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Distractor ignoring: strategies, learning, and passive filtering

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Abstract

Our sensory environments contain more information than we can processes and successful behaviors require the ability to separate task-relevant information from task-irrelevant information. While much research on attention has focused on the mechanisms that result in selection of desired information, much less is known about how distracting information is ignored. Here we describe evidence that strategic, learned, and passive information can all contribute to better distractor ignoring. The evidence suggests that there are multiple ways in which distractor ignoring is supported that may be different than those of target selection. Future work will need to identify the mechanisms by which each source of information adjusts attentional priority such that irrelevant information is better ignored.

Introduction

You sit down at your desk to work on writing, when the blinking message light on your phone captures your attention. You decide not to deal with the message now, and find that you are quickly able to ignore the task-irrelevant blinking light. Ignoring task irrelevant information can certainly be beneficial, but how is this accomplished? Theories of attention posit that we have a limited capacity to process information, with attention serving as a gate to processing. Objects that are unselected remain outside of awareness, in the "dark" side of attention (Chun & Marois, 2002). One assumption that emerges from this perspective is that the ability to ignore objects is a side-effect of selection: things that are not selected are ignored. However, research over the years has suggested that this is not the whole picture. There are specific mechanisms for reducing distraction that are independent of target selection.

The purpose of this review is to provide evidence for three different sources of information that lead to better distractor ignoring and discuss putative mechanisms for each within the larger attentional system. The term "ignoring" is used to describe "a reduction in attention" to objects and does not imply a specific mechanism for how the ignoring was achieved. The first section is on "strategic ignoring" and describes evidence that distractor processing may be actively suppressed when distractor features are explicitly cued in advance. The second

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section on “learned ignoring” provides evidence that predictable distractor properties (e.g., location or features) are learned and suppressed even when observers express no knowledge of those regularities. The third section on “passive filtering” describes findings that simply viewing stimuli leads to better ignoring later on. While each section emphasizes a single source of information that contributes to better distractor ignoring, we do not know yet if they have mutually exclusive or shared underlying mechanisms.

Strategic Ignoring

Some of the earliest evidence that participants can strategically ignore distractor features came from Woodman & Luck (2007). When participants knew an item matching working memory (WM) color would always be a distractor in a visual search task, reaction times (RTs) were faster when the WM distractor appeared in search than when it was absent. Later ERP evidence supported this finding by demonstrating WM-matching distractors elicited a Pd event-related potential component (indicative of neural suppression) during visual search (Carlisle & Woodman, 2011). Similarly, a Pd was elicited by distractors in a probe display before a memory test (Sawaki & Luck, 2011). This suggested that people could use featural information in working memory to actively ignore distractors. Arita, Carlisle, & Woodman (2012) directly tested this by presenting participants with positive cues (indicating target color), negative cues (indicating distractor color), or neutral cues (uninformative; see Figure 1a). Both negative and positive cues led to significant RT benefits over neutral cues, suggesting ‘negative templates’ could be used to actively suppress known distractors proactively, in advance of the “to-be-ignored” stimulus (Geng, 2014; Braver, 2012).

In the same year, in a different type of search task, Moher and Egeth (2012) found that negative cues led to *longer* RT than neutral cues, suggesting negative cued distractors were capturing attention (see also Beck & Hollingworth, 2015). In an experiment using flashed probes to examine early attention, they found more probes reported on the negatively-cued distractor than on other distractors at 110ms, but the opposite at 167ms. They suggested participants were engaging in a ‘search and destroy’ strategy when presented with negative cues, similar to a reactive inhibition mechanism (Geng, 2014).

In spite of this clear behavioral support for search and destroy, later research examining early attention following negative cues has not always supported the ‘search’ portion of the search and destroy mechanism. Electrophysiological measures of attention using the N2pc event-related potential component found no attention capture by negatively cued search items (Carlisle & Nitka, 2019). Similarly, the suppression of negatively cued items seems to increase over the first few saccades of search (Kugler, et al. 2015; Beck & Hollingworth, 2018), but the suppression on later saccades was not dependent on whether overt attention was initially deployed to a negative-cue match (Beck & Hollingworth, 2018). Recent research with early letter probes to assess attentional deployment (25ms to 400ms) also echoes this finding, with no capture for the negative cue when probes were presented 25ms, while at later probe times there was more attention on potential targets following the negative than neutral cues (Zhang, Gaspelin, & Carlisle, in revision).

