

Positional priming of pop-out is nested in visuospatial context

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The present study investigated facilitatory and inhibitory positional priming using a variant of Maljkovic and Nakayama's (1996) priming of pop-out task. Here, the singleton target and the distractors could be presented in different visuospatial contexts—but identical screen locations—across trials, permitting positional priming based on individual locations to be disentangled from priming based on interitem configural relations. The results revealed both significant facilitatory priming, i.e., faster reaction times (RTs) to target presented at previous target relative to previously empty locations, and inhibitory priming, i.e., slower RTs to target at previous distractor relative to previously empty locations. However, both effects were contingent on repetitions versus changes of stimulus arrangement: While facilitation of target locations was dependent on the repetition of the exact item configuration (e.g., T-type followed by T-type stimulus arrangement), the inhibitory effect was more “tolerant,” being influenced by repetitions versus changes of the item's visuospatial category (T-type followed by Z-type pattern; cf. Garner & Clement, 1963). The results suggest that facilitatory and inhibitory priming are distinct phenomena (Finke et al., 2009) and that both effects are sensitive to subtle information about the arrangement of the display items (Geyer, Zehetleitner, & Müller, 2010). The results are discussed with respect to the stage(s) of visual pop-out search that are influenced by positional priming.

Introduction

Trial-based memory guided attention

The role of memory in visual search has been of great interest to researchers over the last one to two

decades. Shore and Klein (2000) argued that memory in search is organized around three different time scales, ranging from milliseconds and seconds through minutes up to hours and days. Conceptually, these effects have been attributed to visual short-term memory (vSTM) operating within (e.g., Soto, Hodson, Rotstein, & Humphreys, 2008) and across (Chun & Nakayama, 2000) search trials. The third form, of longer-lasting memory effects, has been attributed to configural learning, such as contextual cueing (e.g., Rosenbaum & Jiang, 2013). The present study is concerned with one of these mechanisms: cross-trial priming of item locations (Maljkovic & Nakayama, 1996). Specifically, we ask whether positional priming in visual pop-out search is influenced by factors related to the visuospatial arrangement of the search items and, if so, whether these factors differ between priming of target and distractor locations.

In visual pop-out search, observers are required to detect a singleton feature target (e.g., the only red vs. green colored target, with color being the selection-relevant attribute) and report another target feature (e.g., target cut-off side left vs. right; cut-off “orientation” would be the response-defining attribute). Inter-trial priming refers to the fact that reaction times (RTs) are faster for repeated relative to nonrepeated item attributes (see, e.g., Fecteau & Munoz, 2003; Found & Müller, 1996; Goolsby & Suzuki, 2001; Kristjánsson & Campana, 2010; Kristjánsson & Driver, 2008; Lamy, Antebi, Aviani, & Carmel, 2008; Maljkovic & Nakayama, 1994, 1996; Müller, Heller, & Ziegler, 1995; Olivers & Meeter, 2006). Such priming effects have been reported for several stimulus attributes, such as features (which includes target and distractor features; e.g., Lamy, Yashar, & Ruderman, 2010), dimensions

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(e.g., Found & Müller, 1996; Töllner, Rangelov, & Müller, 2012), and locations (e.g., Geyer et al., 2010). Additionally, priming can also manifest for the search objects themselves (e.g., Huang, Holcombe, & Pashler, 2004; Yashar & Lamy, 2011). Of particular relevance in the present context is Huang et al.'s (2004) report that priming from the target's selection-relevant feature (size) was contingent on repetitions versus changes of the target's response-relevant feature (orientation). This led to the proposal that priming effects in visual search reflect the operation of an episodic memory mechanism that stores information about selection-relevant, response-relevant, and irrelevant target features (see also Hillstrom, 2000). At the core of this account is the idea that when processing the current display, observers match the target to other recently experienced items, particularly the target on the immediately preceding trial. A full match or full nonmatch can facilitate processing, whereas a partial match can hinder search performance. Object-specific effects are usually considered as evidence for a "late" priming system, which influences processes that occur after the selection of the target by focal attention (see, e.g., Olivers & Meeter, 2006, for a discussion). The alternative view is that priming facilitates the selection of the target by focal attention (e.g., Kristjánsson & Nakayama, 2003; Müller et al., 1995; Töllner, Gramann, Müller, Kiss, & Eimer, 2008). In recent years, a consensus has emerged that priming can aid processes of response selection and target selection, too (Lamy et al., 2010; Töllner, Gramann, Müller, Kiss, & Eimer, 2008; Töllner et al., 2012; Yashar & Lamy, 2011).

