Positional priming of pop-out: A relational-encoding account

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Three experiments examined whether positional priming of pop-out is modulated by target salience. In Experiment 1, the singleton target appeared among variable numbers of distractors (2, 3, 5, 7; blocked presentation). While facilitation of target locations was not influenced by distractor number, inhibition of distractor locations was evident only with two distractors in the display. In Experiment 2, 3- and 6-item displays, with 2 and 5 distractors, respectively, were intermixed rather than blocked. It was found that, when the majority (but not the minority) of trials contained 3-item displays, there was carryover of distractor location inhibition from 3- to 6-item displays (but not vice versa). In Experiment 3 (1 target, 2 distractors), inhibitory priming of distractor locations could even be evoked when the current target was presented at an empty but merely expected distractor location in the previous trial. These findings argue that target salience is not an adequate account of positional priming. Instead they suggest that the relational encoding of the regular (triangle) stimulus arrangement contributes to positional priming.

Keywords: priming of pop-out, visual short-term memory, set size effects, visual search


Positional priming in visual pop-out search

For detecting a target among a set of distractors, it may be considered important to know how the target differs from the non-target items. For example, the target definition may need to be explicitly represented in working memory, in order to provide criteria for when the search is to be terminated (e.g., Treisman & Gelade, 1980; Treisman & Sato, 1990). However, recent work by Maljkovic and Nakayama (1994, 1996, 2000; McPeek, Maljkovic, & Nakayama, 1999; see also Chun & Jiang, 1998) has demonstrated the automatic and implicit nature of the memory underlying visual search performance, at least with search for simple-feature—that is, “pop-out”—targets. In Maljkovic and Nakayama’s (1994, 1996, 2000) experiments, observers responded to the orientation of a color singleton target: either a single red object among two green distractors or a green object among two red distractors. The search stimuli were presented on the circumference of an imaginary ellipse around central fixation, with near-equal inter-item spacing. The color and position as well as the orientation of the target and of the distractors changed unpredictably from trial to trial. However, the spatial arrangement of the three elements in terms of a near-equilateral triangle remained constant across trials. As a main result, observers identified the target’s orientation faster when the color or, respectively, the position of the singleton target on the previous trial(s) was repeated compared to when it was changed. Maljkovic and Nakayama (2000) attributed these feature- and position-based priming effects to separable implicit visual short-term memory (VSTM) mechanisms that automatically buffer currently (detection-) relevant stimulus settings to optimize search guidance in subsequent task episodes. However, while the existence and functioning of these and other priming mechanisms (such as dimension-based priming; e.g., Found & Müller, 1996; Müller, Heller, & Ziegler, 1995; Töllner, Gramann, Müller, Kiss, & Eimer, 2008) have received a great deal of interest in the meantime (e.g., see Meeter & Olivers, 2006; Olivers & Meeter, 2006, for an attempt to synthesize the various approaches into a unitary account), it remains unclear how positional priming (Maljkovic & Nakayama, 1996) relates to other forms of search guidance—such as bottom-up, saliency-based guidance.

A number of studies have demonstrated target salience to robustly influence feature- and dimension-based priming.
For example, using a task adopted from Maljkovic and Nakayama (1994, 1996), Meeter and Olivers (2006) observed that RT advantages associated with a repetition versus a change in the target color were almost three times as large with 3-item displays (1 target, 2 distractors) as with 12-item displays (1 target, 11 distractors). They concluded that target salience, or in Meeter and Olivers’ (2006) terms: the degree of perceptual “ambiguity” in establishing the presence of the target, is critical for feature-based (color) priming. Similarly, the magnitude of dimension-based priming is dependent on target salience, as demonstrated by Zehetleitner, Müller, Krummenacher, and Geyer (submitted for publication). They varied the feature contrast of a singleton target, which was either orientation- or luminance-defined (variable across trials), relative to the distractors. For example, orientation singletons were tilted either 45° to the left (high contrast) or, respectively, 35° to the right (low contrast) among 45° right-tilted distractors. Zehetleitner et al. (submitted for publication) found the RT advantages associated with repetitions versus changes of the target-defining dimension to be larger in the lowrelative to the high-feature contrast condition. On this background, the present study asked whether positional priming would be similarly influenced by target salience.

This question is important as it may be assumed that memory-based mechanisms (priming effects) influence search guidance via the same representation as bottom-up feature contrast signals, namely: by modulating the activity distribution in an overall-saliency map of the visual field, which guides the allocation of focal attention (e.g., Itti & Koch, 2000; Koch & Ullman, 1985; Wolfe, 1994; see also Kristjansson, Vuilleumier, Schwartz, Macaluso, & Driver, 2007, for fMRI evidence regarding the effects of priming of pop-out on brain areas involved in the guidance of attention). Consistent with this, Maljkovic and Nakayama (2000) consider (positional) priming of pop-out to reflect “the operation of one of the most important visual integrative systems that higher primates are likely to possess, the system for directing focal visual attention and guiding saccadic eye movements” (p. 590). In these terms, memorybased search guidance may be regarded as an “implicit top-down effect” (Wolfe, Butcher, Lee, & Hyle, 2003) on overall-saliency computation, where this top-down influence may be multiplicatively combined with (i.e., scale) the bottom-up signal—that is, the stronger the bottom-up signal, the weaker the scaling effect of the top-down signal. Such a view has recently also been advocated by Geyer, Shi, and Müller (in press) in relation to “contextual cueing”, that is, the guidance of attention in visual search by learnt configurational cues to the target location, which critically depends on a consistent positioning of the target relative to a repeated distractor arrangement.

In the present study, target salience was manipulated by varying the number of distractors in the display. This manipulation was based on Bravo and Nakayama (1992; see also Leonard & Egeth, 2008), who had shown the efficiency of target pop-out in singleton feature search to be dependent on the number of distractors (i.e., effectively, the element density): with the target-defining feature varying unpredictably across trials, RTs were faster when display size was large (4 or more elements, which, given the same underlying size of the display matrix, were more densely spaced on average) rather than small (3 elements, which were more widely spaced on average). Bravo and Nakayama (1992) surmised that improved search performance with larger numbers of distractors and denser element spacing is due to facilitated target pop-out, because feature contrast—or saliency—computations are spatially scaled (see also Krummenacher, Müller, & Heller, 2002; Nothdurft, 1991). Thus, given that target salience can guide search for unknown feature targets in a purely bottom-up manner, the expression of positional-priming effects may also be modulated by this factor. The efficiency of target pop-out is known to reach an asymptotic level where search performance can no longer be improved by further increasing target salience (Gao, Mahadevan, & Vasconcelos, 2008; Nothdurft, 1993). Thus, as target salience approaches optimum level for guiding attention, positional-priming effects would be reduced—because a second guidance signal provided via positional priming would yield (only) a diminishing benefit for the allocation of attention to the target. In summary, according to this salience hypothesis, positional priming should exert a strong influence on the guidance of visual attention when target salience is low (e.g., display size 3), but only a weak, if any, influence when salience is high (e.g., display size ≥4).