FMRI evidence also provides support for the idea that negative cues lead to suppression and operate via different mechanisms than positive cues of target features. For example, Reeder and colleagues found in two studies that pattern of activation in visual cortex was different for negative and positive cues (Reeder, Olivers, & Pollman, 2017; Reeder, Olivers, Hanke, & Pollman, 2018). These results suggest that positive and negative cues may rely on different mechanisms to influence attention, which may explain why negative cues lead to weaker benefits than positive cues and appear later during search (Kugler, 2015, Beck & Hollingworth, 2018, Carlisle & Nitka, 2019). The relationship between working memory and attention may be like a dial: we can turn up attention to target features using one mechanism, and turn down attention to distractor features using another (Carlisle, 2019, see also Kuo, 2014, Cosman et al., 2018).

Although the weight of evidence currently favors active cued suppression, there are recent examples of data that do not support this idea (e.g. Cunningham & Egeth, 2016). One reason for these mixed results may be that engaging proactive attentional suppression is difficult. Gong, et al. (2016) found effective negative cues elicited neural signatures of cognitive control. Participants may only use this strategy when it is necessary for search. Recently, Conci and colleagues (2019) showed no attentional benefit for a negative cue when search was easy. However, when search difficulty increased by making targets and distractors more similar, a negative cue benefit emerged. Therefore, differential influences of negative cues reported in the literature might be due to changes between a mechanism of proactive control (active suppression) for difficult search or a mechanism of reactive control (search and destroy) when search is easier. Future work should address this possibility.

In the studies described above, the attentional effects must be driven from an active strategic, or “top-down” control mechanism, because the cue changed on each trial. Other research has shown a negative cue which remains consistent for a set of trials also leads to attentional benefits (Wen, 2018; Cunningham and Egeth, 2016, Donohue et al., 2018, Kawashima, 2018), which may depend on learned suppression which we turn to next.

Learned ignoring

Learned suppression refers to the finding that distractors are better ignored after being repeatedly experienced while performing an attentional task, mirroring the effect of target selection history (Awh, Belopolsky, & Theeuwes, 2012; Geng & Behrmann, 2005; Jiang, 2018). Learning appears to be based on any statistical regularity that defines the distractors and is characterized by a lack of awareness for the regularities (Geng & Behrmann, 2002; Jiang, Won, & Swallow, 2014; Kim & Anderson, 2019). For example, recent evidence suggests that learned suppression can be applied to spatial locations associated with salient distractors. Wang and Theeuwes found shorter RTs and more accurate performance when a salient distractor was located in a predictable “high probability” location compared to an unpredictable “low probability” location (Failing & Theeuwes, 2018; Ferrante et al., 2018; Reder, Weber, Shang, & Vanyukov, 2003; Wang & Theeuwes, 2018a, 2018b). Moreover, RTs were longer when the target appeared in the high probability distractor location, suggesting observers suppressed the spatial location where the singleton distractor was expected to appear and not the salient distractor itself.

Learned suppression also applies to predictable distractor features. A uniquely colored distractor (i.e., a color singleton; Figure 1b) tends to capture attention and interfere with target selection (Theewes, 1992), but if the color singleton recurs across visual search trials consistently as a distractor, performance costs are reduced (Vatterott & Vecera, 2012). Interestingly, learning can occur at different levels of feature specificity. When observers experience only one singleton color (e.g., orange), new distractor colors (e.g., blue) capture attention and interfere with visual search performance; however, when experienced distractors vary in color during learning, new colors do not capture attention any more than old colors (Stilwell & Vecera, 2019; Vatterott, Mozer, & Vecera, 2018; Won & Geng, 2018; Won, Kosoyan, & Geng, 2019).

Further evidence suggests that learning generalizes beyond specific values to reflect an expected distribution of distractor features. Chetverikov and colleagues (Chetverikov, Campana, & Kristjansson, 2017a, 2017b) used a clever design in which the colors for an ensemble of distractors were sampled from a uniform or Gaussian distribution. Although the distractors in the two cases had the same range of color values, the likelihood of each color differed between conditions. They found that observers not only learned the distractor colors, but were sensitive to the distribution: higher probability distractor colors were more suppressed. Similarly, Won and Geng (2018) found that repeated exposures to a set of non-salient color distractors led to the generalization of suppression to similar colors that were never previously seen. These results indicate that observers build internal models for suppression using expected distributions of distractor features not just specific features.

There is strong evidence that observers learn to suppress distractors based on their statistical properties, but it remains unclear how learning occurs. One possibility is related to repetition priming (Kristjansson & Driver, 2008; Lamy, Bar-Anan, & Egeth, 2008). Cognitive models posit that changes in behavior following repetitions are due to the reinstatement of stimulus-based memories from the same context (Kahneman, Treisman, & Gibbs, 1992; Logan, 1990; Maljkovic & Nakayama, 1996). The context specificity offers a potential explanation for why repetition effects can lead to either facilitation or suppression depending on whether the stimulus was previously encountered as a target or distractor (Fecteau & Munoz, 2003; Gaspelin & Luck, 2018ab; Godijn & Theeuwes, 2002; Kristjansson & Driver, 2008; Tipper, 1995). Also consistent with memory models of repetition priming, the strength of suppression increases with more frequent occurrences (Geyer, Muller, & Krummenacher, 2006; Won et al., 2019), suggesting that learned suppression relies on memory representations of the task-relevance of specific stimuli within specific contexts.

