Is goal-directed attentional guidance just intertrial priming? A review

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According to most models of selective visual attention, our goals at any given moment and saliency in the visual field determine attentional priority. But selection is not carried out in isolation—we typically track objects through space and time. This is not well captured within the distinction between goal-directed and saliency-based attentional guidance. Recent studies have shown that selection is strongly facilitated when the characteristics of the objects to be attended and of those to be ignored remain constant between consecutive selections. These studies have generated the proposal that goal-directed or top-down effects are best understood as intertrial priming effects. Here, we provide a detailed overview and critical appraisal of the arguments, experimental strategies, and findings that have been used to promote this idea, along with a review of studies providing potential counterarguments. We divide this review according to different types of attentional control settings that observers are thought to adopt during visual search: feature-based settings, dimension-based settings, and singleton detection mode. We conclude that priming accounts for considerable portions of effects attributed to top-down guidance, but that top-down guidance can be independent of intertrial priming.

Introduction

When we open our eyes we do not simply see all that is there to see. The amount of information in our visual field at any given time is vastly larger than we can ever expect to process simultaneously (Kristjánsson, 2006a; Lamy, Leber, & Egeth, 2012; Rensink, O'Regan, & Clark, 1997). Preferential processing of important aspects of the visual field is implemented by selective attention—the mechanism that helps us deal with processing capacity limitations by filtering the stream of information.

Stimulus-driven and goal-directed guidance of attention

According to most models of attention, both stimulus-driven and goal-directed factors influence selection in a visual scene (e.g., Bundesen, 1990, 1998; Desimone & Duncan, 1995; Itti & Koch, 2000; Koch & Ullman, 1985; Treisman & Sato, 1990; Wolfe, 2007). Stimulus-driven signals depend on how different an object is from its neighbors. Goal-directed signals depend on the degree of match between an object and the set of target properties specified by task demands. According to the guided search model (e.g., Cave & Wolfe, 1990; Wolfe, 1994, 2007), the overall level of attentional priority of an item is the sum of its stimulus-driven (bottom-up) and goal-directed (top-down) activation levels. Likewise, according to the biased competition model (e.g., Desimone & Duncan, 1995; Kastner & Ungerleider, 2000), both goal-directed and stimulus-driven factors bias neural activity throughout the hierarchy of visual processing, determining which object wins the competition for representation in the brain (see also Bundesen, 1990).

A more radical view (Theeuwes, 1991, 1992, 2010) denies that goal-directed information plays any role in guiding attention to candidate objects at preattentive processing stages (see Lamy et al., 2012, for review). According to this salience-based view, when observers search the environment for a predetermined target, their attention is first deployed to items in the visual field in order of decreasing saliency irrespective of their relevance to the task at hand, with goal-directed control affecting only later processing that follows initial capture by salient objects (e.g., Theeuwes 1992, 2010; see also Belopolsky, Schreij, & Theeuwes, 2010; Hickey, Chelazzi, & Theeuwes, 2010; Theeuwes & Van der Burg, 2011).

In sharp contrast to the salience-based position, an increasing number of studies suggests that perceptual

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salience does not affect attentional priority in a purely automatic and uncontrolled fashion, and that its effects are mostly contingent on top-down settings (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Yantis & Egeth, 1999; for reviews see Burnham, 2007; Lamy et al., 2012; Rauschenberger, 2003; Theeuwes, 2010).

The role of implicit memory in attentional selection

In real world situations selection is seldom carried out in isolation since we typically attend to objects of interest tracking them through space and time. Consistent with these demands, how attention is deployed at a certain moment in time greatly affects how attention will be deployed a moment later (see Kristjánsson & Campana, 2010; Lamy, Yashar, & Ruderman, 2010, for reviews). This should be particularly useful when we attend to the same object over and over again during a short time period, such as when we keep track of our child in a playground or teammates and opponents during a soccer game. This aspect of attentional selection is not satisfactorily captured by the distinction between stimulus-driven and goal-directed guidance.

In the lab, such effects have been most often demonstrated in the context of visual search. When a target is defined as the unique item on some dimension, it is found more easily when on consecutive trials it is unique on the same dimension (dimension repetition effects, e.g., Found & Müller, 1996; Müller, Heller, & Ziegler, 1995; Müller, Krummenacher, & Heller, 2004; Müller, Reimann, & Krummenacher, 2003; Töllner, Gramann, Müller, Kiss, & Eimer, 2008), has the same defining feature (feature priming of Pop-out [PoP], e.g., Maljkovic & Nakayama, 1994), or appears at the same location (position PoP, Maljkovic & Nakayama, 1996). These repetition effects have been shown to be fundamentally bound to the act of attentional selection (Goolsby & Suzuki, 2001; Kristjánsson, Saevarsson, & Driver, 2013; Yashar & Lamy, 2011) and to play a strong role in determining visual exploration (Brascamp, Blake, & Kristjánsson, 2011). Similar repetition effects occur when the target appears at the same temporal position within a rapid serial visual presentation (RSVP) stream on two consecutive trials (Yashar & Lamy, 2010, 2013; see also Kristjánsson, Eyjólfsdóttir, Jónsdóttir, & Arnkelsson, 2010). Finally, when the target is not consistently a singleton, search performance on singleton-target trials is faster when the target was also a singleton on the previous trial (singleton priming, Lamy, Bar-Anan, & Egeth, 2008; Lamy, Bar-Anan, Egeth, & Carmel, 2006). Thus, when the same attentional selection is made repeatedly, performance improves—accuracy becomes higher and response times are speeded, sometimes by as much as 30%.

Implicit intertrial priming as an alternative account for effects attributed to goal-directed attention

The role of implicit intertrial memory in visual search is increasingly acknowledged, and a growing body of research is devoted to characterizing its behavioral (Kristjánsson & Campana, 2010; Lamy et al., 2010) and neural mechanisms (Campana, Cowey, Casco, Oudsen, & Walsh, 2007; Campana, Cowey, & Walsh, 2002; Kristjánsson, Vuilleumier, Schwartz, Macaluso, & Driver, 2007; Rorden, Kristjánsson, Pirog-Revill, & Saevarsson, 2011; Saevarsson, Jóelsdóttir, Hjaltason, & Kristjánsson, 2008). The study of intertrial priming has also strongly influenced the debate over the relative contributions of stimulus-driven and goal-directed factors in guiding attention. While some (e.g., Awh, Belopolsky, & Theeuwes, 2012; Kristjánsson, 2008; Lamy, Carmel, Egeth, & Leber, 2006; Wolfe, Butcher, Lee, & Hyle, 2003) have suggested that attentional priority is determined not only by goal-directed and stimulus-driven selection but also by traces of past selection (i.e., intertrial priming), others have proposed intertrial priming as an alternative account for effects traditionally attributed to goal-directed attentional control settings (e.g., Belopolsky et al., 2010; Kristjánsson, Wang, & Nakayama, 2002; Lamy, Bar-Anan, et al., 2006; Maljkovic & Nakayama, 1994; Pinto, Olivers, & Theeuwes, 2005). Finally, others have suggested that intertrial priming sometimes masks effects of stimulus-driven salience (e.g., Lamy & Zoaris, 2009), thereby challenging the notion that attentional settings are the sole determinant of attentional allocation with no role for physical salience (e.g., Yantis & Egeth, 1999).