Recent research has identified at least one further factor, besides the potential effect of target salience, modulating the strength and temporal extension of positional priming: predictability of item arrangement (Geyer, Müller, & Krummacher, 2007; see also Chun & Jiang, 1998). Using a paradigm similar to Maljkovic and Nakayama’s (1996), Geyer et al. showed that positional priming is influenced by the overall arrangement of the display items (in their study: 1 target and 2 distractors). In more detail, Geyer et al. (2007) compared positional priming (target facilitation, distractor inhibition) between “regular” (equilateral) and “irregular” (random) triangular arrangements. They observed reliable facilitation for target locations (i.e., faster RTs to trial N targets presented at trial N − 1 target locations relative to trial N − 1 blank locations) with both regular and irregular displays; by contrast, inhibition for distractor locations (i.e., slower RTs to trial N targets presented at trial N − 1 distractor locations relative to trial N − 1 blank locations) was observed only with regular (predictable) but not irregular (non-predictable) displays. Geyer et al. (2007) concluded that facilitatory and inhibitory positional-priming effects are dissociable, with the latter being critically dependent on regular, in Gestalt terms: “good” item arrangement. Furthermore, they surmised that inhibitory priming is dependent on the distractor locations on trial N being encoded relative to an anchor point provided by the target location. This relational
encoding of distractor positions (see also Jiang, Olson, & Chun, 2000) is based on the (top-down) application of a “regular” mental spatial frame, which is acquired as a result of extended practice on the task (see Geyer et al., 2007, Experiment 2). Critically, the findings of Geyer et al. (2007) argue against the view that positional priming is simply the result “of a passive association of isolated characteristics of previously attended sites and the response of attentional deployment” (Nakayama, Maljkovic, & Kristjánsson, 2004, p. 403). While this may be true for facilitatory priming, it does not seem to play a major role for inhibitory priming. Note that the hypothesis of distinct memory systems in positional priming mirrors a similar proposal with respect to the priming of pop-out, where target color facilitation is dissociable from distractor color inhibition (e.g., Kristjánsson & Driver, 2008; Lamy, Antebi, Aviani, & Carmel, 2008).

In sum, on the relational-encoding hypothesis, positional priming in pop-out search is attributable to two separate memory mechanisms modulating the deployment of focal attention on the current trial: a passive positional memory of individual target and distractor locations (along the lines of suggested by Nakayama et al., 2004) and, importantly, a relational memory mechanism that is dependent on “good” item arrangement (along the lines suggested by Geyer et al., 2007). While the former type of memory may have a stronger influence on the expression of positional facilitation, the latter type exerts a stronger influence on distractor inhibition.

If the memory for previously selected target and deselected distractor locations influences search guidance via the same representation as bottom-up feature contrast signals (e.g., as is explicitly assumed with regard to another form of memory operating within single experimental trials, namely, “inhibition of return”; see Itti & Koch, 2000; Koch & Ullman, 1985), one would expect that target salience, manipulated in terms of the number and density of display elements, can influence the manifestation of positional priming. However, hitherto, positional priming has been examined only under conditions in which the singleton target was presented among just two distractors (e.g., Geyer et al., 2007; Maljkovic & Nakayama, 1996). Thus, it is an open issue whether a saliency-based account (e.g., deriving from Bravo & Nakayama, 1992) would generalize to positional priming, or whether positional priming is a special case for which some other explanatory principle, such as “relational encoding” (Geyer et al., 2007), would have to be invoked. The present study was designed to decide between these alternatives.

**Experiment 1**

Experiment 1 examined whether positional priming in regularly arranged displays (Geyer et al., 2007) is influenced by set size or inter-item density, and, if so, under which set size conditions facilitatory and inhibitory positional priming effects would emerge.

The search displays (Figure 1) consisted of one unique-color target among two, three, five, or seven distractors. The target was either red with green distractors, or vice versa. All stimuli were “diamond”-shaped, with a corner section missing to either the left or the right. Observers had to select the unique color target and respond to the side of the missing corner section (i.e., the task was a compound-search task; Duncan, 1985). Regarding sequences of target positions, on a given trial N, the target could appear at any one of N − 1 empty locations (“neutral” baseline), at a location previously occupied by a target, or by a distractor. Based on prior studies (e.g., Maljkovic & Nakayama, 1996), relative to the neutral baseline, facilitation of target detection and, consequently, compound-search task RTs was expected for targets appearing at the location of a previous target, and inhibition for targets appearing at the location of a previous distractor. Such a pattern would replicate the results reported by Maljkovic and Nakayama (1996) and others (e.g., Geyer et al., 2007).

The systematic variation of set size was intended to examine whether positional priming is influenced by target salience. If so, the function relating priming to set size would be expected to converge asymptotically toward the neutral-baseline level at some larger set size (with the baseline RT itself decreasing asymptotically), and this would be expected for both facilitatory and inhibitory priming. Systematic departures from this pattern, whether in facilitatory or inhibitory priming, would provide evidence against a general explanatory role of saliency, and therefore point to the need to invoke some other explanatory principle, such as “relational encoding”.

**Methods**

**Participants**

Twenty observers (mean age: 23.9 years; seven males; all reporting normal or corrected-to-normal color vision) took part in Experiment 1. They were paid at a rate of 8 € (12 US$) per session and were naive as to the purpose of the study.

**Apparatus**

The experiment was conducted in a dimly lighted laboratory. Stimulus presentation and RT measurement were controlled by a standard (2.8 GHz Pentium IV) PC, running under DOS. Stimuli were presented on a 19-inch color monitor, at a frame rate of 60 Hz (256 colors; resolution of 640 × 480 pixels). The experimental control software was purpose-written in C++. Observers viewed the monitor from a distance of approximately 60 cm, maintained by a chin rest. They responded by pressing the right and, respectively, left buttons of a serial Microsoft
Stimuli

The stimuli were red and green diamonds, all with a cut-off section to the left or right, with the cut-off side being determined randomly for each stimulus (henceforth, the side of the cut-off section will be referred to as the diamond’s “orientation”). There was always one target among either two, three, five, or seven distractors in the display. The target was unique in color: when the target was red, the distractors were green, and vice versa (i.e., the target and distractor color changed randomly across trials). The colors were near-equiluminant: red, 7.7 cd/m²; green, 8.0 cd/m². The screen background was black (0.5 cd/m²). The size of the diamonds was 1.2° × 1.2° of visual angle, with a cut-off section of 0.3° either to the left or the right side. The search elements were arranged on a near-circular ellipse, with horizontal and vertical axes of 17.5° and 14.0°, respectively. Note that an elliptical frame had also been used by Maljkovic and Nakayama (1996). The center of the ellipse was marked by a white fixation point, 0.5° × 0.5° in size (13.7 cd/m²).

