# The Rapid Disengagement Hypothesis and Signal Suppression Hypothesis of Visual Attention Capture

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## Abstract

The rapid disengagement hypothesis and the signal suppression hypothesis are both hybrid model hypotheses that integrate traditional bottom-up capture with top-down control. The rapid disengagement hypothesis posits that a salient distractor always captures attention initially, and when the salient distractor is inconsistent with task demands, attention rapidly disengages from that location. The signal suppression hypothesis proposes that salient distractors all generate a "look-at-me" signal, and when a salient distractor is inconsistent with task demands, this signal is suppressed top-down to prevent attentional capture from occurring. Research related to the former predominantly employs the spatial cueing paradigm and the oculomotor disengagement paradigm, with participants adopting a singleton detection strategy in experiments, whereas research related to the latter primarily utilizes variants of the additional singleton paradigm, with participants adopting a feature detection strategy in experiments. Future research should employ different stimulus types and experimental methods to provide further evidentiary support for both hypotheses, while also attending to the influence of factors such as reward and training on "capture-disengagement" and "signal-suppression."

## Full Text

## Preamble

### Rapid Disengagement Hypothesis and Signal Suppression Hypothesis of Visual Attentional Capture

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## Abstract

Both the rapid disengagement hypothesis and the signal suppression hypothesis represent hybrid models that integrate traditional bottom-up capture with top-down control. The rapid disengagement hypothesis posits that salient distractors always capture attention initially, but when they are inconsistent with task demands, attention rapidly disengages from that location. The signal suppression hypothesis suggests that salient distractors generate an "attend-to-me" signal, which is then suppressed by top-down mechanisms to prevent attentional capture when the distractor is task-irrelevant. Research supporting the rapid disengagement hypothesis primarily employs spatial cueing paradigms and oculomotor disengagement paradigms, where participants typically adopt a singleton detection strategy. In contrast, studies supporting the signal suppression hypothesis predominantly use variants of the additional singleton paradigm, forcing participants to employ a feature detection strategy. Future research should employ diverse stimulus types and experimental methods to provide further evidence for both hypotheses, while also examining how factors such as reward and training influence "capture-disengagement" and "signal-suppression" processes.

**Keywords:** visual attentional capture; rapid disengagement hypothesis; signal suppression hypothesis

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## 1. Introduction

Every moment, countless pieces of information enter the visual system, yet only a small fraction receives further processing. Attention can be actively allocated to task-relevant locations or objects to select specific information for processing (Folk et al., 1992), or it can be automatically and unconsciously drawn to salient stimuli (Yantis, 1993)—a phenomenon known as "attentional capture." A typical real-world example occurs when searching for a friend wearing black clothes in a winter crowd, and your attention is involuntarily captured by a girl in fluorescent green. While such attentional capture scenarios are easily created in laboratory settings, the underlying mechanisms remain one of the central unresolved issues in attention research. In other words, it is still unclear why certain task-irrelevant salient stimuli can automatically capture attention and how to prevent such capture to improve search efficiency (Roque et al., 2016).

Over the past two decades, theories of attentional capture have been continuously refined through scholarly research. Two traditional theories have dominated the debate: (1) attentional capture is bottom-up and stimulus-driven

(Theeuwes, 2004; Theeuwes et al., 2003); and (2) attentional capture is top-down and goal-driven (Folk et al., 1992; Folk & Remington, 1998; Folk et al., 1994). Chu and Zhou (2004) have reviewed these theories and related issues. In summary, the stimulus-driven view holds that sufficiently salient stimuli can automatically capture attention independent of current task goals, with task goals influencing only strategic attention allocation and reallocation (Hickey et al., 2009; Hickey et al., 2010; Theeuwes, 1992, 2004, 2010; Theeuwes et al., 2003; Yantis, 1993; Yantis & Hillstrom, 1994). The goal-driven view, conversely, emphasizes that whether salient stimuli capture attention depends heavily on current task goals. Some researchers explain this using contingent attentional capture theory, which posits that capture is conditional (Chen & Mordkoff, 2007; Folk et al., 1992; Folk et al., 2002; Folk & Remington, 2006; Livingstone et al., 2017). According to this perspective, the attentional system can be flexibly configured to respond only to stimuli carrying task-relevant features, with the degree to which salient distractors capture attention depending on their match to the task-relevant attentional setting (Folk et al., 1992; Folk & Remington, 1998). These two traditional perspectives have been debated for twenty years, each supported by substantial evidence.