The goal of the present review is to provide a detailed overview and critical appraisal of the arguments, experimental strategies, and findings that have been used to promote the idea that goal-directed or top-down effects are best understood as intertrial priming effects. Considerable research has addressed whether advance knowledge can guide attention preattentively, that is, help information pass from the parallel to the capacity-limited stage of analysis (Wolfe, 1994, 2007). Here, we mainly focus on the subset of studies addressing this question using visual search for singletons, because these have generated later interpretations that intertrial priming accounts for effects of top-down knowledge.

The studies are divided according to the property for which preknowledge is provided, and we review the literature relevant to each type of attentional control in separate sections. Advance knowledge may pertain to the target and induce a feature-specific setting (e.g., the target is always the only red item in the display), a dimension-specific setting (the target is always unique on the color dimension, but may be unique red or blue among gray), or "singleton-detection mode," a set for a singleton target, in whatever dimension. Advance knowledge may also pertain to a salient distractor that observers are instructed to ignore.

In the first part of each section, we describe the paradigms and experimental results that have been the hallmarks of the goal-directed (also known as the contingent-capture) view. Because our objective is to assess the role of priming, we mainly limit our scope to the subset of findings that have been (re)interpreted in terms of intertrial priming. In the second part, we critically review the findings that underlie such alternative accounts as well as counterarguments supporting the idea that the observer's attentional set can guide attention. In the closing section, we reevaluate the role of intertrial priming based on this review and suggest directions for future research.

Advance knowledge of the target's feature

Feature-based attentional settings: Key paradigms and findings

Effects of feature-based attention have been investigated with two main paradigm types. In some studies observers either know what the target feature will be on each trial or they do not: The target feature is known either because it remains constant across a block of trials (e.g., Bravo & Nakayama, 1992) or because it is precued (e.g., Humphreys, 1981; Laarni, 1999). Other studies test the role of feature-based control by comparing the extent to which a salient irrelevant distractor captures attention when it either matches the task-induced attentional set or does not (e.g., Folk et al., 1992).

The blocked- versus mixed-target paradigm

A blocked-target condition, in which the target-defining feature remains constant (always a red target among green distractors) is contrasted with a mixed-target condition, in which the target feature changes unpredictably across trials. To ensure that the task requires focal attention, the defining and reporting attributes differ (Duncan, 1985): The target may have a unique color and observers are required to report its shape. We will refer to this as the "*blocked- vs. mixed-target*" *paradigm*.

If attention can be guided towards the target based on a known feature, then search should be qualitatively different in blocked- and mixed-target conditions, since a top-down set for the known feature can be used in the former but not the latter. Three main findings have emerged from this literature, supporting the idea of preattentive guidance of attention by nonspatial features. (a) Reaction times are substantially faster when the target is known than when it is not (e.g., Bravo & Nakayama, 1992; Hillstrom, 2000; Lamy, Carmel, et al., 2006, Lamy & Yashar, 2008; Leonard & Egeth, 2008; Pinto et al., 2005). (b) When the target feature is known, reaction times remain constant as the number of nontargets increases (flat search slopes). By contrast, slopes are negative when the target feature is unknown, because search relies exclusively on the target's salience and adding distractors enhances target salience due to increased density (e.g., Bravo & Nakayama, 1992; Lamy et al., 2006a). (c) Interference from a distractor unique on an irrelevant dimension and more salient than the target (e.g., a high-contrast color singleton in search for a shape singleton) is considerably larger in the mixed-target than blocked-target conditions (e.g., Lamy et al., 2006a; Pinto et al., 2005; Theeuwes, 1991 vs. Theeuwes, 1992).

Feature cueing

Advance knowledge of the target feature can also be provided by precues. Typically, a precue indicates the feature of the upcoming singleton target on a trial-by-trial basis. The cue may be valid on a proportion of the trials (e.g., 75% of the trials) and invalid on the remaining trials. Alternatively, a 100%-valid cue may be compared to a noninformative precue condition. Faster reaction times (RTs) on valid- relative to invalid- or noninformative-cue trials are taken to indicate that knowledge of the target feature guided search. This rationale has been criticized when it is applied to target present/absent search tasks (e.g., Theeuwes, Reimann, & Mortier, 2006): Knowledge about what to search for may speed responses once the target has been detected (i.e., after selection) rather than speeding search. This argument does not hold for compound search tasks, however—that is, when the target-defining feature is different from the response feature. Yet, several studies have reported feature-cuing validity effects with compound search tasks (e.g., Leonard & Egeth, 2008).

The contingent-capture paradigm

Effects of feature-based control settings have also been tested using the *contingent-capture paradigm* (Folk et al., 1992). For instance, Folk and Remington (1998) had observers search for a target that could appear in one of four boxes surrounding fixation. The target was defined by its color (for one group the target was the unique red item among white ones, while for another group, it was the unique green item). The target display was preceded by a "distractor" display where each box was surrounded by four dots. One set of dots (the distractor) was either red or green, unpredictably across trials, and the other sets of dots were all white. Distractor and subsequent target locations were completely uncorrelated, so observers had no incentive to voluntarily shift attention to the distractor's location.

If attentional allocation is determined by feature-based top-down attentional settings, then a distractor should capture attention only when its color matches the target color. RTs should be faster when the target appears at the previous distractor location than at a different location—but *only* when this distractor has the target color. Folk and Remington's (1998) findings confirmed this prediction and have been replicated in numerous experiments (e.g., Ansorge & Heumann, 2003; Remington, Folk, & Maclean, 2001).

Feature-based attentional settings: Intertrial priming as an alternative account

As is clear from the foregoing review, there is strong evidence that attentional settings for a specific target feature can guide attention. However, it has been argued that intertrial priming effects can account for this (e.g.,; Belopolsky et al., 2010; Maljkovic & Nakayama, 1994; Pinto et al., 2005). For the blocked- versus mixed-target paradigm, the argument is that knowledge of the target feature is entirely confounded with repetition of the target feature from the previous trials. For the contingent-capture paradigm, the claim is that spatial capture by a distractor may depend not on whether this distractor matches the known target color (i.e., the attentional set), but on whether it has the color of the target on the previous trial: In other words, attention may be automatically captured by the color selected on the previous trial, irrespective of the observers' intentions. This might explain the findings of Folk and colleagues (e.g., Folk et al., 1992; Folk & Remington, 1998) because in those studies target color was constant.

Several authors have tested this alternative account by investigating whether cumulative effects of several intertrial repetitions yield the same pattern of results as effects attributed to attentional settings, both qualitatively and quantitatively.