The singleton color target could appear at any one of 24 possible locations around the circumference of the ellipse. The distractors were then positioned such that the distances between adjacent stimuli on the circumference were equal. For example, with 3 search items, the separation between adjacent stimuli was eight locations with seven intervening locations; with four items, the separation was four locations with three intervening locations, and so on (see Figure 1 for illustrations of the four set size conditions of Experiment 1).

Design and procedure

The experiment consisted of 3,000 experimental trials, with 750 trials for each set size condition (3, 4, 6, 8). The location, color, and orientation of the target were varied randomly from trial to trial. The color and location of the target determined the color and locations of the distractors. When the target appeared, say, at the top of the ellipse in the 3-item condition, the stimuli formed an apparent regular (near-equilateral), upward-pointing triangle; in the 4-item condition, the stimuli formed a regular (near-) square or, respectively, diamond arrangement; and analogously for the 6- and 8-distractor conditions. The number of distractors was held constant...
within each trial block, but it was varied randomly across blocks.

At the beginning of each trial, a fixation cross was presented in the center of the monitor. After 1,000 ms, the search array was displayed (with the fixation cross remaining on) until the observer responded to the orientation (i.e., the side of the cut-off section) of the target by pressing the left or the right mouse button, respectively, using the index finger of the corresponding hand. The response was followed by a blank screen for 1,000 ms, after which the next display was presented. Error feedback (an error occurred when the right section of the target was cut off and the observer pressed the left button, and vice versa) was not provided.

The experiment consisted of three sessions (each of about 50 min), with sessions separated by a minimum of 2 h, but not more than 2 days. No more than two sessions were conducted in a single day. Each session consisted of eight blocks with five (unrecorded) warming-up trials and 120 experimental trials, with blocks separated by short breaks. At the beginning of the first session, observers performed one block of 100 practice trials (data not recorded).

Results and discussion

Data were analyzed using R (R Development Core Team, 2007). For each experimental condition (set size x target location), RTs outside the range of ±2.5 standard deviations from the mean were discarded as outliers (overall, 2.1% of trials). Response error trials were also excluded from the RT analysis (4.4% of all trials). Note that when examining for the effects of repetition, the current trial may have been influenced by the preceding trial or it may have influenced the subsequent trial. Therefore, responses on trials that preceded or followed an erroneous response were not analyzed. In other words, repetition effects were analyzed only for two consecutive trials on which the responses were correct.

A repeated-measures ANOVA of the error rates (see Table 1) with the factors set size (3, 4, 6, 8) and target location (at neutral position, at target position, at distractor position) revealed both main effects to be significant: set size \([F(3,54) = 3.52, p < 0.05, \text{MSE} = 18.04]\), target location \([F(2,36) = 5.28, p < 0.01, \text{MSE} = 30.40]\). As confirmed by post-hoc (Tukey HSD) tests, more errors were made with 3- compared to 4-, 6-, and 8-item displays (5.9% vs. 3.6%, 3.7%, and 4.4%, respectively). In addition, error rates were overall smallest when the target appeared at a previous target location (2.8%), intermediate when it appeared at a neutral location (4.6%), and largest when it appeared at a distractor location (5.7%).

RTs to the target on trial \(N\) (see Table 1) were also examined by a set size x target position ANOVA, which revealed all effects to be significant: set size \([F(3,57) = 22.06, p < 0.01, \text{MSE} = 3,110.95]\), target position \([F(2,38) = 23.54, p < 0.01, \text{MSE} = 4,006.26]\), and set size x target position \([F(6,114) = 2.26, p < 0.05, \text{MSE} = 1,376.19]\). The effect of set size occurred because detection of the target within each trial block, but it was varied randomly across blocks. At the beginning of each trial, a fixation cross was presented in the center of the monitor. After 1,000 ms, the search array was displayed (with the fixation cross remaining on) until the observer responded to the orientation (i.e., the side of the cut-off section) of the target by pressing the left or the right mouse button, respectively, using the index finger of the corresponding hand. The response was followed by a blank screen for 1,000 ms, after which the next display was presented. Error feedback (an error occurred when the right section of the target was cut off and the observer pressed the left button, and vice versa) was not provided.

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Singleton target became asymptotically faster with increasing set size: 721, 677, 654, and 646 ms for 3-, 4-, 6-, and 8-item displays. Although post-hoc tests revealed only the differences between 3-item displays and all other set sizes to be significant, the data are best explained by an asymptotic, exponential function \( \ln(\text{RT}) = \ln(\text{neutral RT}) - \lambda \cdot (\text{set size}) \), where \( \lambda \) represents the magnitude of facilitatory and inhibitory positional priming, \( \Delta_f/\text{RT} \) and \( \Delta_i/\text{RT} \). The relative magnitude of facilitatory priming (\( \Delta_f/\text{RT} \)) was essentially stable across set size (0.072, 0.060, 0.046, and 0.061 for 3-, 4-, 6-, and 8-item displays, respectively; main effect of set size: \( F < 1 \)). In contrast, the relative magnitude of inhibitory priming (\( \Delta_i/\text{RT} \)) was significantly larger and reliably (\( p < 0.01 \)) different from zero only for 3-item displays (0.067) as compared to 4-, 6-, and 8-item displays (0.011, 0.012, and 0.005, respectively; all \( p's > 0.10 \); main effect of set size: \( F(3,57) = 17.23, p < 0.01, \text{MSE} = 0.00097 \)).

The set size \( \times \) target location interaction indicates that positional priming exerted its effects by both facilitation and inhibition of target and, respectively, distractor locations, with the latter, however, being reliable only with 3-item displays. This is not to say that positional inhibitory memory was strictly limited to 3-item displays, as there was numerical inhibition in the remaining distractor conditions, in particular with 4-item displays. To gain a better picture of inhibitory priming as a function of set size, we have since replicated Experiment 1 nine times (with 107 participants in total, including Experiment 1). The results are summarized in Figure 3. Almost all replications yielded evidence of significant distractor inhibition with 3-item displays, some with 4-item displays, but hardly any with 6- and 8-item displays. A set size \( \times \) target location ANOVA of the data of all 107 participants revealed reliable inhibitory priming with 3- and 4-item displays (32 and 11 ms), but not with 6- and 8-item displays (7 and 7 ms).

[By contrast, facilitatory priming was reliable across all set size conditions (34, 33, 37, and 42 ms for 3-, 4-, 6-, and 8-item displays, respectively).]

Given the asymptotic decline in mean RTs across set size, the pattern revealed in Experiment 1 for inhibitory positional priming (though not for facilitatory priming) would be consistent with a salience-based account, that is: increasing target saliency may mask the expression of inhibitory priming. However, this pattern would also be in line with the relational-encoding hypothesis. Recall that, in the 3-item condition, the stimuli were always arranged as a regular, near-equilateral triangle configuration. Thus, observers may have come to use this regular stimulus arrangement—and its apparent “rotation” from one trial display to the next—to guide their search. That is, inhibitory priming could be contingent on the 3-item

Figure 2. Positional priming and associated standard errors in Experiment 1. Presentation of the target on trial \( N \) at the target location on trial \( N-1 \) produced RT facilitation independently of the set size (black symbols). In contrast, presentation of the target on trial \( N \) at a distractor location on trial \( N-1 \) produced inhibition (white symbols), but only with 3-item displays.