In the past decade, researchers have proposed two hybrid models that integrate traditional theories to further interpret attentional capture mechanisms: the rapid disengagement hypothesis (or speed-of-disengagement hypothesis) and the signal suppression hypothesis (Gaspelin & Luck, 2018a, 2018c, 2018d; Sawaki & Luck, 2010; Theeuwes, 2010; Folk & Remington, 2010). This paper focuses on recent research concerning these two hybrid models, reviewing their theoretical proposals, supporting evidence, and comparative aspects. Our aim is to provide researchers with a more comprehensive theoretical perspective for investigating attentional capture mechanisms and to offer insights for future research directions.

## 2.1 Proposal and Core Content of the Rapid Disengagement Hypothesis

The rapid disengagement hypothesis posits that salient distractors always capture attention initially, regardless of whether they match task requirements. However, attention only remains at the location of task-relevant salient distractors. When a salient distractor is inconsistent with task demands, attention rapidly disengages from that location. This hypothesis emerged as an amendment to stimulus-driven theory. During the traditional theoretical debates, researchers led by Folk conducted numerous studies using variants of the spatial cueing paradigm (or precuing paradigm) to challenge stimulus-driven theory (Anderson & Folk, 2010, 2012; Folk et al., 1992; Folk et al., 2002; Folk & Remington, 1998, 2006). In this paradigm, cues appear approximately 150 ms before the target. The results showed that cues lacking target features did not produce cueing effects (RT non-cued minus cued), a finding inconsistent with stimulus-driven theory but consistent with goal-driven theory. From the goal-driven

perspective, attention is allocated only to stimuli matching the top-down attentional set, so cues without target features fail to capture attention, resulting in no cueing effects. However, Theeuwes (2010) challenged this interpretation from a stimulus-driven standpoint by proposing the rapid disengagement hypothesis. They argued that attention is initially always allocated to the most salient stimulus, so when a cue appears as the most salient stimulus on the screen, it should capture attention. The top-down attentional set influences not whether capture occurs, but the speed of disengagement from the cued location. They hypothesized that when a cue is inconsistent with the task goal, attention rapidly disengages from the cued location, preventing facilitation for targets appearing there. Thus, the rapid disengagement hypothesis essentially supports stimulus-driven theory by supplementing it.

## 2.2 Evidence for the Rapid Disengagement Hypothesis

Following Theeuwes et al. (2010) proposal, numerous studies have investigated the rapid disengagement hypothesis (Blakely et al., 2012; Brockmole & Boot, 2009; Schoeberl et al., 2018; Wang et al., 2019; Wright, Boot, & Jones, 2015; Geng & DiQuattor, 2010). Supporting evidence primarily comes from variants of the spatial cueing paradigm (Belopolsky et al., 2010; Theeuwes, 2010) and the oculomotor disengagement paradigm (Brockmole & Boot, 2009; Wright, Boot, & Brockmole, 2015; Wright, Boot, & Jones, 2015), with a few studies using the additional singleton paradigm (Wang et al., 2019).