Intertrial effects in the blocked- versus mixed-target paradigm: Findings

Reaction times: Maljkovic and Nakayama (1994) showed that in the mixed-target condition, response times are faster if the target has the same feature on consecutive trials. Such repetition effects, which they called "priming of pop-out" (PoP), accumulated over up to eight consecutive same target-feature trials, at which point performance reached the fixed-target performance level. They concluded that the same salience-based mechanism underlies pop-out regardless of whether the target feature is known, thus denying any role for feature-based attentional guidance. This finding should be interpreted with caution, however, because the probability of a target feature change on the next trial was much lower than the probability that the target feature would remain the same. Therefore, expectancy may have played a role in addition to PoP effects.

Other studies without this confound have reported substantial effects of target repetition but also a large RT advantage for the blocked relative to the mixed-target condition even after repetition effects reach their asymptote (e.g., Hillstrom, 2000, with orientation singletons; Lamy, Carmel, et al., 2006, with shape singletons). Thus, PoP cannot account for all the RT reduction attributed to feature-based attention.

Search slopes: If intertrial priming accounts for the qualitative differences observed between the blocked- and mixed-target conditions, then the negative search slopes found when the target feature is unknown should become flatter as the number of target-feature repetitions increases and become as flat as the search slopes that characterize blocked-target search (Bravo & Nakayama, 1992). The studies addressing this issue have yielded inconsistent findings.

On the one hand, Lamy, Carmel, et al. (2006) reported no effect of intertrial priming on search slopes for shape-singleton search: While search slopes were flat in the blocked-target condition, search slopes were equally negative when the target feature repeated and when it switched.

On the other hand, Meeter and Olivers (2006) reported that search slopes in a color singleton search were −13 ms/item after a color switch versus −7 ms after a color repetition, showing the expected slope reduction. Leonard and Egeth (2008) reported similar findings for color singleton search. Importantly, however, the latter results clearly suggested that the apparent slope reduction on repeated-target trials was due to floor effects: The faster conditions (i.e., the larger-set, denser displays) benefited less from target repetition than the slower conditions (i.e., the smaller-set, sparser displays) only when RTs approached floor levels.

Distractor interference: Pioneering the additional-singleton paradigm, Theeuwes (1991) had observers search for a shape singleton, either a unique diamond among circles or a unique circle among diamonds.

Observers responded to the orientation of a bar inside the circle/diamond. On half of the trials, one nontarget had a unique color (distractor-present condition) while on the remaining trials all nontargets had the same color (distractor absent condition). The presence of the color singleton distractor slowed search by 150 ms. This interference was reduced to just 20 ms when target shape was known (blocked-target condition; Theeuwes, 1992). These findings suggest that advance knowledge of the target shape reduced interference from an irrelevant singleton.

If PoP provides an alternative account for such reduction, then target-feature repetition should reduce interference to the blocked-target level. Pinto et al. (2005) reported that three successive repetitions of the target shape reduced distractor interference in the mixed-target condition to levels of interference observed in the blocked-target condition. By contrast, Lamy, Carmel, et al. (2006) found no modulation of distractor interference by PoP. In a later study, Lamy and Yashar (2008) resolved the discrepancy by showing that PoP reduces distractor interference when distractor presence is blocked (as in Pinto et al.'s 2005 study) but not when distractor presence conditions are randomly intermixed (as in Lamy, Carmel et al.'s 2006 study). A recent study by Lamy, Zivony, and Yashar (2011) provides clues as to why target repetition reduces distractor interference only when distractor presence must be blocked. They showed that when the search task is difficult, observers resort to heuristics that inflate PoP (response-based component of PoP, see Huang, Holcombe, & Pashler, 2004; Lamy et al., 2010). Furthermore, they showed that this strategy is used on both easy and difficult trials when conditions of difficulty are mixed within blocks, but only on difficult trials when the conditions are blocked. These findings might therefore explain why PoP produced different effects on distractor-present and distractor-absent trials when these were blocked versus mixed in Lamy and Yashar's (2008) study.

Taken together, the findings reviewed in the foregoing section suggest that intertrial PoP strongly reduces search RTs, but this effect accounts only for a portion of the RT benefits resulting from advance knowledge of the target feature. Likewise, priming cannot account for the larger distractor interference found when the target is known relative to when it changes unpredictably from trial to trial. Whether PoP affects search slopes is more controversial, and the resolution of this issue awaits further research.

However, it is important to realize that while findings showing that differences remain between the blocked and mixed conditions even after PoP has been taken into account strongly argue against the PoP alternative account, findings showing that the two conditions yield similar patterns should be interpreted with caution. Even if two different manipulations elicit similar performance patterns this does not necessarily reflect the operation of the same mechanism. The findings of Leonard and Egeth (2008) illustrate this point. They modified Maljkovic and Nakayama's task (1994) by adding a word precue, which either indicated the target color with 100% validity or was uninformative. Thus, advance knowledge of the target feature was provided by a precue, not by repeating the target feature on each trial, as in the blocked condition of previous experiments. RTs were faster (but see Theeuwes & Van der Burg, 2011), and search slopes less negative in the informative condition, replicating earlier findings thought to reflect feature-based guidance of attention (Bravo & Nakayama, 1992). In the uninformative cue condition, RTs became faster and slopes less negative when the target feature repeated on successive trials (i.e., PoP). Crucially, however, PoP did not account for the effects of feature-based information because, unlike in blocked target-feature conditions, the target color was as likely to repeat as it was to change on consecutive trials in both informative and noninformative conditions. Thus, Leonard and Egeth's (2008) findings show that providing advance knowledge of the target and repeating target color both produce similar effects, even though the feature-based advantage of advance cueing cannot be accounted for by PoP.

In conclusion, studies using the blocked versus mixed paradigms do not provide strong support for the claim that PoP accounts for effects attributed to foreknowledge of the target feature.

Intertrial effects in the contingent-capture paradigm

As explained earlier, what is manipulated in the contingent-capture paradigm to demonstrate effects of feature-based attentional settings is not knowledge of the target feature—which remains constant—but the match between the distractor and target feature. To test whether priming accounts for contingent-capture effects—whether a distractor captures attention only if it matches the feature of the previous target (rather than the task-relevant feature), a modified version is run in which the target feature changes from trial to trial. Such studies can be divided into two groups: (a) studies where the target display follows the distractor display (typically by 150 ms), as in Folk and colleagues' original paradigm (e.g., Folk et al., 1992) and (b) studies where the target and critical distractor appear in the same display.

Sequential distractor and target displays: Folk and Remington (2008) tested whether the match between the distractor's unique feature on trial n, and the unique target feature on trial $n-1$ modulates the extent to which this distractor captures attention. The target and distractor on each trial could be either red or green. There were strong intertrial priming effects: When the distractor's color matched the color of the target on the previous trial, spatial capture effects were 42% larger than when the colors were different. However, replicating this finding has been difficult.