Most importantly, the set size \( \times \) target location interaction was also significant (see Figure 2). This interaction reflects the fact that, while the facilitatory effect was significant and stable across all set size conditions (51, 47, 55, 46 ms for 3-, 4-, 6-, and 8-item displays, respectively; all \( p < 0.01 \)), the inhibitory effect was reliably different from zero only with 3-item displays (47 ms; \( p < 0.01 \)), but not with larger set sizes (8, 7, and 2 ms; all \( p > 0.10 \)). However, the decline in inhibitory priming with larger display sizes may be due to the (asymptotic) speeding-up of the overall RTs, that is, the magnitude of priming might relate to base RT performance. This was tested by examining, in separate ANOVAs, the magnitude of facilitatory and inhibitory positional priming, \( \Delta_f \) and \( \Delta_i \), relative to the neutral-location base RT, that is:

\[
\Delta_f/\text{RT} = \text{RT}_{\text{target}} - \text{RT}_{\text{neutral}}
\]

\[
\Delta_i/\text{RT} = \text{RT}_{\text{distractor}} - \text{RT}_{\text{neutral}}
\]

The results are summarized in Figure 3. Ten experiments (including the present Experiment 1) showing that while facilitation of target locations is reliable across all set size conditions (3, 4, 6, 8; left panel), inhibition of distractor locations seems to be confined to the special cases of 3- and 4-item displays (right panel). Error bars represent the standard error. Note that there were various differences between the 10 experiments (relating, e.g., to whether target and distractor colors were constant or variable across trials or whether item sequences were predictable or random; cf. Geyer & Müller, 2009); for this reason, the replications are presented as separate experiments.
displays being arranged regularly, with distractor locations being inhibitorily tagged with reference to the target location (i.e., relational-encoding hypothesis—Geyer et al., 2007; Jiang et al., 2000). This strategy would not be readily available with larger displays, as the configurations, though still regular, become more “amorphous” perceptually. Even with a square/diamond-shape arrangement of four display items, the pointing direction of the configuration (which is given by the target location) may be less well defined than with an overlearnt triangle arrangement, making it harder to perceive a cross-trial rotation of the whole configuration. Accordingly, inhibitory priming may not be in operation with displays of more than four items but may be confined to the special cases of 3- and 4-item displays. Experiment 2 was designed to examine this relational-encoding hypothesis more directly.

In contrast, for target facilitation, the results (and conclusions) are more clear-cut. Facilitatory priming remained relatively constant across all set sizes, indicative of a strong spatial-attentional bias to resample the item presented at the previous target location, which is not overcome, or masked, by saliency-driven processes of target individuation (e.g., Bravo & Nakayama, 1992). For example, the response-defining feature of this item may be encoded rapidly and in parallel with the processes that single it out as the target, so that a response can be issued quickly once target individuation has been accomplished. Assuming that this spatial bias (facilitating the encoding of the item at the previous target location) becomes stronger as the number of nearby items competing with the target for attentional representation increases (e.g., Luck, Girelli, McDermott, & Ford, 1997), while parallel saliency computations would also be expedited by increasing display density, this could explain the relative stability of facilitatory positional priming. Thus, stable facilitatory effects require a number of additional, though plausible, assumptions to be accommodated by a saliency-based account of positional priming. The same would appear to apply to the relational-encoding account, which would have to introduce similar assumptions, in addition to a strong bias to resample the previous target (“anchor”) location, to explain the stability of facilitatory priming (see General discussion section for a more detailed development and justification of these ideas).

**Experiment 2**

Experiment 1 revealed robust evidence for inhibitory priming of distractor locations with 3-item displays, which may have been due to the less efficient target pop-out in this condition. Conversely, with larger set sizes, the expression of positional inhibitory priming, while itself remaining in operation, may be masked by rapid target pop-out. This would be the case, for example, if there were a race between fast saliency-based and relatively slow memory-based (“positional priming”) mechanisms of attentional guidance, with the latter taking too long to influence selection. Alternatively, positional priming may not be functional under conditions of rapid target pop-out, that is, positional priming may operate only when enabled by some form of “implicit” top-down set (see Wolfe et al., 2003) dependent on regular triangular stimulus arrangement (Geyer et al., 2007). To decide between these alternatives, Experiment 2 used 3- and 6-item displays, which were presented randomly intermixed with each other. Under these randomized conditions, it was possible to derive predictions as to the priming effects in a given 6-item display.

Geyer et al. (2007) had shown that, with 3-item displays, inhibition of distractor locations (in terms of backward extension) was highly practice-dependent, suggesting that practice improves observers’ ability to utilize regular stimulus arrangement to inhibit distractor locations. A similar finding was obtained for Experiment 1: inhibitory priming (collapsed across trials N – 1 through N – 5) was enhanced with practiced task performance (last 1,000 experimental trials) compared to unpracticed performance (first 1,000 experimental trials), particularly with 3-item displays [12 vs. 32 ms; significant set size × practice interaction: F(3,57) = 11.85, p < 0.01, MSE = 122.59]. These results cannot easily be explained by the notion of target saliency (e.g., Bravo & Nakayama, 1992), as practice is unlikely to change the target’s bottom-up salience. If anything, saliency coding would improve with practice, as a result of which inhibitory priming should be diminished, rather than increased.

In Experiment 2, the difference in inhibitory priming between practiced and unpracticed performances was made use of by introducing two conditions: “memory” and “salience”. In the memory condition, 80% of trials contained 3-item displays (promoting the acquisition of memory-based inhibitory priming based on relational encoding of distractor locations relative to the target location) and 20% contained 6-item displays; conversely, in the salience condition, 80% of trials contained 6-item displays (fostering a salience-based search strategy without relational encoding) and 20% contained 3-item displays. Thus, in both conditions, a 6-item display (on trial N) could be preceded by a 3-item display (on trial N – 1). However, only in the memory condition did observers have a high incentive to utilize the regular 3-item stimulus arrangement to inhibit the two distractor locations, so that the inhibition of these locations may be carried over to the subsequent 6-item display. Thus, according to the relational-encoding hypothesis, distractor inhibition in a 6-item display following a 3-item display should become manifest only in the memory, but not the salience, condition. In contrast, if inhibitory priming is determined by relative target saliency, distractor inhibition (in a 6-item display) should become evident independently of the proportion of
3-item displays. In summary, the target-salience hypothesis predicts an RT disadvantage (i.e., inhibitory priming) for transitions of 3-item displays on trial \(N - 1\) to 6-item displays on trial \(N\) in both the memory and the salience condition, whereas the relational-encoding hypothesis predicts an RT disadvantage only in the memory condition.