In spatial cueing paradigm experiments, cueing effects serve as the marker of "capture-disengagement" —the presence of a cueing effect indicates that the cue captured attention as a salient stimulus, while the disappearance of the cueing effect suggests that attention had "disengaged" from the task-inconsistent cued location before capture could be completed. Anderson and Folk (2010) used the spatial cueing paradigm and found that the similarity between cue and target determined the magnitude of attentional capture, with more target-similar cues receiving more attentional resources and producing larger cueing effects. However, Theeuwes (2010) argued that this result primarily stemmed from non-cued conditions, suggesting that the effect mainly depended on the speed of attentional disengagement in non-cued conditions. When the cue matched the target, attention disengaged most slowly from the cued location, producing the largest cueing effect. Conversely, when the cue was completely different from the target, attention could rapidly disengage, resulting in minimal cueing effects. Belopolsky et al. (2010) provided direct evidence for the rapid disengagement hypothesis using a paradigm similar to Folk et al. (1992). In their Experiment 3, they combined the spatial cueing paradigm with a go/no-go task and found that when a cue contained a feature of a no-go target (e.g., when the target type was an onset stimulus but the cue was a color stimulus), participants responded significantly slower to targets appearing at the cued location, producing a reversed cueing effect. They interpreted this as attention being captured by the color cue that lacked target features, then rapidly disengaging, with strict top-down

control even inhibiting the cued location (Belopolsky et al., 2010). Anderson and Folk (2012) obtained similar results in their Experiments 1 and 2.

Studies using the additional singleton paradigm and its variants to support the rapid disengagement hypothesis typically combine eye-tracking technology, using saccade latency and singleton interference effects (RT singleton present minus absent) as measures. Van Zoest, Donk, and Theeuwes (2004) found that saccades with shorter latencies tended to point toward salient stimuli, while slower eye movements more frequently targeted the actual target. The researchers argued that this supported the rapid disengagement hypothesis: (1) before overt eye movement occurs, covert attention has already disengaged from the salient non-target, resulting in large RT costs when singletons are present without overt capture effects; and (2) covert attention may initially be captured by the salient stimulus, but relatively fast eye movements can occur before covert attention disengages, leading to larger oculomotor capture effects in trials with fast saccades and smaller effects in trials with slow saccades. Wang et al. (2019) used the additional singleton paradigm and manipulated the probability of singleton distractor locations, finding that interference effects from singleton capture decreased when singletons appeared in high-probability locations. This effect can be interpreted as participants learning to rapidly disengage from high-probability singleton locations, consistent with Brockmole and Boot' s (2009) proposal that participants can more quickly disengage from locations where distractors are expected, providing further support for the rapid disengagement hypothesis.

Both spatial cueing and additional singleton paradigms are capture paradigms that struggle to distinguish between RT costs caused by attracting attention to a location versus maintaining attention at that location (Blakely et al., 2012). In contrast, the oculomotor disengagement paradigm, using saccade latency as a measure, can more directly observe whether the disengagement process is delayed. Numerous researchers have used this paradigm to investigate factors influencing attentional disengagement, providing evidence for the critical "disengagement" component of the rapid disengagement hypothesis (Boot & Brockmole, 2010; Wright, Boot, & Brockmole, 2015). Results show that when features of stimuli at central fixation match target features, disengagement time from that location is delayed, increasing saccade latency. Additionally, studies using oculomotor capture task variants have found that the greater the feature match between attention-capturing distractors in peripheral vision and the target, the longer attention remains at that location. The oculomotor capture process is primarily driven by bottom-up stimulus salience, while eye disengagement from distractor locations is driven by top-down target-distractor similarity (Born et al., 2011).

## 2.3 Debates Surrounding the Rapid Disengagement Hypothesis

Despite continuous efforts to find supporting evidence, the rapid disengagement hypothesis remains controversial, with insufficient empirical support. The