Belopolsky et al. (2010) reported a similar finding in search for an onset target: An onset distractor produced stronger capture when the target on the previous trial was also a unique onset relative to when it was a color singleton. In the same experiment, however, capture by a color distractor was equally strong whether the previous target had been a color or an onset singleton.

Likewise, Irons, Folk, and Remington (2012) failed to replicate their previously reported intertrial priming effects (Folk & Remington, 2008) in a very similar experiment (and so did Eimer & Kiss, 2010). The only noticeable difference between the conflicting studies was that on part of the trials, the distractor was blue, a color that the target never took on. Yet, as acknowledged by Irons et al. (2012), it is not clear how this difference might explain the absence of priming.

Simultaneous distractor and target: Ansorge and colleagues (Ansorge & Becker, 2012; Ansorge & Horstmann, 2007; Ansorge, Horstmann, & Carbone, 2005; Becker, Ansorge, & Horstmann, 2009) applied a similar rationale, but the measure of attentional capture was interference by a distractor appearing simultaneously with the target. For instance, Becker et al. (2009) had observers search for a diamond target among nontarget circles. In the one-color condition, the target was always red, whereas in the two-color condition the target was unpredictably either red or green. Nontarget circles were gray. On 50% of trials, one of the circles, the distractor, was either red (as the target, same-color condition) or green (different-color condition).

The comparison of interest was whether a distractor with the color of the previous target would capture attention to a larger extent than a differently colored distractor. An important difference between this "simultaneous distractor-and-target paradigm" and Folk's original paradigm is that priming concerns an incidental property, that is, a property that does not define the target. Becker et al. (2009) found that in the single-target condition, the same-color distractor produced a stronger capture effect than did the different-color distractor, thus replicating the contingent-capture effect.

To determine to what degree this effect could be attributed to priming, Becker et al. (2009) examined whether in the two-color condition, a distractor with the color of the previous target produced stronger capture than a differently colored distractor. While this effect was significant, it was smaller than the same versus different color effect in the single-color condition (28 vs. 76 ms, respectively) and did not accumulate over consecutive repetitions. Furthermore, the same group failed to observe priming effects using a similar rationale (Ansorge et al., 2005; Ansorge & Horstmann, 2007). Taken together, these findings suggest that intertrial priming accounts for only a small part of the contingent-capture effect.

To conclude, the studies employing the classical or modified "simultaneous" contingent-capture paradigms have provided relatively scarce evidence for any intertrial priming effects, so these effects are very unlikely to provide an alternative account to the influence of feature-based attentional control. Note, however, that relatively few such studies have yet been reported, so this conclusion may be premature.

Advance knowledge of a singleton distractor's feature, dimension, or presence

Distractor suppression: Key findings

The results from several studies suggest that the ability to ignore a salient singleton is mediated by an active, top-down suppression process (e.g., Sawaki & Luck, 2010). Some studies showed that attention capture can be reduced if the color of the to-be-ignored singleton is known. For instance, in a serial search experiment, Theeuwes and Burger (1998) had observers search for a target letter among nontarget letters, and the observers were instructed to ignore an irrelevant, highly salient color singleton. The study showed that knowing the distractor singleton color was necessary to prevent attentional capture.

Other studies provided indirect support for distractor suppression. For instance, using a variant of Folk et al.'s (1992) spatial cueing paradigm, Lamy and colleagues (Lamy & Egeth, 2003, experiment 5; Lamy, Leber, & Egeth, 2004; see also Eimer, Kiss, Press, & Sauter, 2009) reported that search performance is slowed when the target appears at the location of an irrelevant singleton distractor in the preceding display, indicating that the location of the irrelevant singleton is suppressed. In addition, as such suppression was independent of distractor-to-target stimulus-onset asynchrony (SOA) (50 to 300 ms), it did not result from fast disengagement from the distractor location but rather from preattentive inhibition of the location occupied by a known-to-be irrelevant color. However, as the color of the irrelevant singleton was constant in all conditions, it is unclear whether the observed suppression concerned the distractor's specific feature, the dimension on which it was unique, or irrelevant singletons on any dimension.

Finally, resistance to capture is also enhanced when the irrelevant singleton occurs on a large majority of trials (e.g., Geyer, Müller, & Krummenacher, 2008; Müller, Geyer, Zehetleitner, & Krummenacher, 2009; Sayim, Grubert, Herzog, & Krummenacher, 2010). These authors showed that the more frequent the presence of an irrelevant singleton, the less it interferes with search. Similar findings showed that experience with salient distractors reduces their ability to capture attention (e.g., Vatterott & Vecera, 2012; Zehetleitner, Goschy, & Müller, 2012). For instance, in Vatterott and Vecera (2012), observers searched for a shape-defined target. They completed four blocks of trials, each with a different-colored irrelevant singleton present on half of the trials. Color singletons captured attention early within a block, but not later in the block, following sufficient experience with the irrelevant singletons. This result suggests that experience-dependent suppressive attentional tuning can be specific to distractor features. However, other studies indicated that such tuning is dimension specific (e.g., Zehetleitner et al., 2012).

Can intertrial priming account for feature-/dimension-based distractor suppression?

Several studies show that ignoring a singleton on a given trial has measurable consequences on search performance on the following trial. The reported effects are qualitatively similar to the effects attributed to goal-directed distractor inhibition reviewed in the previous section. They can be divided into three categories, reviewed below.

Distractor repetition effects

In Meeter and Olivers' study (2006, experiment 3), the target was either red or green and the critical singleton distractor was either blue or yellow. Thus, the target and critical distractor were singletons in the same dimension and the target never took on the color of the distractor on the previous trial and vice-versa. Performance was faster when the distractor color repeated, consistent with the notion that ignoring a singleton on a given trial entails feature-specific carry-over effects onto the next trial. However, the findings reported by Theeuwes, Atchley, & Kramer (2000, experiment 3) are inconsistent with this conclusion. Their participants searched for a known shape. A salient color singleton appeared at various SOAs prior to the target display, and its color varied unpredictably across trials. Distractor color repetition did not affect performance: The irrelevant color singleton captured attention to the same extent, irrespective of whether its color repeated or changed on successive trials.

Olivers and Humphreys (2003) showed that in search for a size singleton, an irrelevant singleton (e.g., on the orientation dimension) was less disruptive when it followed an irrelevant distractor on the same dimension than on a different dimension (e.g., color), suggesting the existence of intertrial dimension-based distractor suppression.. However, they did not test whether there was also a feature-specific distractor repetition effect.

Finally, Müller et al. (2009; see also Geyer et al., 2008) used an additional singleton search task in which they varied how often a color singleton distractor appeared, in different blocks. They showed that interference from a salient irrelevant singleton was smaller when the previous trial also included an irrelevant singleton relative to when it did not. However, because this effect did not occur in all distractor-frequency conditions, they concluded that intertrial priming cannot account for top-down distractor suppression. Consistent with this conclusion, Sayim et al. (2010) reported that abrupt-onset distractors are suppressed more effectively when they occur frequently, yet they failed to observe any intertrial distractor suppression effects.