**Methods**

The design and procedure in Experiment 2 were the same as in Experiment 1, with the following exceptions.

**Participants**

Ten new and unpracticed observers (6 females; mean age: 24.2 years; all reporting [corrected-to-] normal vision, including color vision) took part in Experiment 2. All 10 observers participated in both the memory and salience conditions, with the order of conditions counterbalanced across observers. They performed the respective condition in two separate sessions, each of about 45 min.

**Design and procedure**

As in Experiment 1, the color, orientation, and position of the singleton target changed randomly across trials. The singleton target could appear either among two (3-item display) or five distractors (6-item display). In the memory condition, the ratio of 3- to 6-item displays was 8:2; in the salience condition, it was 2:8. The search items appeared on a maximum of 24 different locations, with equidistant spacing between the items (i.e., regular search displays). The independent variables were search condition (memory, salience) and target position (target at neutral, at target, at distractor location). The total number of trials in each search condition was 2,000 (1,000 trials in each session). In order to investigate inhibitory priming in 6-item displays (trial \(N\) arising from 3-item displays (trial \(N - 1\)), the search displays were organized as trial pairs: in the majority (60%) of pairs, observers were presented with 3-item displays followed by 3-item displays (memory condition) or 6-item displays followed by 6-item displays (salience condition). In the remaining pairs (40% in each search condition), there were 3-item displays followed by 6-item displays. In 8% of these trial pairs, the target location in the critical 6-item display (trial \(N\)) was identical to a target or distractor location in a previous 3-item display (trial \(N - 1\)). In the remaining 32% of these pairs, the target on trial \(N\) (6-item display) appeared at a location that was empty (“neutral”) on trial \(N - 1\) (3-item display). Because the number of 6-item displays (memory condition) and 3-item displays (salience condition) was set to 400 (20%), there were at least 40 observations in each search condition in which the current target appeared at an \(N - 1\) target or, respectively, distractor location.

Each experimental session consisted of eight blocks, each of five (unrecorded) warming-up trials and 120 experimental trials, with blocks separated by short breaks. At the beginning of the first session, observers performed one block of 125 practice trials (data not recorded).

**Results and discussion**

For the RT analyses, the same RT outlier filtering procedure was used as in Experiment 1, which led to the elimination of 2.4% of all trials. Response error trials (see Table 1) were also excluded from the RT analysis (5.3% of all trials). Error rates (for 6-item following 3-item displays) were examined by a repeated-measures ANOVA with the factors search condition (memory, salience) and target location (target at neutral, target at distractor location). This ANOVA revealed only a significant effect of target location \([F(2,18) = 5.37; p < 0.01; \text{MSE} = 3.59]\): more errors were made when the trial \(N\) target appeared at a trial \(N - 1\) distractor, rather than a target, location (3.6% vs. 1.6%).

RTs were overall faster for 6-item displays compared to 3-item displays (700 vs. 721 ms), consistent with Experiment 1. This was confirmed by a set size \(\times\) search condition ANOVA, which revealed only a significant main effect of set size \([F(1,9) = 6.05; p < 0.05; \text{MSE} = 746.62]\). To examine the effect of inhibitory priming in 6-item displays resulting from immediately preceding 3-item displays, RTs for trial pairs of 3-item (\(N - 1\)) and 6-item displays (\(N\)) were examined in an ANOVA with the factors search condition (memory, salience) and target location (target at neutral location, target at distractor location). This ANOVA revealed the target location main effect \([F(1,9) = 16.89; p < 0.01; \text{MSE} = 158.28]\) and the target location \(\times\) search condition interaction \([F(1,9) = 5.09; p < 0.05; \text{MSE} = 226.03]\) to be significant. RTs were overall slower when the trial \(N\) target (in a 6-item display) was presented at a trial \(N - 1\) (3-item display) distractor, as compared to a neutral, location (735 vs. 719 ms). However, as indicated by the significant interaction, this effect was more pronounced in the memory than in the salience condition (memory: 745 vs. 717 ms [28-ms effect; \(p < 0.01\)]; salience: 726 vs. 720 ms [6-ms effect; \(0.10 > p > 0.05\)]). Thus, inhibitory priming of distractor locations was reliable only in the memory condition. This pattern is consistent with the relational-encoding hypothesis according to which an important factor in the determination of inhibitory priming is observers’ incentive to (top-down) utilize regular triangular stimulus arrangement provided by the majority of trials containing 3-item (regular) displays. In contrast, it is inconsistent with the alternative salience account according to which relative target salience (instead of regular item arrangement) is the critical
determinant of inhibitory effects arising from 3-item displays. Note that additional analyses of cross-trial transitions other than 6-item displays following 3-item displays essentially confirmed the results of Experiment 1: while inhibitory priming was reliable for pairs of 3-item displays (33-ms effect; \( p < 0.01 \); memory condition), it was non-significant for pairs of 6-item displays (10-ms effect, \( p > 0.10 \); salience condition).

Two further results are worth mentioning. A control experiment (10 new observers; 7 females; mean age: 26.0 years; all reporting normal or corrected-to-normal color vision) revealed that, while RTs were slower for targets presented at distractor relative to neutral locations in 3–6 transitions (memory condition), they were not systematically influenced by whether the current target appeared at a previous distractor or a neutral location in 6–3 transitions [salience condition: 676 vs. 665; one-tailed \( t(9) = 0.61, p = 0.27 \); memory condition: 675 vs. 666 ms; one-tailed \( t(9) = 1.29, p = 0.11 \)]; conducting a control experiment was necessary because the number of observations for 6–3 transitions in Experiment 2 was too small to permit statistical analyses. Second, an additional ANOVA of facilitatory priming in Experiment 2, with the factors search condition (memory, salience) and target location (target at neutral location, target at target location), revealed only the effect of target location to be significant [\( F(1,9) = 106.32, p < 0.01, \text{MSE} = 141.95 \)], with faster RTs when the trial \( N \) target (6-item display) was presented at a trial \( N - 1 \) target relative to a neutral location (3-item display): 680 vs. 719 ms (39-ms effect). This effect was not significantly influenced by whether observers were presented, in the majority of trials, with a 3- or 6-item display (memory condition: 673 vs. 718, 45-ms effect; salience condition: 687 vs. 720 ms, 33-ms effect). Thus, it appears that target facilitation (in contrast to distractor inhibition) is relatively independent of observers’ incentive to utilize regular stimulus arrangement.

**Experiment 3**

The finding of inhibitory priming with 6-item following 3-item displays (memory condition of Experiment 2) is interesting because it suggests that inhibitory priming from 3-item displays can carry over to 6-item displays—provided that the majority of trials contain 3-item displays and observers can, thus, utilize regular (“triangle”) stimulus arrangement. This is in line with the relational-encoding hypothesis (Geyer et al., 2007), which assumes that distractor locations are encoded and inhibitorily tagged relative to the “anchor” point provided by the target location.