main controversies stem from two issues: (1) the lack of a complete capture-disengagement evidence chain in the temporal domain, and (2) the absence of electrophysiological evidence. Regarding the temporal issue, some researchers argue that the hypothesis' s explanation for the presence or absence of cueing effects depends on the interval between cue and target (Chen & Mordkoff, 2007). Previous studies typically used a 150 ms cue-target interval. The rapid disengagement hypothesis suggests that when cue and target features are inconsistent, attention has sufficient time to disengage from the cued location, eliminating the cueing effect. Researchers therefore hypothesized that if the hypothesis is correct, shortening the cue-target interval to a value insufficient for attentional disengagement should produce a cueing effect, while longer intervals would replicate previous null results. However, Chen and Mordkoff (2007) shortened the interval to 35 ms and found that onset cues still failed to produce cueing effects when cue and target types were inconsistent, a result they interpreted as challenging the rapid disengagement hypothesis. Additionally, Anderson and Folk (2012) manipulated cue and target features and found a dissociation between inhibition processes and attention shifts. They suggested that the negative cueing effect observed by Belopolsky et al. (2010) might reflect top-down feature-based inhibition independent of whether attention was captured by the cue or disengaged from it, a phenomenon they termed the capture-independent inhibition account.

Regarding electrophysiological evidence, a major reason the rapid disengagement hypothesis remains questioned is the lack of empirical support from electrophysiological studies. The hypothesis is built upon the premise of stimulus-driven theory, which has substantial evidence from additional singleton paradigms and electrophysiological studies—areas where the rapid disengagement hypothesis remains underdeveloped. While eye-tracking technology can support overt attentional shifts to salient stimuli and delayed disengagement through measures like saccade latency and direction, covert attentional shifts and disengagement require more electrophysiological evidence. Since attentional capture includes both overt and covert components, electrophysiological support is essential.

In summary, the rapid disengagement hypothesis suggests that in spatial cueing paradigms, disengagement occurs before target presentation, with its speed depending on cue-target similarity and the interval between them. The hypothesis' s "capture-disengagement" framework integrates bottom-up capture with top-down control, offering a plausible explanation for the disappearance of cueing effects in spatial cueing paradigms.

## 3.1 Core Content of the Signal Suppression Hypothesis

To reconcile the debate between bottom-up and top-down theories, Sawaki and Luck (2010) proposed another hybrid model combining bottom-up capture and top-down control, termed the "signal suppression hypothesis." The core tenet is that regardless of whether salient distractors match task requirements, they

generate a bottom-up "attend-to-me" signal. Attentional capture fails to occur because this signal is suppressed by top-down attentional control before attention can actually be captured. The first part of this hypothesis resembles stimulus-driven theory in that salient stimuli produce a signal attempting to capture attention. Crucially, however, the hypothesis posits that if the salient stimulus is task-irrelevant, this signal is rapidly suppressed top-down, preventing actual capture—a notion consistent with top-down goal-driven theory. The hypothesis shares similarities with both traditional theories while diverging from each. Unlike stimulus-driven theory, it claims that salient stimuli only generate an "attend-to-me" signal without actual attentional shifts. Unlike goal-driven theory, it suggests that if the signal is not suppressed, attention will be automatically captured.

## 3.2 Evidence for the Signal Suppression Hypothesis

Since its proposal, numerous studies have investigated the signal suppression hypothesis (Failing & Theeuwes, 2019; Failing et al., 2019; Gao & Theeuwes, 2019; Gaspelin & Luck, 2018a, 2018c, 2018d; Gong et al., 2017; Hu et al., 2019; Sun et al., 2018; Wang & Theeuwes, 2018; Lee & Geng, 2017; Marini et al., 2016; Cosman et al., 2015; Lega et al., 2019; Tran, 2020). Supporting research primarily employs variants of the additional singleton paradigm (Gaspelin et al., 2017) or combines this paradigm with capture-probe tasks (Gaspelin et al., 2015; Gaspelin & Luck, 2018a), along with custom paradigms following attentional capture research design principles (Sawaki & Luck, 2010). While evidence for the rapid disengagement hypothesis relies on relatively uniform methods, support for the signal suppression hypothesis is comprehensive, including numerous behavioral experiments (Gaspelin et al., 2015; Moher & Egeth, 2012; Moher et al., 2014; Sawaki & Luck, 2010; Vatterott & Vecera, 2012) as well as electrophysiological (Eimer & Kiss, 2008; Gaspar & McDonald, 2014; Gaspelin & Luck, 2018a; Jannati et al., 2013; Sawaki & Luck, 2010, 2011; Sun et al., 2018) and eye-tracking methods (Gaspelin et al., 2017; Gaspelin et al., 2019) providing converging support.