Passive filtering

The previous sections provided evidence that human observers can use explicit strategies or implicitly learned statistical regularities to reduce distraction. It is possible that these mechanisms are complemented by passive ones based on simple exposure, such as habituation. Habituation is defined as “a behavioral response decrement that results from repeated stimulation and that does not involve sensory adaptation/sensory fatigue or motor fatigue.” (Gover & Abrams, 2009; Rankin et al., 2009). Habituation is thought to result from a reduction in the firing rate of neurons that encode prevalent, but irrelevant, sensory properties (Bell et al., 2012; Gover & Abrams, 2009; Rankin et al., 2009). This effectively creates an internal model of what is unimportant within an environment and dampens the orienting response to those stimuli (Cowan, 1999; Sokolov, 1863). Habituation does not require strategic control and occurs even when there are no task-defined "distractors" to be learned.

Although considerable work has shown the importance of habituation for the attenuation of auditory stimuli (Bell, Roer, Dentale, & Buchner, 2012), less has been done in the domain of visual attention. An exception is work by Turatto and colleagues (Bonetti & Turatto, 2019; Turatto, Bonetti, Pascucci, & Chelazzi, 2018). Turatto et al., (2018) hypothesized that a salient distractor would produce less interference if observers passively viewed the search display before engaging in active visual search. To test this, one group of subjects started the experiment immediately with an active visual search task. Another group first engaged in a "passive exposure" task during which the visual search displays appeared and disappeared without requiring subjects to respond in any way. Consistent with the habituation hypothesis, the "passive exposure" group experienced less interference from the salient distractor when they started the visual search task compared to the other group.

Similar conclusions were drawn from a paradigm in which passive exposure to colored stimuli occurred on completely different "habituation" displays interleaved with active visual search displays (Figure 1C; Won and Geng, under review). Subjects that saw the "habituation" displays performed better than a control group when the "habituated" colors suddenly became visual search distractors. However, similar to the previously described studies (Bell et al., 2012; Turatto, Bonetti, & Pascucci, 2018) attentional capture by the previously habituated distractors was not eliminated. This suggests that habituation attenuates feature processing and attentional capture, but may need to operate in conjunction with mechanisms of strategic or learned ignoring to fully suppress unwanted distractors.

Conclusions and open questions

Ignoring distractors is necessary for goal-oriented behaviors to be successful. The studies described in this review highlight evidence that distractor ignoring is supported by multiple sources of information (see also, Chelazzi, Marini, Pascucci, & Turatto, 2019; Noonan, Crittenden, Jensen, & Stokes, 2018). Distractors can be ignored by direct knowledge of what is going to be irrelevant, statistical learning of what is unlikely to be relevant, and passive exposure to stimuli (e.g., habituation). However, there are still many open questions regarding the mechanisms that might support distractor ignoring based on these different sources of information. Here, we highlight two.

First, there is the question of whether the internal models of "irrelevance" encoded from these sources of information are similar and rely on shared neural mechanisms (Cowan, 1999; Yamaguchi, Hale, D'Esposito, & Knight, 2004) or if they are unique and operate at different levels of cognitive or neural processing (Reeder et al., 2017; 2018). In particular, it seems plausible that habituation may play a role in learned ignoring, even if learned ignoring involves additional mechanisms that attenuate recurring salient-but-irrelevant information. Future work will need to disambiguate the contribution of stimulus exposure from active suppression, address the underlying neural mechanisms of each, and their relationship to strategic ignoring.

Second, the link between distractor ignoring and of target selection is virtually unexplored. Some evidence suggests that abilities in target selection may be related to the ability to suppress distractors (Beck, & Hollingworth, 2015; Forster & Lavie, 2014; Fukuda & Vogel, 2011). However, distractor ignoring may involve some unique mechanisms, including passive ones that identify task-irrelevant stimuli (discussed above), or ones that lead to greater generalization to new stimuli (Stilwell & Vecera, 2018; Vatterott, et al., 2018; Won & Geng, 2018; Won et al., 2019). While it may be functionally optimal to maintain precise representations of targets, the opposite may be true for distractors and this might result in dependence on different mechanisms for target selection and distractor suppression. Building a taxonomy of information sources and the mechanisms they engage to filter unwanted distractors should be a goal of future research. The evidence reviewed here provides the empirical groundwork for that endeavour by describing the exciting and relatively unexplored aspect of attention dealing with distractor ignoring.