Experiment 3 was designed to further corroborate the hypothesis that observers are exploiting the regularity of the stimulus arrangement to (learn to) assign inhibitory tags to distractor locations with reference to the target location. The critical manipulation in Experiment 3 was the number of distractors in a given search display (presented in the center of the screen). On the majority of trials (91%), observers were presented with regularly arranged 3-item displays consisting of 1 target and 2 distractors, as in the 3-item conditions of Experiments 1 and 2 (henceforth referred to as “standard” trials). However, on a small proportion of randomly inserted trials (9%), the search displays contained only two stimuli: 1 target and only 1 distractor (2-item display; henceforth referred to as “non-standard” trials). In contrast to Experiments 1 and 2, the color of the target, as well as that of the distractor(s), had to be kept constant in Experiment 3, which is not problematic as prior studies (e.g., Geyer & Müller, 2009) had already shown positional priming effects to be independent of feature priming effects (see also Footnote 4 for evidence pertaining to the present stimuli).

Thus, on trials following such rare 2-item displays, the target could be presented either at a previously visible distractor location or at a previously empty location, that is, the location where a distractor would have been expected on a standard trial. The rationale for this manipulation was as follows: If inhibitory tagging of distractor locations is based on the regular arrangement of the distractor locations relative to the target location (i.e., on the stimulus “configuration”), then, on non-standard trials, an RT disadvantage was expected not only when the target on trial \( N \) appeared at the position of a (real) distractor on trial \( N - 1 \) but also when it appeared at the previously empty position where a distractor would have been presented on the majority of trials. Alternatively, if inhibitory tagging depended solely on the presence of a distractor at a particular location (regardless of its relation to the target location), then, on non-standard trials, an RT disadvantage was expected only when the target on trial \( N \) appeared at the position of a visible (but not that of a merely expected) distractor on trial \( N - 1 \).

**Methods**

The design and procedure in Experiment 3 were generally the same as in Experiment 1, with a number of exceptions specified below.

**Participants**

Ten unpracticed observers (8 females; age range 19–31 years; all with [corrected-to-] normal vision, including color vision) took part in Experiment 3. The experiment consisted of two 50-min sessions, separated by at least 2 h, with a single session consisting of 10 blocks of 88 trials (giving a total of 1,760 trials). At the beginning of the experiment, participants practiced the task on 3 blocks of 88 trials each (data not recorded).
Design and procedure

The standard search displays consisted of one target and two distractors. On a small proportion of non-standard trials (160 out of 1,760 trials), the target and only one distractor were presented (2-item display). In order for observers to find the target and respond to its orientation (even with 2-item displays), the color of the target, as well as that of the distractor(s), was kept constant throughout the whole experiment: the target was either red (with green distractors) or green (with red distractors), counter-balanced across observers.

Within each experimental block (of 88 trials), eight non-standard trials were randomly inserted among the standard trials. Since the target could appear at 24 positions on the circular ellipse, after a non-standard trial, statistically, the target was quite unlikely to appear at a previously visible or empty distractor location (each \( p = 0.04 \)). Thus, in order to increase the number of relevant observations, after a non-standard trial \( (N-i) \), the target on the critical standard trial \( N \) was presented exclusively either at a (on trial \( N-i \)) visible or an empty distractor location, with the critical standard trial being randomly chosen out of the five standard trials following the non-standard trial \( N-i \). The random insertion of the critical standard trial in one out the next five standard trials following a non-standard trial was intended to prevent observers from developing any bias and expecting the \( N \) target (standard trial) at an \( N-1 \) visible or empty distractor location (non-standard trial). Because the number of non-standard trials was set to 160, there were at least 16 observations in the target-at-visible- and target-at-empty-distractor-location conditions for trial \( N-1 \).

Results and discussion

For the RT analyses, the same RT outlier filtering procedure was used as in Experiment 1, which led to the elimination of 2.3% of all trials from further analysis. Response error trials were also excluded from the RT analysis (4.6% of all trials; Table 1). An ANOVA of the error rates on standard trials revealed the effect of the single factor target location to be significant \( [F(2,18) = 5.83, p < 0.05, \text{MSE} = 5.89] \); error rates were largest when the target appeared at a previous distractor location, intermediate when it appeared at a previously neutral location, and smallest when it appeared at a previous target location (6.7% vs. 4.6% vs. 3%). An analogous ANOVA of the error rates on non-standard trials revealed no significant effect. Furthermore, RTs produced on non-standard trials were generally excluded from analysis. However, to examine inhibition arising from standard trials, RT performance was analyzed only if a given standard trial \( N \) was preceded by a standard trial \( N-1 \). In contrast, to examine for inhibition arising from non-standard trials, RT performance was analyzed only if a given standard trial \( N \) was preceded by a non-standard trial \( N-i \). Since, following a non-standard trial, the target on the critical standard trial was presented exclusively at either the visible or the empty distractor location, inhibition arising from non-standard trials was assessed by comparing RTs in both the target-at-visible- and the target-at-empty-distractor-location conditions with the target-at-neutral-location condition on standard trials.

Positional priming effects on a standard trial \( N \) arising from a standard trial \( N-1 \) were examined in an ANOVA with the single factor target position (target at neutral, at target, at distractor location), which revealed the position effect to be significant \( [F(2,18) = 38.49, p < 0.01, \text{MSE} = 210] \). As confirmed by post-hoc tests, RTs were fastest for targets presented at a previous target location, intermediate for targets presented at a previously neutral location, and slowest for targets presented at a previous distractor location (544 vs. 581 vs. 599 ms). Thus, relative to the neutral baseline, there was facilitation of 38 ms when the target appeared at a previous target location and inhibition of 19 ms when the target was presented at a previous distractor location. This result closely resembles the findings of Experiments 1 and 2 (memory condition), where inhibitory (as well as facilitatory) priming was observed with regularly arranged 3-item displays.

A separate ANOVA, with the single factor target position (target at neutral, at visible distractor, at empty distractor location), was carried out to examine inhibitory cross-trial priming arising from non-standard trials. This ANOVA revealed the target position effect to be significant \( [F(2,18) = 4.32, p < 0.05, \text{MSE} = 250] \), with faster RTs in the target-at-neutral-position condition (581 ms) relative to both target-at-distractor-location conditions (598 and 599 ms for the target-at-visible- and, respectively, target-at-empty-distractor-location conditions). The most interesting comparison concerns the inhibitory effects between conditions with a target on trial \( N \) presented at a previously visible relative to a previously empty distractor location (18 vs. 19 ms), which was non-significant. In other words, even empty locations where a distractor was merely expected by the observer showed evidence of inhibition, and importantly, the magnitude of the inhibition for such locations did not differ from that for locations with a visible distractor. Given the absence of confounding variables, this finding strongly argues against inhibition of distractor locations being based on the actual presence of a distractor at a particular location. Rather, it suggests that distractor locations are inhibited based on a spatial reference frame, exploiting the regularity of the placement of the distractor locations relative to the target location.