In behavioral research, Gaspelin et al. (2015) used a variant of the additional singleton paradigm combined with a capture-probe task. When task-irrelevant targets were defined by different shapes, the shape-defined target was no longer a singleton, forcing participants to adopt a feature detection strategy. Under these conditions, the visual search task showed not only an absence of RT costs typically marking attentional capture (i.e., slower responses when singletons were present), but actually produced RT benefits from task-irrelevant salient singletons. Additionally, participants reported probe letters at salient singleton distractor locations less frequently than at other locations, indicating that singleton processing was suppressed below baseline levels. In behavioral studies, RT benefits from salient singleton distractors and reduced probe reporting at singleton locations are two key indicators of suppression at singleton locations.

In electrophysiological research, initial support for the signal suppression hy-

pothesis came from the PD component (positivity contralateral to the distractor) evoked by salient stimuli in the absence of behavioral capture (Burra & Kerzel, 2014; Eimer & Kiss, 2008; Gaspar et al., 2016; Gaspar & McDonald, 2014; Jannati et al., 2013; Sawaki & Luck, 2010, 2011). Jannati et al. (2013) used a variant of the additional singleton paradigm and found that even in trials with slow responses, salient distractors did not evoke the N2pc component (N2 posterior contralateral) that marks attentional shifts. However, in trials with faster responses, salient distractors evoked the PD component, indicating that participants suppressed the processing of salient distractors in fast-response trials—or conversely, that effective suppression of salient distractors enabled rapid responding.

While behavioral and electrophysiological studies demonstrate that participants can inhibit covert shifts of attention toward salient but task-irrelevant distractors, eye-tracking technology reveals that participants can similarly inhibit overt shifts toward irrelevant singletons. Ipata et al. (2006) discovered singleton suppression effects in macaque monkeys, finding that well-trained monkeys made fewer initial saccades toward singleton distractors than toward other non-singleton distractors. However, whether this oculomotor suppression effect universally exists in humans performing laboratory tasks remained unclear. Gaspelin et al. (2017) conducted a series of eye-tracking experiments demonstrating that humans also actively inhibit saccades toward salient but task-irrelevant stimuli, providing direct evidence from eye movements for the suppression process postulated by the signal suppression hypothesis. In their experiments, Gaspelin et al. (2017) combined a variant of the additional singleton paradigm with eye-tracking methods. They predicted that when participants adopted a singleton detection strategy, initial saccades would be more likely to direct toward singleton distractors than non-singleton distractors, producing an oculomotor capture effect. Conversely, if participants adopted a specific feature search strategy, this effect would reverse, producing oculomotor suppression with fewer saccades toward singleton distractors. In Experiment 1, where participants used a singleton detection strategy, results showed that initial saccades were indeed more likely to target singleton distractors, demonstrating bottom-up attentional capture. In Experiment 2, where participants were forced to use a specific feature detection strategy, initial saccades were less likely to target salient singleton distractors compared to other non-singleton distractors, producing oculomotor singleton suppression. These studies provide evidence for the signal suppression hypothesis from the perspective of inhibited overt attentional shifts.

## 3.3 Debates Surrounding the Signal Suppression Hypothesis

Beyond "suppression,"the signal suppression hypothesis includes another critical component: the "signal." Debates about the hypothesis primarily focus on how to demonstrate the existence of this signal. The hypothesis posits that before