Taken together, the findings pertaining to distractor-repetition effects allow us to delineate tentative boundaries of intertrial distractor suppression: It is dimension specific when the target and to-be-ignored singletons are defined on different dimensions and feature specific when they are defined on the same dimension. Further research is nevertheless needed to test this conclusion directly. In addition, studies investigating intertrial feature- and dimension-specific suppression have typically not compared mixed-distractor to fixed-distractor conditions, so it is not possible to draw any conclusions as to whether the observed intertrial effects might account for findings attributed to goal-directed feature / dimension suppression. By contrast, studies with repetition of distractor presence (rather than of its specific feature or dimension) clearly showed that intertrial priming cannot account for the total effect of top-down distractor interference suppression (e.g., Müller et al., 2009; Sayim et al., 2010).

Costs of attending to a target with the feature/dimension of a previously ignored distractor

Distractor suppression has also been probed by looking at the cost of attending to a target when it takes on the unique feature of a singleton distractor that has just been ignored. Such a feature-specific cost was reported in a variety of studies (e.g., Hickey, Olivers, Meeter, & Theeuwes, 2011; Lamy & Zoaris, 2009; Theeuwes & Van der Burg, 2011;).

In Hickey et al.'s (2011) experiment, for instance, the target was a unique shape singleton and the critical distractor was a color singleton as in Theeuwes' typical additional-singleton paradigm (e.g., 1992). Crucially, however, the colors of the target and critical distractor either switched or remained the same randomly across trials. Thus, the target might be the unique green diamond among green circles and a red circle or the unique red circle among red diamonds and a green diamond. The authors did not investigate the effect of repeating the target-*defining* feature—its shape—on the magnitude of distractor interference. Instead, they examined whether repetition of target color (which was *task irrelevant*) reduced distractor interference and found that it did.

This finding indicates that an irrelevant singleton (e.g., a unique red object among green ones in search for a shape singleton) is actively suppressed, so that when the target on the next trial takes on the suppressed feature, search performance is slowed. Accordingly, when the distractor was absent, there was no effect of repeating an irrelevant target feature.

Likewise, Olivers and Humphreys (2003) showed that in search for a size singleton, responses to targets were slower following an irrelevant singleton distractor on the same dimension, but again, they did not test whether there was also a feature-specific distractor repetition effect.

Spatial costs at the distractor location

Finally, several studies have shown that responses to a target that appears at locations previously occupied by an ignored distractor are slowed when the ignored distractor appears very shortly before the target—or probe—(e.g., Cepeda, Cave, Bichot, & Kim, 1998; Müller, von Mühlenen, & Geyer, 2007) but also when it appeared on the previous trial. For instance Kumada and Humphreys (2002) showed that search for a left-tilted target among right-tilted nontargets was slower when the target appeared where an irrelevant color singleton had appeared on the previous trial. Although such intertrial priming might provide an alternative account for effects attributed to feature-based suppression (e.g., Eimer et al., 2009; Lamy & Egeth, 2003; Lamy et al., 2004), the mechanisms behind it are undetermined. In particular, it is not clear whether the observed spatial cost reflects feature-based or dimension-based suppression, or inhibition of the just ignored distractor's location irrespective of its specific feature or dimension.

Feature- and dimension-based distractor suppression: Conclusions

Studies that addressed the issue of intertrial distractor suppression have yielded mixed findings. For instance, feature-specific intertrial distractor suppression when the target and distractor features are defined on different dimensions seems to be robust when measured as the cost of attending to a target with the feature/dimension of a previously ignored distractor but not when its measurement relies on distractor feature repetition. Moreover, most studies did not clearly establish whether intertrial suppression pertains to the distractor's specific feature, dimension, or presence. To resolve these issues, it will be particularly useful to conduct experiments where the irrelevant distractor's presence, features, and dimensions are concomitantly manipulated, and the spatial congruency between the target on the current trial and the distractor on the previous trial is also examined.

Overall, however, intertrial distractor suppression does not seem to account for top-down distractor suppression. Intertrial suppression was sometimes absent despite clear effects of top-down distractor suppression (e.g., Müller et al., 2009; Sayim et al., 2010). In addition, findings that experience with specific singleton distractors across several tens of trials reduces interference (e.g., Vatterott & Vecera, 2012; Zehetleitner et al., 2012) cannot be attributed to intertrial priming, which typically reaches asymptote over much fewer trials (e.g., Maljkovic & Nakayama, 1994).

Advance knowledge of the target's dimension

Dimension-based attentional settings: Key findings and theory

Advance knowledge can also guide attention to particular feature dimensions. The paradigms used to study dimension-based guidance are conceptually similar to those used to study feature-based guidance.

In blocked- versus mixed-dimension studies, the target dimension is either constant across a block of trials or changes unpredictably. For instance, in Egeth's (1977) studies of *dimensional uncertainty,* observers viewed sets of small, black disks and searched for targets that were either *red* or *large*. Egeth compared blocks in which the target was red (or big) for the entire session, to blocks in which the observer was uncertain about the dimension of the target but knew the specific feature on each dimension (red or large). Search was efficient (i.e., unaffected by set size) in both blocked and mixed conditions, but there was an overall cost of approximately 50 ms in the mixed condition (see also Cohen & Magen, 1999; Treisman, 1988).

In Müller, Heller, and Ziegler (1995; see Wolfe et al., 2003 for similar findings) the singleton target identity was unpredictable in all conditions but the dimension on which the target differed from distractors was either known in advance or not. The critical manipulation was whether target identity varied *within* or *across* dimensions. Müller et al. (1995) examined whether search for an unknown-feature target is based on dimension-specific salience signals by measuring the mixed- versus fixed-dimension cost in a simple detection task. They reasoned that if pop-out can occur from an overall saliency map and observers do not need to *identify* the target but only detect its presence in a heterogeneity-versus-homogeneity judgment of the display, differences between within- and between-dimension searches should disappear. Nevertheless, cross-dimension uncertainty still incurred a large cost (55–60 ms).

In *dimension-cueing* studies, precues inform observers about the upcoming target's dimension during parallel visual search. Müller et al. (2003) found large effects of symbolic dimension trial-by-trial cues (i.e., the words "color" or "orientation") in a target present/absent task. Theeuwes et al. (2006) questioned whether this reflected preattentive attentional guidance suggesting instead that it reflected speeded response-related processes following selection. To test this alternative they replicated Müller et al.'s (2003) study using a compound search task instead of a detection task and failed to observe cueing effects. Yet, Müller and Krummenacher (2006) showed that when observers are strongly encouraged to use the cues, cueing effects are observed in compound search tasks.

Contingent-capture studies have shown that when observers search for a certain type of discontinuity, such as a moving target among stationary distractors, motion singletons produce spatial capture, while color singleton distractors do not (Folk, Remington, & Wright, 1994). Similar findings were reported for color (Folk et al., 1992, experiment 4), but later studies showed that attentional settings are not specific to the whole dimension but to the specific color known to characterize the target (e.g., Folk & Remington, 2008). This line of research has not been pursued with regard to dimension-based attention.