General discussion

Bravo and Nakayama (1992) demonstrated that, if a singleton feature target (under conditions of variable
Experiment 3 was designed to demonstrate more directly the involvement of a regular spatial frame for the manifestation of inhibitory priming by presenting, on some rare trials, the target in a regular 3-item display (trial $N$) at an empty “distractor” location in a 2-item display (trial $N - 1$). Since 3-item displays were highly frequent, observers would have expected both (standard) distractor locations to be occupied even on trials on which one of the distractors was actually missing (2-item display, which were rather rare). Consequently, assuming that inhibitory priming depends on a regular spatial frame, inhibition (in a 3-item display) was expected to arise even from an empty “distractor” location (in a 2-item display). Experiment 3 revealed this to be the case, with inhibition being equivalent in magnitude whether it arose from an occupied or a merely expected-to-be-occupied distractor location. This finding argues in favor of the spatial-frame hypothesis and is at variance with the notion that inhibition is passively associated with (occupied) distractor locations. Taken together, the results of the three experiments appear to argue against (the expression of) positional priming—in particular, inhibitory priming—being strongly modulated by target salience; rather, they suggest a major contribution of another factor: relational location encoding (Geyer et al., 2007; Jiang et al., 2000).

Multiple mechanisms underlying inhibitory and facilitatory position priming

This is not to say that relational encoding is the only factor determining inhibitory positional priming, but rather that it is the main component underlying inhibitory priming in displays that lend themselves to relational encoding of distractor locations. Some evidence that may be regarded as pointing toward another component comes from Experiment 1 (and Experiment 2), which consistently showed at least numerical (albeit in the individual conditions non-significant) inhibition with 4- and 6-item displays (of 8 and 7 ms, respectively), though hardly any inhibition with 8-item displays (2 ms). These small effects may reflect a component of inhibitory priming that is relatively independent of item layout—such as passive association of inhibition with distractor locations, as suggested by Nakayama et al. (2004)—and may be masked by salient target pop-out (vanishing completely with 8-item displays). This “bottom-up” priming component may also explain why Maljkovic and Nakayama (1996) found gradients of inhibition (facilitation) around previous distractor (target) locations. In any case, saliency-, or ambiguity-, based accounts of inhibitory positional priming can at best explain a fraction of the effect.

A similar argument would appear to apply to facilitatory positional priming. The fact that facilitatory priming remained relatively stable across set sizes ranging from 3 to 8 items does not rule out that the manifestation of facilitation is modulated by target saliency. However,
on a pure salience-based account, the bias to redeploy focal attention to a previous target location would have to be assumed to increase with set size in order to explain the relative stability of facilitatory priming. This is the exact opposite to what would be predicted by accounts that regard the mechanisms underlying priming as a means to resolve target ambiguity (e.g., Meeter & Olivers, 2006; Olivers & Meeter, 2006). However, this counterintuitive assumption may be justified if one assumes the following scenario: On the one hand, increasing the set size—and, thus, the item density—would increase bottom-up target salience, thereby decreasing the influence of the memory-based (facilitatory) guidance signal. On the other hand, increasing item density would also increase the potential for distractor stimuli nearby the target to interfere with the processing of the response-relevant feature (the side of the cut-off section of the target shape)—this is known as the “lateralized attentional interference” (LAI) effect (e.g., Luck et al., 1997). To minimize this interference, the processing weight allocated to the target location must be increased (i.e., attention must be focused more narrowly on the target location). Assuming that this spatial bias (facilitating the encoding of the item at the previous target location) becomes stronger as the number of nearby items competing with the target for focal-attentional representation increases, while parallel salience computations would also be expedited by increasing item density, this could explain the relative stability of facilitatory positional priming. Thus, if the current target is presented at a spatially weighted location, the response-defining feature of this item may be encoded rapidly and in parallel with the processes that single it out as the target, so that a response could be issued quickly once target individuation has been accomplished. Consistent with this set of assumptions, Krummenacher, Müller, Zehetleitner, and Geyer (2009) have recently shown that the spatial processing bias (1) carries over across trials and (2) is dependent on task demands: it is more narrowly focused in compound-search tasks (such as the one used in the present study), in which a response-relevant feature has to be extracted from the target item, than in simple detection tasks, in which it is sufficient to establish the mere presence of a target.

In summary, the present findings suggest that the role of target saliency for facilitatory priming is a rather complicated one, as factors such as lateralized attentional interference have to be taken into account. Furthermore, they suggest that target saliency plays only a minor role for inhibitory priming, which instead appears to largely depend on other factors, in particular: encoding of the distractor locations relative to the target location.

Relational encoding in positional priming

As a result of perceptual learning, the visuo-attentional system becomes highly sensitive to regularities in the arrangement of (small numbers of) search items and their transformation (e.g., rotations, which maintain the regularities) across trials. Whether inhibitory priming will be observed depends largely on observers learning to utilize regular stimulus arrangement, in terms of building up a mental spatial frame centered on the target location, to inhibit the distractor locations. Based on this frame, inhibition of distractor locations (trial \( N - 1 \)) can then be carried over to the next trial \( (N) \), facilitating shifts of focal attention toward a repeated or a new target location. When the target is selected, inhibitory tags are updated if the target location repeats, or reassigned—with reference to the current target location. Thus, in this scheme, the target provides a landmark for the inhibition of distractor locations.

Evidence for such a learning process is provided by the finding of Experiment 1 that inhibitory priming was more robust, in terms of backward extension, with practiced as compared to unpracticed performance (see also Geyer et al., 2007). Furthermore, in Experiment 2, carryover of inhibition from 3-item to 6-item displays was observed only when 3-item displays were frequent, providing an opportunity to develop the corresponding spatial frame. By contrast, facilitatory priming is little influenced by regular stimulus arrangement and practice (see Geyer et al., 2007). Consequently, and in line with the relational-encoding account, inhibition of distractor and facilitation of target locations are likely to reflect different memory mechanisms in terms of the underlying representations: while target locations are encoded largely in terms of the spatiotopic \( x \) and \( y \) stimulus coordinates (see below), distractor locations are encoded relative to the target location, where facilitation and inhibition are linked via being coded in common object-centered coordinates.

The question of the retinotopic versus spatiotopic nature of positional priming effects has recently been examined by Bucher (2009), using the typical 3-item displays that were introduced by Maljkovic and Nakayama (1996). Their study involved three conditions: a “standard” control condition in which participants kept fixating the center of the 3-item configuration; a retinotopic condition in which the 3-item configuration was presented alternately on the left or the right side of the screen center and participants always made an eye movement to the (fixation marker in the) center of the configuration; and a spatiotopic condition in which the 3-item configuration was always presented in the display center, but participants alternately made an eye movement to a fixation marker on the left or the right side of the configuration. Importantly, although positional priming effects were reduced overall in the eye movement (i.e., the retinotopic and spatiotopic) conditions as compared to the control condition (facilitatory priming—70 ms, inhibitory priming—74 ms), they were at least as large in the spatiotopic condition (facilitation—50 ms, inhibition—30 ms) as in the retinotopic condition (facilitation—40 ms, inhibition—20 ms). This would argue, at the least, that the priming
effects are coded in spatiotopic coordinates (see, e.g., Pashkam & Cavanagh, 2009, for a similar conclusion).