attentional suppression occurs, distractors generate an "attend-to-me" signal (Sawaki et al., 2012; Sawaki & Luck, 2010). While numerous studies have demonstrated the suppression process, this "attend-to-me" signal has not been identified in behavioral or eye-tracking research. Only in electrophysiological studies have some researchers suggested that this process might be marked by a positive component Ppc (Positivity posterior contralateral) occurring between 100-200 ms (Barras & Kerzel, 2016; Fortier-Gauthier et al., 2013; Jannati et al., 2013), though others interpret it as an early component of the PD. Consequently, the functional significance of Ppc is not as clearly established as that of N2pc and PD. Jannati et al. (2013) found that salient color singletons always evoked Ppc, whether they served as distractors or targets, leading them to suggest that Ppc might reflect asymmetry in perceptual processing, stimulus salience, or transient salience-driven spatial selection that does not affect target judgment. Alternatively, Ppc might not be entirely stimulus-driven but related to search difficulty, disappearing when search is inefficient or when distractors and targets are easily confused. In essence, there is no stable and reliable component to mark the "attend-to-me" signal in the signal suppression hypothesis; it remains more of a hypothetical concept. To definitively demonstrate that salient singleton distractors generate this signal at the initial moment of stimulus presentation, future research requires more effective methods such as brain imaging.

In summary, studies supporting the signal suppression hypothesis almost exclusively use variants of the additional singleton paradigm, following two principles: (1) the target is not a singleton in any feature dimension, forcing participants to adopt a feature detection strategy; and (2) for each participant, target features remain constant throughout the experiment or block, meaning participants know what the target will be in upcoming trials. Although results supporting the signal suppression hypothesis are constrained by these two factors, the hypothesis' s integration of bottom-up capture and top-down suppression offers a reasonable explanation for RT benefits and oculomotor suppression effects that mark inhibited attentional capture.

## 4. Differences and Connections Between the Two Hypotheses

Overall, both the rapid disengagement hypothesis and the signal suppression hypothesis emerged from ongoing investigations into attentional capture mechanisms and represent hybrid models built upon the traditional bottom-up versus top-down debate. They share similarities but also exhibit important differences. Their common ground lies in the belief that the attentional capture process initially occurs automatically in a bottom-up manner, followed by top-down attentional control. The differences are twofold: (1) the former believes that bottom-up capture involves covert or overt attentional shifts, whereas the latter posits no attentional shift occurs; specifically, the rapid disengagement hypothesis holds that when singletons and search arrays are presented simultaneously, shifting attention to color singletons takes time (Theeuwes, 2010) and produces

observable RT costs (Chen & Mordkoff, 2007; Theeuwes et al., 2003). When cues precede targets, attention shifts to the most salient stimulus on the screen—the cue. In contrast, the signal suppression hypothesis argues that when singletons and search arrays appear simultaneously, irrelevant distractors are suppressed without initial attentional shifts, thus producing no RT costs. (2) The former attributes the failure of attentional capture to sufficient time for attention to disengage from task-inconsistent cues, while the latter attributes it to suppression of salient singleton distractors. Specifically, the signal suppression hypothesis holds that salient singleton distractors are suppressed, reducing the likelihood of initial saccades toward them (the oculomotor suppression effect). The rapid disengagement hypothesis could also explain reduced saccades toward singleton distractors by positing that covert attention is captured by salient stimuli but can rapidly disengage, eliminating oculomotor capture effects. These differences may arise from experimental paradigms, search strategies, and other factors.

### 4.1 Experimental Paradigms

The primary paradigm for the rapid disengagement hypothesis is the spatial cueing paradigm (sometimes combined with go/no-go tasks), originally developed by Folk et al. (1992) to support the view that attentional selection is entirely top-down controlled. In this paradigm, a cue appears before the target with an interval of approximately 150 ms. Participants search for a color-defined target (e.g., red or blue) while ignoring non-predictive cues (e.g., red, green, or blue). For example, participants might respond to red targets but not to blue targets. The rapid disengagement hypothesis suggests that when the cue appears, it automatically captures attention as the most salient stimulus on the screen. During the interval between cue and target presentation, attention disengages from different cues at varying speeds. Disengagement is slowest from cues sharing the target color, producing large cueing effects. Disengagement is faster from non-target color cues, eliminating cueing effects. Most importantly, disengagement is fastest from cues sharing no-go target colors, producing inhibition at that location and negative cueing effects. This paradigm is sensitive to both key components of the rapid disengagement hypothesis—capture and disengagement—with the crucial feature that the attention-capturing salient stimulus is asynchronous with the target.