Can intertrial dimension priming explain effects attributed to dimension-based attentional settings?

Müller et al. (1995) reported that when there was dimensional uncertainty with regard to the target, RTs were faster when the target's dimension was the same on consecutive trials than when it changed. In further systematic investigations of this, Found and Müller (1996) had observers search for an odd-one-out target among white distractors. The target was present on 50% of trials and observers determined its presence or absence. The target was either a white bar tilted to the left or right from vertical or a red or blue vertical bar. This design allowed for a direct comparison of intertrial effects when targets on successive trials had the same feature (and dimension) versus when they had different features on the same dimension. Found and Müller reported large dimension repetition effects (see also Olivers & Humphreys, 2003; Rangelov, Müller, & Zehetleitner, 2011; Wolfe et al., 2003) but very small feature repetition effects.

Müller and colleagues (e.g., Found & Müller, 1996; Müller et al., 1995; Müller & Krummenacher, 2006; Müller et al., 2003; Müller et al., 2010) suggested a dimension-weighting account (DWA) to explain benefits of top-down knowledge about the target dimension and intertrial dimension repetition. According to DWA, attentional priority is based on the weighted sum of dimension-specific saliency signals on a "master map of locations" that codes the overall saliency of each filled location in the visual array. If the target dimension is known in advance, that dimension is assigned a large weight and receives high attentional priority. They also argued that patterns of dimensional weighting generated when observers respond to targets persist, so that responses to a target on one trial depend on the dimensional identity of the previous target. Specifically, they suggested that the distribution of weights across dimensions established on a given trial determines the speed at which a feature contrast signal becomes salient on the master map in the following trials.

Unlike feature priming, dimension priming has not been suggested as an alternative account to dimension-based goal-directed guidance of attention, perhaps because the leading model of dimension-based attention, DWA, assumes that the two reflect the same mechanism. Theeuwes et al. (2006; experiment 5) raised the objection that priming might account for effects of dimension cueing, yet they empirically tested only effects of feature repetition and not of dimension repetition. Evidence pertaining to this issue is therefore only indirect.

Müller et al. (1995) reported 60-ms effects for both dimension knowledge (known vs. unpredictable target dimension) and intertrial dimension repetition. It is difficult to compare these magnitudes, however, because while the former effect pertained to targets on all dimensions, the latter concerned only orientation targets.

Olivers and Humphreys (2003) demonstrated that a variety of dimension repetition effects substantially influence visual search performance. In their experiment, the target was always a larger bar among shorter and thinner distractor bars (i.e., a size singleton). On a portion of trials (singleton-target trials), the target also had a unique (but irrelevant) color or a unique (but irrelevant) orientation. On other trials, a distractor of a unique color or orientation replaced one of the nontargets (distractor-singleton condition). Finally, on baseline trials, neither the target nor any of the distractors had a unique color or orientation. Olivers and Humphreys (2003) showed that responses to singleton targets were faster following a target on the same dimension, and slower following an irrelevant singleton distractor on the same dimension; in addition, singleton distractors were most disruptive following a trial containing a target on the same dimension and less disruptive after a distractor on the same dimension. They acknowledged, however, that their data "do not speak clearly for or against an overall attentional set" (p. 656) because their design did not allow direct comparison of magnitudes of top-down attentional control settings and intertrial priming effects.

Note that dimension-cueing effects (e.g., Müller & Krummenacher, 2006) demonstrate an influence of dimension knowledge that cannot result from intertrial priming, yet such effects are typically small. Firm conclusions on this issue must therefore await further research.

Dimension priming versus feature priming

It is noteworthy that proponents of DWA have typically reported small and inconsistent feature-priming effects, which emerged in the color dimension but in not the orientation dimension. (e.g., Found & Müller, 1996; Krummenacher, Grubert, & Müller, 2010). By contrast, the conclusion of the previous section was that feature priming plays a prominent role in selection during visual search. What may account for the discrepancy between the two lines of research?

Olivers and Meeter (2008) suggested that the search context may be important: Feature priming might be especially weakened when the search task involves dimension changes in addition to feature changes (as in Found & Müller, 1996) relative to when only feature can change (e.g., Hillstrom, 2000). They tested this claim, yet they found that search context does not modulate feature-priming effects (see also Kristjánsson, Bjarnason, Hjaltason, & Stefánsdóttir, 2009; Wolfe et al., 2003).

Müller and colleagues suggested that feature priming only weakly affects selection speed and mainly occurs at a postselective stage where the selected stimulus is compared against the target template held in working memory, hence its relatively weak effect on visual search performance (Krummenacher et al., 2010). However, inconsistent with this claim, several studies have shown that feature priming affects early, selection-related processes (e.g., Ásgeirsson & Kristjánsson, 2011; Lamy et al., 2010; Yashar & Lamy, 2011).

Finally, Müller and colleagues (e.g., Found & Müller, 1996) also proposed that the color dimension might be unique in representing broad subcategories (such as red, green, and blue), thereby arguing that feature priming is an instance of dimension priming. Yet, feature-priming effects have been reported for dimensions other than color, for instance shape (e.g., Lamy, Bar-Anan, et al., 2006; Lamy, Carmel et al., 2006), size (Ásgeirsson & Kristjánsson, 2011; Huang et al., 2004) and facial expressions of emotion (Lamy, Amunts, & Bar-Haim, 2008b).

For orientation, however, the current literature is mixed: Some found repetition effects (e.g., Hillstrom, 2000; Kristjánsson, 2006b, 2009; Sigurðardóttir, Kristjánsson, & Driver, 2008; Wolfe et al., 2003) while others did not (e.g., Found & Müller, 1996; Lustig, Simons, Lleras, & Beck, 2012; McBride, Leonard, & Gilchrist, 2009; see also Weidner, Pollmann, Müller, & von Cramon, 2002, who failed to observe feature priming effect on orientation/direction of motion).

A recent study by Lamy, Yashar, and Ruderman (2013) seems to resolve the uncertainty surrounding the existence of orientation repetition effects and to explain why Müller and colleagues have typically reported weak feature-priming effects. Lamy et al. (2013) relied on the notion introduced by Lamy, Antebi, Aviani, and Carmel (2008; see also Bichot & Schall, 2002; Kristjánsson & Driver, 2008; Maljkovic & Nakayama, 1994) that two independent components contribute to feature priming: firstly, a target-activation benefit (when the target feature repeats on consecutive trials) and a target-activation cost (when the distractor shares the feature of the preceding target), and secondly a distractor-inhibition benefit (when the distractor feature repeats on consecutive trials) and a distractor-inhibition cost (when the target shares the feature of the distractor on the previous trial).