In Maljkovic and Nakayama’s (1996) paradigm, inhibition of distractor locations is carried over across trials—arguably because inhibition is object-centered, that is, based on a stable (regular) frame that links separate stimulus locations. Evidence (albeit indirect) for this idea comes also from Maljkovic and Nakayama (1996) themselves. In their Experiment 3, displays contained 1 target and 2 distractors arranged in a horizontal row. There were two conditions: “absolute-same” and “relative-same”. In both conditions, the target could be in the left, middle, or right position (relative position), and the horizontal row formed by the three stimuli could appear in one of four quadrants of the search display (absolute position). In the “absolute-same” condition, the three search items appeared at the same absolute position (e.g., top left quadrant) and the same relative position (e.g., middle position). In contrast, in the “relative-same” condition, only the relative, but not absolute, position of the target was the same across consecutive trials; that is, the target changed its absolute (i.e., spatiotopic) location on each trial. Maljkovic and Nakayama (1996) found that repetitions of target locations led to RT facilitation in both conditions, but that this effect was more marked in the “absolute-same” compared to the “relative-same” condition. The fact that facilitatory priming was larger in the former condition suggests that a large proportion of positional inter-trial priming can be attributed to spatiotopic coordinates (see also Bucher, 2009). However, the finding of RT gains in the “relative-same” condition suggests that at least parts of the facilitation of target locations are coded in object-, or frame-, centered coordinates. Note, though, that Maljkovic and Nakayama (1996) examined only facilitatory priming in this manner. However, given that the assignment of inhibitory tags to distractor locations is referenced to the target location within a common spatial frame, their finding (of an object-, or frame-, centered effect) is likely to generalize to the inhibitory tagging of distractor locations. Indeed, inhibitory tagging may be solely based on frame-centered coordinates—otherwise, it would be hard to explain the finding in the present Experiment 3 that even an “empty” frame location (where there would normally have been a distractor) may be inhibitorily tagged.

The results of a recent study by Wedell, Fitting, and Allen (2007) are consistent with the view of frame-centered encoding of spatial locations. They found that, when observers were required to localize a target dot (presented at the beginning of each trial and followed by a mask and, thus, no longer visible when performing the localization task), the shape of the surrounding task field (e.g., a triangle or a square) systematically biased observers’ localization responses toward these geometrical “frames”. In other words, attending to an object (location) is accompanied by the formation of two different representational frames in which the attended object is encoded—a spatiotopic and a frame-centered representation (e.g., Barrett, Bradshaw, & Rose, 2003; see also Tsal & Lamy, 2000).

Summary

In summary, while salience-based modulations of positional priming in pop-out search are not ruled out, (1) they would appear to be counteracted by some other mechanism (such as increasingly focused spatial processing biases) for facilitatory priming and (2) play at best a minor role for inhibitory priming. The latter appears much more strongly dependent on (the acquisition) of a top-down spatial frame.

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Footnotes

1Although Meeter and Olivers (2006) explicitly state “… that it is not the absolute salience of the target that determines whether intertrial priming occurs, but whether it is unambiguously the most salient element in the display” (p. 206), the idea of ambiguity, at least at the perceptual level, is very difficult to distinguish from a salience-based view of inter-trial priming. In the present context, the ambiguity hypothesis is thus considered as an example of a salience-based account.

2This prediction assumes that the capacity of the memory underlying positional priming is larger than the maximum number of (eight) display items, so that any variations in the strength of positional priming can be attributed to relative target salience. Although visual short-term
memory (vSTM) seems to limited to 4–5 features/objects (Luck & Vogel, 1997; Olson & Jiang, 2002; Phillips, 1974; Pylyshyn & Storm, 1988; Yantis & Johnson, 1990), recent findings concerning spatial vSTM suggest a larger capacity of the memory, ranging between 6 (Jiang & Wang, 2004) and 10 items (Müller, von Mühlener, & Geyer, 2007). In addition, with larger display sizes, the search items (distractors) may be grouped and observers may direct their attention to groups of, rather than to individual, items (Pashler, 1987; see also Takeda, 2007).

3Note that there may be a gradient of facilitation around the target location (see Maljkovic & Nakayama, 1996), so that inhibition may be reduced for displays with more than three items because the target on trial \( N \) might appear at a distractor location that was relatively close to the target location on trial \( N - 1 \). To rule this out, an additional ANOVA examined the inhibitory effect (i.e., the RT difference between the target-at-distractor- and target-at-neutral-location conditions) as a function of distance, in terms of the exact spatial separation of the target and distractors on the circular ellipse, between trial \( N - 1 \) distractor and target locations (5.9°, 7.7°, 11.0°, 13.6°, 14.4°, 15.6°; distance values in degrees of visual angle for the 4-, 6-, and 8-item conditions). This effect was non-significant \( F(5,95) = 0.80, p = 0.54, \text{MSE} = 7.70 \), that is, inhibition showed no systematic variation with distance.

4A control experiment with a separate group of 10 observers (8 females; mean age: 25.2 years) was carried out to examine the impact of constant versus variable target and distractor color assignments on positional priming. In this experiment, the target and distractor colors could switch across trials (as in Experiments 1 and 2). A mixed-design ANOVA with the factors target color (constant [Experiment 3], variable [control experiment]; between-subject variable) and target location (target at neutral, at target, at distractor location; within-subject variable) revealed both main effects to be significant: target color \( F(1,9) = 10.13, p < 0.05, \text{MSE} = 29.487,37 \); RTs were faster when target color was constant rather than variable—574 vs. 715 ms] and target position \( F(2,18) = 16.69, p < 0.01, \text{MSE} = 816.88; \text{RTs were fastest when the N target appeared at a trial N - 1 target, intermediate when it appeared at a trial N - 1 neutral, and slowest when it appeared at a trial N - 1 distractor location—617 vs. 648 vs. 668 ms}. Importantly, the target color \( \times \) target position interaction was non-significant \( F(2,18) = 0.49, p = 0.61, \text{MSE} = 521.38 \), indicating that the magnitude of inhibitory priming was comparable between the two color conditions (color constant: 19 ms; color variable: 22 ms).

5It may be argued that parts of the RT disadvantage for targets presented at previously empty distractor locations is attributable to increased noise (“confusion”) associated with the relatively rare appearance of non-standard search displays (on the preceding trial). This was examined by comparing RTs between non-standard and standard trials, which, however, revealed only a 7-ms slowing of RTs on non-standard relative to standard trials [583 vs. 576; one-tailed \( t(9) = 1.69, 0.10 > p > 0.05 \]).

References