Another major paradigm for the rapid disengagement hypothesis is the oculomotor disengagement paradigm. Participants first view a central fixation point and several peripheral placeholders. After a random interval, both the central fixation and peripheral placeholders change color, and a target appears at one peripheral location. The color change at central fixation signals participants to begin searching. The critical manipulation involves varying the similarity between central fixation color and target color to examine the speed of attentional disengagement from central fixation, defined as the interval between peripheral stimulus onset and disengagement from central fixation. Results show that disengagement is delayed when central fixation is a novel color singleton, with

greater delays for colors more similar to the target. In this paradigm, although distractors and targets appear simultaneously, they are not presented in the same visual field.

The primary paradigm for the signal suppression hypothesis is the additional singleton paradigm variant (sometimes combined with capture-probe tasks). In these experiments, different-shaped stimuli are presented in a virtual circular array in peripheral vision. Participants search for a specific shape and make judgments about the target while a task-irrelevant color singleton appears elsewhere. Results show that participants can suppress the color singleton' s attentional capture. In this paradigm, distractors and targets appear simultaneously in the same visual field, making it unsuitable for studying the rapid disengagement hypothesis. The ability to suppress singletons and facilitate target processing stems from "competition" between them.

### 4.2 Search Strategies

The rapid disengagement hypothesis is premised on stimulus-driven theory. Studies supporting stimulus-driven theory typically use the additional singleton paradigm that encourages a singleton detection strategy, with features of salient distractors and targets randomized across trials—meaning features of salient distractors in the current trial might have been target features in the previous trial. In the spatial cueing paradigm, when the target appears as a feature singleton distinct from simultaneously presented stimuli (e.g., a red or green target among white non-targets), participants adopt a singleton detection strategy. Consequently, when the cue appears as the current singleton, it automatically captures attention. In contrast, studies supporting the signal suppression hypothesis modify the classic additional singleton paradigm by requiring participants to search for a diamond or circle among different shapes, forcing them to abandon singleton detection in favor of feature detection strategies with fixed features across trials, so participants know upcoming distractor features in advance. These differences in search strategies may determine whether results reflect "suppression" or "capture-then-disengagement." Additionally, whether suppression or capture-disengagement effects emerge may also depend on stimulus type, task difficulty, and working memory capacity—factors requiring further investigation (Zhang & Wang, 2012).

Despite differences in experimental paradigms and search strategies, both hypotheses represent hybrid models combining bottom-up capture and top-down control, both preventing attentional capture by eliminating or weakening distractor processing to improve search efficiency. Their underlying mechanisms may be unified (Cosman et al., 2018; Geng, 2014; Chelazzi et al., 2019). Both hypotheses involve reactive suppression mechanisms (disengaging from irrelevant stimuli) and proactive suppression mechanisms (suppressing locations previously containing task-irrelevant stimuli) (Geng, 2014). In rapid disengagement hypothesis evidence, erroneous saccades with very short latencies are quickly corrected—a result of reactive suppression. Strict top-down control can even inhibit

previously cued locations, indicating that proactive suppression also participates in reallocation of attention away from task-irrelevant locations. In the signal suppression hypothesis, participants suppress salient singleton distractors before capture in most trials—also a result of proactive suppression (Aron, 2011). When cognitive load is insufficient to maintain suppression before attentional capture, reactive suppression mechanisms provide supplementary control. Notably, no study has directly tested the unified nature of these underlying mechanisms, and how reactive and proactive suppression mechanisms specifically contribute requires further investigation.