Lamy et al. (2013) noted that a common aspect of the studies that failed to report feature priming in orientation singleton search is that only target-activation was probed. For instance, in Found and Müller's (1996) study, the target feature could change unpredictably from trial to trial, but the distractor feature remained constant. Likewise, Wolfe et al. (2003) found a significant orientation priming effect when target and distractors could exchange roles but not when distractor orientation was constant across trials. Based on this observation, Lamy et al. (2013) hypothesized that only distractor-inhibition should contribute to feature priming in orientation-singleton search. To test this, they used four instead of only two possible orientations. On each trial, two different orientations were randomly drawn from the four possible orientations and assigned to the target and distractors. This design allowed disentangling target activation and distractor inhibition effects. The results confirmed Lamy et al.'s (2013) prediction: They found distractor-inhibition benefits and costs but neither target-activation benefits nor costs. This framework also explains why feature-priming effects are typically smaller in dimension-priming experiments than in feature-priming experiments: Distractors are typically constant in the former, such that only target-activation benefits contribute to feature priming, whereas in the latter (including Olivers & Meeter, 2008), both target and distractor features either remain the same or switch, such that target activation and distractor inhibition benefits and costs all contribute to feature priming.

Dimension-based attention: Conclusions

Intertrial dimension contingencies have substantial effects on visual search performance. However, there has been no systematic investigation of whether they account for effects attributed to dimension-based attention (aimed at either enhancing processing of relevant targets or suppressing processing of irrelevant distractors). In addition, the claim that intertrial effects are dimension specific rather than feature specific has not been supported: The smaller effects reported for feature relative to dimension repetitions seem to reflect the use of designs that are not optimal for measuring the full magnitude of feature repetition effects.

Advance knowledge of the target's status as a singleton

Key findings and theory: Singleton-detection versus feature search mode

Additional singleton paradigm

Theeuwes (e.g., 1992, 2010, but see Awh et al., 2012) has claimed that attention cannot be guided by knowledge of the target property at preattentive stages. Instead, attention is captured by the element with the highest bottom-up salience in the display, regardless of task relevance. Evidence for this comes from Theeuwes' additional singleton paradigm (e.g., Theeuwes, 1992). On each trial, the target is a shape singleton, such as the unique circle among diamonds. On distractor-absent trials, all items have the same color (e.g., green). In the distractor-present condition one of the nontargets has a different color. The typical finding is that the presence of the irrelevant singleton slows RTs significantly. However, this effect occurs only when the irrelevant singleton is more salient than the singleton target, suggesting that items are selected in order of salience. Theeuwes concluded that top-down selectivity at the preattentive stage is not possible.

Using a distinction initially suggested by Pashler (1988) and Bacon and Egeth (1994) proposed an alternative account for Theeuwes' (1992) findings. They claimed that because the target was consistently a singleton and its shape was known, two search strategies were possible: (a) *singleton detection mode*, where attention is directed to the location with the largest local feature contrast, and (b) *feature search mode*, where attention is directed to items possessing the target feature. They further suggested that singleton-detection mode is the default search strategy whenever applicable, accounting for the finding that despite knowing the target feature, observers searched for the most salient object in Theeuwes' (1992) experiment. To test this claim, they designed conditions where singleton-detection mode was disadvantageous for task performance. They presented either up to three identical target shapes on each trial, or up to two different unique shapes in addition to the unique target shape, thus ensuring that the target could not be found by simply looking for a singleton. The disruption caused by the unique distractor disappeared, even on trials on which the target happened to be a singleton. Folk, Leber, and Egeth (2002) reported similar findings using an RSVP paradigm.

Irrelevant-singleton paradigm

Yantis and Egeth (1999) had observers search for a nonsalient target (a vertical bar among tilted bars of various orientations). Each display also contained a color singleton, the unique red bar among blue ones. When the unique red bar coincided with the vertical target on each trial, search was highly efficient, as reflected by flat search slopes, which suggests that the largest attentional priority was allocated to the red singleton. By contrast, when the locations of the vertical target and red singleton were uncorrelated, search slopes for a target that happened to be the red singleton (singleton-target trials) were steep. Yantis and Egeth (1999) concluded that unless observers adopt singleton-detection mode, stimulus-driven salience plays little or no role in the guidance of attention.

Criticisms of the singleton-detection versus feature-search mode distinction

Although the distinction between singleton-detection mode and feature-search mode has been widely accepted in the literature (e.g., Pashler, Johnston, & Ruthruff, 2001; Ruz & Lupianez, 2002), its usefulness has been challenged (e.g., Kawahara, 2010; Lamy, Bar-

Anan, et al., 2006; Lamy, Carmel, et al., 2006; Lamy & Zoaris, 2009; Theeuwes, 2004).

It is important to emphasize that the crux of the "singleton-detection mode" account of capture is that observers use singleton-detection mode as *default* whenever the target is reliably a singleton, irrespective of whether the unique feature is known or unknown. There is agreement that observers use salience-based search when the only defining characteristic of the target is its uniqueness (e.g., when the target singleton feature varies unpredictably, e.g., Inukai, Kawahara, & Kumada, 2010; Leber & Egeth, 2006). What is disputed is whether stimulus-driven and goal-directed effects on attentional priority are strictly encapsulated within singleton-detection and feature-search modes, respectively, or in other words, whether salience should play a role only when observers use singleton-detection mode and none when they adopt feature-search mode.

A detailed inventory of the criticisms of the notion of a default singleton-detection mode is beyond the scope of this review. We instead focus on suggestions that intertrial priming accounts for the presumed adoption of singleton-detection mode.

Can intertrial priming account for effects attributed to singleton-detection mode?

Intertrial priming in the additional singleton paradigm

Lamy, Bar-Anan, et al. (2008) showed that directing attention to a singleton on a given trial facilitates the direction of attention to a singleton on the next trial. They used one of the procedures pioneered by Bacon and Egeth (1994) to induce observers to search for a known target feature: The target was always a circle among diamonds, but there could be one, three, or five identical target circles on each trial. Lamy, Bar-Anan, et al. (2008) found that on singleton-target trials, search was faster when the target was a singleton on the previous trial than when there had been several targets. Search was not affected by whether or not other target numbers were repeated on successive trials. They replicated this with color instead of shape singletons, and both when the target was a singleton on a target-defining or irrelevant dimension.

Lamy, Bar-Anan, et al. (2006) suggested that attending to a singleton on a given trial makes an irrelevant distractor more likely to capture attention on the next. This could explain Bacon and Egeth's (1994) findings, since this occurred on every trial when the target was reliably a singleton (known singleton condition), but only on one third of the trials when the target was only occasionally a singleton (e.g., multiple-target condition). Lamy, Bar-Anan, et al. (2006) argued that this might explain why distractor interference was observed in the former but not the latter condition. They tested this, showing that following two consecutive singleton-target trials in the multiple-target condition, distractor interference was similar to the known singleton-target condition. From this, they concluded that there is no default singleton-detection mode.

