed as a means of reducing distraction in prior theories of selective attention (e.g., Cowan, 1988; Elliott & Cowan, 2001). In the context of attentional capture, habituation predicts that repeating the features or locations of a salient distractor will reduce the orienting response (i.e., attentional capture) to salient distractors. In this way, our revised account is a bit like habituation.

Habituation is more of a description than a single specific account. However, as noted by Turatto (2023), specific accounts of habituation generally assume that organisms learn to predict events that occur frequently, and orienting is reduced for events that match predictions and increased for events that mismatch predictions. For instance, Sokolov (1963) proposed that the neural system develops an internal model that is updated with each exposure to a stimulus. If a stimulus matches the prediction of the internal model, the response to that stimulus is halted (or at least reduced). If a stimulus mismatches the prediction of the internal model, the response will occur, and the internal model will be updated with information about that stimulus for the next iteration. Thus, this kind of habituation model proposes a key role of prediction: the stimulus is compared to the prediction of an internal model, and if it is not predicted it will attract attention.

Although this account has similarities with Signal Suppression 2.0, it also has some potential differences. First, unlike habituation accounts, the signal suppression account does not involve a prediction process. Instead, learning occurs due to a comparison process between the intended and actual attentional outcome (as shown in Fig. 8). A suppressive process is then used to adjust gain controls on attention. In this manner, the features and location of the salient distractors are downweighted without an independent prediction model about the properties of future stimuli. It is important to highlight that this form of learning by signal suppression requires a voluntary goal, so that attended objects can be compared with the goal to determine whether updating is needed. In this sense, signal suppression might be considered a more active form of learning than habituation (but see Turatto, 2023, for theoretical explanations of habituation that seem to involve active learning).

Habituation also does not, by itself, explain *below-baseline* suppression. That is, habituation merely predicts a reduction in attentional capture and does not provide any mechanism to reduce orienting toward a salient distractor below the level of orienting to nonsingleton distractors. Indeed, habituation should be greatest for the nonsingleton distractors, which are the most predictable stimuli in a typical capture experiment. This highlights an important point: A reduction of attentional capture effects as a function of learning that does not produce below-baseline responding could result from either suppression or habituation (e.g., Vatterott & Vecera, 2012). A reduction in attentional allocation to a salient item below baseline levels, however, can be explained by a suppressive mechanism but not by habituation (e.g., Gaspelin et al., 2015). It is also important to note that suppression and habituation may co-occur. At present, below-baseline responding appears to be the only way to determine that bona fide suppression is occurring. Until some other method is developed to distinguish between suppression and habituation, studies that show a reduction in capture without demonstrating below-baseline responding should be considered compatible with either habituation or suppression.

Another difference between habituation and suppression is related to the degree of salience. As noted by Turatto (2023), habituation should be greater for less salient stimuli than for more salient stimuli:

"The weaker the stimulus, the more rapid and/or more pronounced is habituation. Strong stimuli may yield no significant habituation" (p. 1134)

As outlined under Challenge #1: Highly salient distractors, however, singleton suppression is often greater for more salient stimuli than for less salient stimuli. This surprising result can be explained by our account (as reviewed next) but is the opposite of what would be expected from habituation.

In sum, the currently proposed signal suppression account shares some similarities with habituation accounts. We have proposed some potential distinctions between the two accounts, which will be an important area for future research. In any case, the rich history on habituation leads to many interesting predictions that can be asked about attention, many of which are described by Turatto (2023).

Novel predictions

The revised signal suppression account makes several new predictions that can be tested by future research. Perhaps the most counterintuitive prediction is that, because we propose that people learn to downweight irrelevant features by means of a feedback signal that occurs when a nontarget is attended, suppression will tend to be greater (once learning has occurred) for items that were more likely to attract attention in the early phases of learning. Indeed, recent studies have already shown that more salient singletons are suppressed more strongly than less salient singletons (Stilwell et al., 2023; Zhang & Gaspelin, 2024). However, existing research has not "connected the dots" to demonstrate that this reflects a greater probability of capture early in the session, which then triggers downweighting of the distractor features.

A related prediction is that artificially boosting the probability of attentional capture early in a session could improve suppression later in the session. For example, one could combine a low-salience color singleton with a high-salience motion signal, leading to a high probability of capture, and then after several trials test whether the color singleton without the motion is suppressed more than it would be without the initial combination with motion.

Another related prediction is that no suppression of the singleton distractor will occur until the singleton has captured attention at least once. Capture appears to be probabilistic (Rigsby et al., 2023; but see Anderson & Folk, 2010), so it is reasonable to expect that a singleton might fail to capture attention on the first few trials in some participants (which could be verified via eye tracking), so no suppression should be observed on those trials for those participants (which could be verified with the behavioral probe technique or with the P_D component).

A final prediction is that, if an implicit learning system is keeping the score of whether attention has been captured, there may be neural indicators that an initial error was registered by the attentional system when capture occurs. For example, there is an anterior N2 ERP component that has been hypothesized to reflect error monitoring (Eimer et al., 2009), and this component is observed for task-irrelevant singleton distractors (Luck & Hillyard, 1994). We would predict that a larger anterior N2 on the first few trials would predict greater suppression over the next several trials. Relatedly, there may be behavioral or oculomotor-based approaches to measuring whether an error signal has been implicitly registered by the cognitive system.

Conclusion

An abundance of recent research indicates that salient-but-irrelevant distractors are suppressed to prevent attentional capture, consistent with the predictions of the signal suppression account. The current update to the signal suppression account contends that (a) participants typically suppress specific feature signals or location signals rather than a generalized salience signal, and (b) much of distractor suppression is driven by implicit learning rather than explicit goals. Our revised theory makes several new predictions. The most important of these is that an initial event of capture by an object containing a salient feature needs to occur before suppression is possible. The revised account also proposes that some kind of feedback signal occurs after the currently attended item is compared to the target definition, which should be measurable by physiological signals. Ultimately, these new predictions will need to be tested by future studies.

Acknowledgements This project was supported by the National Science Foundation Grant BCS-2345898 to N.G. and NIH Grant R01MH065034 to S.J.L. As suggested by the title, the idea for a version 2.0 of the signal suppression account is a homage to the classic Guided Search 2.0 paper by Wolfe (1994), which directly inspired the current paper. We would also like to thank Seah Chang, Howard Egeth, Han Zhang, John Jonides, and Shaun Vecera for providing data that were used in recreations of data figures.

Funding This article was funded by grants from the National Science Foundation (BCS-2345898 to N.G. and National Institutes of Health (R01MH065034) to S.J.L.

Availability of data and materials Not applicable.

Code availability Not applicable.

Declarations

Conflicts of interest/Competing interests Not applicable.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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