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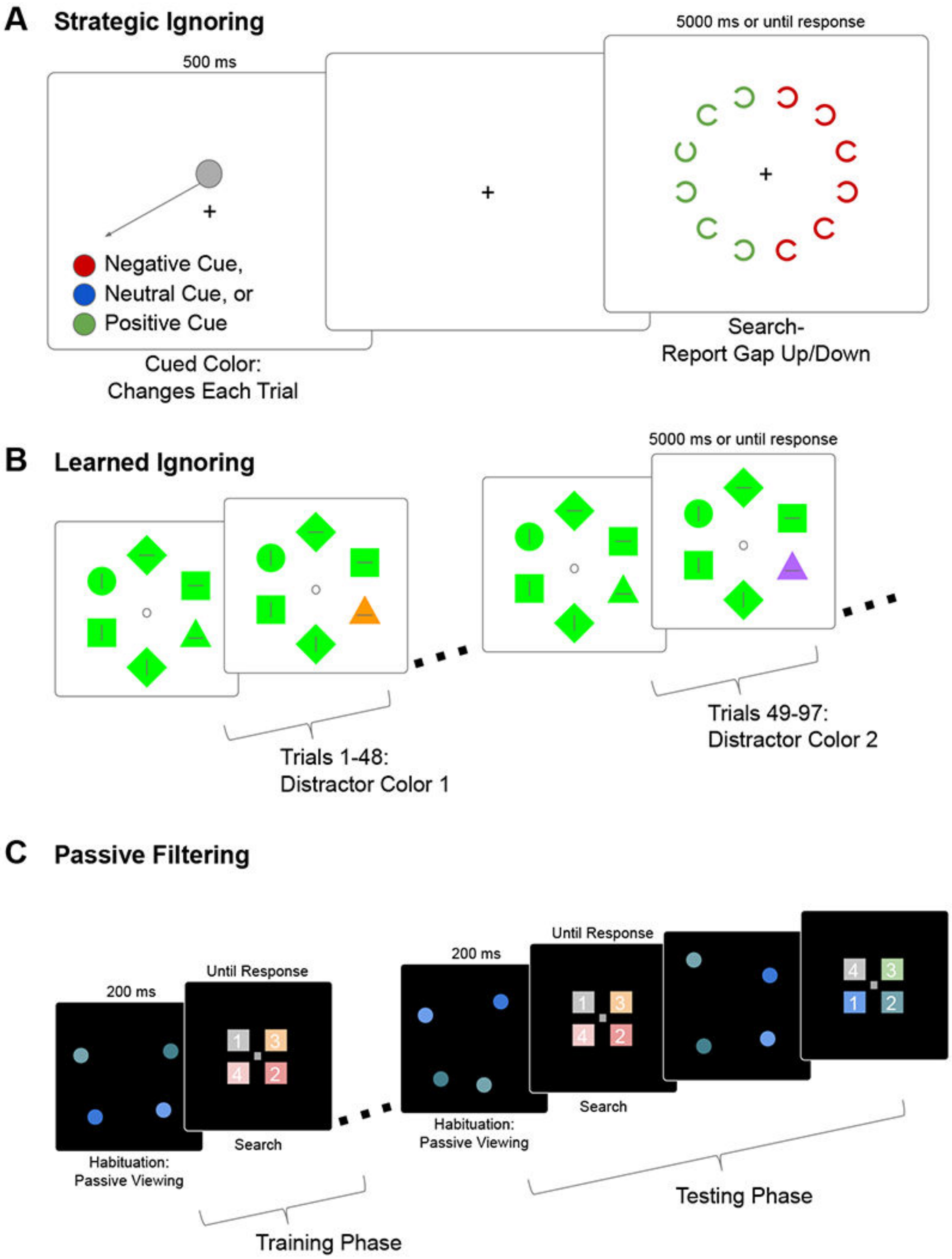

Figure 1:

Example experimental paradigms to test distractor ignoring. A. Illustration of paradigm from (Arita, Carlisle, & Woodman, 2012) that presented observers with a color cue prior to each search display of either the target (the “positive cue) or distractors (the “negative cue”). The strategic use of the negative cue led to better distractor suppression. B. Illustration adapted from Vatterot and Vecera (2012). Each block of trials contained a single colored singleton distractor. Interference by the distractor reduced over each block, but recurred when the color of the singleton changed. C. Illustration from Won and Geng (2019) of a paradigm in which “habituation displays” expose observers to colors during a “training phase” before they become distractors during visual search in the “testing phase”.