Intertrial priming in the irrelevant-singleton paradigm

Lamy and Zoaris (2009) demonstrated that various intertrial priming effects masked capture by irrelevant color singletons in Yantis and Egeth's (1999) study even though observers were engaged in feature-search mode. They first replicated these authors' initial finding: A color singleton did not capture attention when it coincided with the target at chance level. They then modified the paradigm to eliminate target-feature repetitions, the cost of attending to a singleton when a singleton had been ignored on the previous trial (see Olivers & Humphreys, 2003, for a report of a similar cost) and the advantage of ignoring a singleton when a singleton had been ignored on the previous trial (see also Müller et al., 2009). When these intertrial effects no longer affected performance, search slopes when the target happened to be a color singleton were flat. Capture by an irrelevant color singleton thus occurred in search for a target with a known orientation among variously oriented nontargets, that is, under conditions in which observers could not have adopted singleton detection mode.

Conclusions on the role of intertrial priming in singleton-detection mode

Taken together, the reviewed findings suggest that intertrial priming accounts for effects attributed to the adoption of a *default* singleton-detection mode. Note, however, that the singleton-priming alternative account to the singleton-detection default mode was tested with only part of the procedures used to encourage feature-search mode (Bacon & Egeth, 1994, experiment 2; Yantis & Egeth, 1999). This should therefore be tested with other procedures (e.g., Bacon & Egeth, 1994, experiment 3).

Conclusions

In this review, we asked whether intertrial priming accounts for effects that have been attributed to goal-directed allocation of attention. The short answer is that they don't. However, our review clearly demonstrates that recent selection history has dramatic effects on visual search performance. If these effects are not taken into account, the contribution of current selection goals may be overestimated, while effects of stimulus-driven salience on visual search performance are underestimated.

Main findings

Most investigations of intertrial priming as an alternative for goal-directed attention have been guided by the same rationale: If cumulative effects of intertrial repetition of, say, the target feature, modulate search performance in the same way as does advance knowledge of this feature, both qualitatively and quantitatively, then one may conclude that current selection goals cannot guide attention and that their effects are entirely confounded with intertrial priming. Conversely, finding that residual effects of top-down attention remain after intertrial priming effects have been discounted leads to the opposite conclusion.

It is important to emphasize that these alternative patterns of results should not be treated on a par: Finding differences between effects of top-down information and intertrial priming strongly suggests that they reflect different phenomena. Yet, finding similar results does not necessarily imply that the same mechanism underlies the two effects, because the list of measures used to dissociate them cannot be exhaustive: Intertrial priming and goal-directed attention might be dissociable on a measure yet to be identified.

With this caveats in mind, our review points to the following conclusions: (a) intertrial priming cannot account for the benefits of selection goals resulting from advance knowledge of the target feature or from knowledge that a distractor on a given dimension will appear on a majority of trials. (b) Dimension-based intertrial priming effects, whether they pertain to the target or to to-be-ignored singletons attention, are substantial, but have not been systematically compared to goal-directed selection biases. (c) Singleton priming yields the same behavior patterns as the so-called "singleton-detection default mode," a finding that suggests—yet not definitively so—that observers do not resort to a search strategy that relies exclusive on salience signals when feature-based information is provided.

Varieties of intertrial priming effects

In this review, we also showed that intertrial effects are diverse. Intertrial repetition effects pertaining to the target facilitate performance: Search is faster when the target-defining feature repeats (although not when the target is defined on the orientation dimension), when the target is a singleton on successive trials, and when the dimension on which it is unique repeats. Likewise, performance benefits resulting from distractor repetition have been observed: Search is faster when the homogeneous nontargets surrounding the singleton target have the same feature on the relevant dimension on consecutive trials, when the salient feature of a singleton distractor repeats on the task-relevant dimension, and when the dimension in which a salient distractor is unique repeats.

Intertrial contingencies are also associated with costs. Some of these result from carry-over effects of attending to a distractor on the previous trial: Search is slowed when the target takes on the salient irrelevant feature of a previously ignored singleton distractor, when the target appears at the location previously occupied by an irrelevant singleton on the relevant or an irrelevant dimension. Other costs result from carry-over effects of ignoring a distractor that shares the feature of the target on the previous trial, or is unique on the same dimension.

Intertrial contingencies in the spatial domain (e.g., Geyer, Müller, & Krummenacher, 2007; Maljkovic & Nakayama, 1996) and in the temporal domain (e.g., Kristjánsson et al., 2010; Los, 2010; Yashar & Lamy, 2010, 2013) were not considered here. Yet, it would be useful to conduct a systematic evaluation of the extent to which these may account for effects attributed to goal-directed attention in space (e.g., Posner, Snyder, & Davidson, 1980) and in time (e.g., Lamy, 2005; Nobre & Coull, 2010).

Current goals and intertrial priming may not affect the same processing stages

In a dramatic departure from his long-standing claim that current goals do not affect attentional selection, Theeuwes (Awh et al., 2012) recently acknowledged that current models of attentional control should be modified so as to integrate selection history with current goals and physical salience in shaping an integrated priority map. Implicit in this statement is the assumption that, like goal-directed and salience-based biases, intertrial priming affects visual search before attention is deployed to the highest-priority object in the visual field, that is, at preattentive stages of processing. There is, however, little experimental support yet available for this claim. Moreover, a glance at the literature investigating the mechanisms underlying intertrial priming suffices to show that this assumption is highly controversial.

First, there is a relative consensus that intertrial priming effects reflect composite mechanisms (e.g., Kristjánsson & Campana, 2010; Lamy et al., 2010; Töllner et al., 2008) and only part of the effects of recent selection history are perceptual (see e.g., Ásgeirsson & Kristjánsson, 2011; Lamy et al., 2010; Lamy et al., 2011; Yashar & Lamy, 2010, 2011). Thus, the impact of intertrial priming on attentional selection may be smaller than usually thought.

Second, what perceptual stages are affected by intertrial priming has also been debated. While the DWA stipulates that dimension-based repetition effects modulate attentional weights prior to selection (e.g., Found & Müller, 1996; Rangelov et al., 2012), other authors suggest that they affect processing after the target has been selected (e.g., Becker, 2008). Likewise, Yashar and Lamy (2011) claimed that PoP affects attentional engagement in the target rather than earlier preattentive stages of processing as suggested by others (e.g., Becker, 2008; Maljkovic & Nakayama, 1994).

Finally, current investigations of the processing stages that are modulated by intertrial priming have typically not relied on a fine-grained classification of intertrial priming effects. Dimension priming and PoP have been investigated separately, but other intertrial effects have been conflated. For instance, several studies have shown that PoP affects perceptual processing (e.g., Lamy et al., 2010; Sigurðardóttir et al., 2008) but as target and distractor features either both repeated or switched, it was not possible to determine whether both target- and distractor-related intertrial contingencies affect perceptual processing. It will therefore be important to investigate whether the different intertrial effects reviewed here affect similar processing stages. This issue is critical for our understanding of how selection history interacts with goal-directed and stimulus-driven guidance of attention.

Keywords: intertrial priming, priming of pop-out, top-down attentional control, bottom-up attentional control, dimension priming, singleton-detection mode, visual search

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