Positional priming of pop-out

In Maljkovic and Nakayama's study (1996), the search displays contained three diamond-shaped items (one target, two distractors) presented in a virtual (equilateral) triangle arrangement. The target was a color singleton: It was either red amongst green distractors or green amongst red distractors. All stimuli had a notch on either the right or the left side. Observers' task was to respond to the orientation (side) of the target notch. Maljkovic and Nakayama (1996) analyzed RTs as a function of the target location on the current trial relative to the previous trial(s). There were three basic intertrial transitions (amongst others). The current target (*trial n*) could appear at a previous (*trial n - 1*) target position, at a previous distractor position, or at a previous neutral (i.e., empty) location. It was observed that re-presentation of the target at a previous target location facilitated RTs, whereas the presentation of the target at a previous distractor location slowed RTs—relative to the neutral location, respectively. Maljkovic and Nakayama (1996) referred to the two effects as *target facilitation* and

distractor inhibition, respectively. Further work (Maljkovic & Nakayama, 1996; experiment 3) indicated that target locations are maintained in positional vSTM within an object-centered reference frame, in addition to location-specific representations. The crucial finding was that positional facilitation was still evident even when only the target's "relative" position was repeated across trials. In this experiment, the three search items were presented in a "row" arrangement, with the target appearing at the left, middle, or right position of the row. There were two conditions: "absolute-same" and "relative-same." In the absolute-same condition, the target was positioned at identical locations across trials, in terms of both its exact (i.e., absolute) X-Y screen coordinates and its relative row position. In the relative-same condition, the target's location was the same in the row, but this time the row of items was presented in a different display quadrant compared to the previous trial. Both conditions yielded significant priming, suggesting that positional facilitation minimally requires that the target is presented at the relative-same location within a given visuospatial configuration. Note, though, that target location priming was larger in the absolute-same condition, indicating that at least parts of the priming effects are due to location-specific, that is, retinotopic and/or spatiotopic, representations.

The finding of configuration-centered facilitation was further elaborated by Geyer et al. (2010), who showed that distractor locations, too, are represented in positional vSTM within an object-centered reference frame. The critical manipulation was the number of distractors on a given trial: In the majority of trials (91%), observers were presented with search displays that contained three-item, equilateral-triangle configurations. However, in the remaining 9% of the trials, the search displays contained only two items: one target and one distractor (the color of the target was fixed in this experiment). Thus, on trials following a two-item display, the target could appear either on a previously visible or empty distractor location within the triangle frame, the latter being a location where observers would have expected a distractor in the majority of trials. The result was that of inhibitory priming arising from empty distractor locations (note that the inhibition effect was comparable between conditions of occupied and empty distractor locations). The finding of inhibition arising from empty distractor locations led Geyer et al. (2010; see also Geyer, Gokce, & Müller, 2011) to propose that distractor locations are maintained in positional priming memory within a "triangular" (object) reference frame.

Configural effects in vSTM

Visual priming may be considered as a form of implicit sensory memory that automatically buffers

information for the task at hand. Working memory, that is, vSTM, by contrast, is a system that actively maintains information for a given task. Although there is good evidence that the two forms of memory reflect qualitatively different phenomena, a number of recent studies suggest that priming and vSTM nevertheless share functions and neural resources. This idea is consistent with investigations of the brain structures underlying priming and working memory, showing that biasing signals from both types of memory modulate activity in the same brain areas (i.e., visual cortices V1 and V2; see Soto, Llewelyn, & Silvanto, 2012, as well as Soto, Humphreys, & Rotshtein, 2007). Other studies using behavioral measures have demonstrated that priming effects are modulated by the addition of a secondary working memory task. For example, Geyer et al. (2011) showed that the maintenance of a triangular shape in working memory enhanced positional priming in three-item “triangle” displays. Similarly, Kristjánsson, Saevarsson, and Driver (2013; see also Lee, Mozer, & Vecera, 2009) found featural priming to be attenuated when observers had to maintain featural (i.e., color) information in vSTM.

Another line of evidence for overlapping priming and vSTM mechanisms comes from studies that address the issue of the maintenance of information in vSTM. Their results suggest that vSTM, like positional priming, is supported by configural representations. For example, Jiang, Olson, and Chun (2000; see also Boduroglu & Shah, 2009) presented their observers with a prime and probe display (on the same experimental trial), with a blank interval in-between. In both displays, several green squares were presented at random locations (experiment 2B). Prior to the presentation of the probe display, one of the squares was marked and the task was to indicate whether the location of the marked square had been occupied or empty in the preceding prime display (the dependent variable here was accuracy). There were three different types of probe displays: In the “single-probe” condition, only one item was presented in the probe display. In the “minimal-change” condition, the probe display was by and large the same as the prime display, except that the latter display contained an additional item. Finally, in the “partial-change” condition, only half of the items from the prime were presented in the probe display. Response accuracy was highest in the minimal-change, intermediate in the single-item, and lowest in the partial-change condition. Interestingly, similar findings were obtained when observers had to memorize item colors, that is, when location was completely irrelevant for solving the experimental task (Jiang et al., 2000; experiment 1). Jiang et al. (2000) took their results to mean that individual items are stored in vSTM with regard to their placement within the spatial item configuration (difference between minimal-change

and single-item condition) and that the existence of only a partial match between prime and probe display may even hamper vSTM performance (difference between single-item and partial-change condition). Subsequent work by Gmeindl, Nelson, Wiggin, and Reuter-Lorenz (2011) showed that even when there is a feature singleton in the prime display (e.g., red item amongst black items), observers maintain the position of the singleton element in terms of its relation to the other items.