## 5. Summary and Outlook

Following the debate between stimulus-driven and goal-driven theories, two hybrid models integrating bottom-up capture and top-down control have emerged in visual attentional capture research: the rapid disengagement hypothesis and the signal suppression hypothesis. Since their proposal, both hypotheses have accumulated substantial empirical support, creating ongoing controversy. This paper reviews the theoretical proposals and related research to provide new perspectives for better validating these hypotheses and advancing attentional capture theory. The rapid disengagement hypothesis maintains that salient stimuli always attract attention, producing covert or overt attentional shifts, and that capture fails to occur because attention has sufficient time to disengage upon discovering the stimulus is task-irrelevant. The signal suppression hypothesis holds that all stimuli have the potential to capture attention and generate an "attend-to-me" signal, and that capture fails when salient singleton distractors are presented simultaneously with targets because the attentional system can actively suppress task-irrelevant salient stimuli top-down.

Given that research supporting the rapid disengagement hypothesis primarily uses spatial cueing and oculomotor disengagement paradigms where participants likely employ singleton detection strategies, while signal suppression hypothesis research predominantly uses additional singleton paradigm variants forcing feature detection strategies, we speculate that the two hypotheses may not be mutually exclusive. Instead, both may constitute essential components of attentional capture theory with partially unified mechanisms, explaining different attentional capture processes depending on experimental paradigms and participant strategies. Additionally, effects may depend on distractor type, task difficulty, and working memory capacity.

Future research on the rapid disengagement and signal suppression hypotheses should pursue several directions:

First, investigate how different stimulus types in paradigms related to both hypotheses affect attentional capture. Current research primarily uses meaningless stimuli varying in color and shape, yet real life contains numerous socially meaningful stimuli such as emotional and semantic stimuli. Recent studies have combined complex stimuli with search tasks to examine their impact on atten-

tional capture. For example, Glickman and Lamy (2017) found that emotional face targets among neutral face distractors captured attention only when the emotional faces were "singletons" in some dimension. Biggs et al. (2012) examined both emotional and semantic information, finding that increased semantic knowledge about distractors reduced their attentional capture and that participants disengaged more slowly from negative than positive stimuli. Although these studies demonstrate that complex meaningful stimuli affect attentional capture, they are limited to behavioral research with single measures and have not been integrated into rapid disengagement and signal suppression hypothesis research. Future studies should employ paradigms related to both hypotheses, combining eye-tracking, EEG, and neuroimaging methods to provide converging evidence for how different stimulus types influence attentional capture.

Second, examine how reward history affects "capture-disengagement" effects in the rapid disengagement hypothesis and "suppression" effects in the signal suppression hypothesis. Awh et al. (2012) proposed that selection history contributes to priority map integration alongside bottom-up and top-down factors, with reward history being a crucial component. Research shows that reward information can drive attentional effects in associated stimuli, distinct from bottom-up and top-down influences (Wang et al., 2013; Gong et al., 2016). Given that both hypotheses are hybrid models combining bottom-up and top-down processes, future research should integrate reward history—independent of these two factors—with the additional singleton paradigm to examine its impact on capture-disengagement and suppression effects.

Third, investigate the neural basis of reactive and proactive suppression mechanisms involved in both hypotheses. Studies using transcranial magnetic stimulation (TMS) and transcranial direct-current stimulation (tDCS) have implicated the prefrontal cortex and posterior parietal cortex (PPC) in proactive distractor suppression (Cosman et al., 2015; Lega et al., 2019; Tran, 2020). Since both hypotheses involve not only proactive but also reactive suppression mechanisms (Geng, 2014), future neuroimaging research should examine the relationship between the fronto-parietal attention network and reactive suppression mechanisms. This would help clarify the respective roles of reactive and proactive suppression in both hypotheses.

Fourth, systematically examine how training affects capture-disengagement effects in the rapid disengagement hypothesis and suppression effects in the signal suppression hypothesis. Both effects ultimately serve to improve search efficiency, and training is an effective method for enhancing search efficiency. In current research related to these hypotheses, participants typically perform only one experimental session lasting about one hour, which cannot reveal training effects. Future research should increase experimental duration and training days to investigate how training influences these effects.

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*Note: Figure translations are in progress. See original paper for figures.*