Present study

The literature reviewed above suggests that item locations are stored in positional priming memory (and vSTM) by means of configural representations. The aim of the present study is to further evaluate the roles of position versus configuration in facilitatory and inhibitory positional priming, by disentangling the effects of repetitions versus changes of individual item locations from those repetitions versus changes of their spatial context relations. To preview the results, we found that target and distractor locations are stored in positional priming memory with regard to their placement in the item configuration, rather than their placement, in terms of exact screen locations, in the visual search display. We conclude that the storage of item information in position priming memory is inherently configural in nature.

Category-based coding in perception and vSTM

Individual display items are perceptually organized into (object-like) groupings (e.g., Wertheimer, 1950) and, conceivably, may subsequently be maintained in object-based reference frames. For the present study, we distinguish between reference frames based on visuospatial “categories” versus frames based on “configurations.” An object category is formed by a set of unique geometrical elements that share features that are perceptually distinct from elements of other categories. An example is the “Z”-category, consisting of the four Z-shaped elements “└┘,” “┘└,” “┌┐,” and “┐┌”; a second set would be the “T”-category, consisting of the four T-shaped elements “└┘,” “┘└,” “┌┐,” and “┐┌.” A configuration, by contrast, refers to a particular element in a given item category (e.g., “└┘” in the Z-category or “┘└” in the T-category). This distinction between categories and configurations was motivated by Garner and Clement (1963), who had their observers classify visuospatial patterns and rate them according to how well the individual patterns formed a spatial category (cf. Garner & Clement’s goodness-of-pattern measure). For this task, Garner and Clement created 90 different patterns on a 3×3

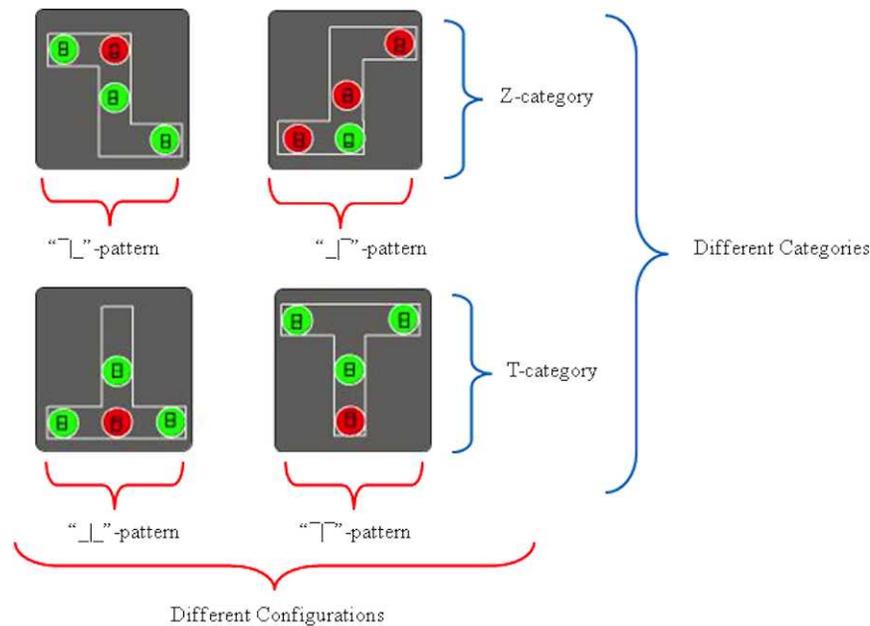


Figure 1. Examples of the four different visuospatial layouts used in the present study.

matrix, with the restriction that each row and column contained at least one dot. Furthermore, they partitioned the individual patterns into 17 equivalence sets—or categories, such as the “Z” or “T” set—based on the principles of the reflection and rotation of individual elements (e.g., in the Z- and T-sets, each item can be transformed into another item by the operations of rotation and reflection). Garner and Clement found a negative correlation between observers’ goodness-of-pattern ratings and the size of the equivalence set (besides a set size of four elements, as in the Z- and T-groups, there were equivalence sets consisting of one and, respectively, eight elements). Moreover, and more importantly, observers’ ratings could almost entirely be predicted by the factor equivalence set (1–17) in a regression analysis, suggesting that observers do indeed form spatial categories by the operations of reflection and rotation. Overall, Garner and Clement (1963) took their findings to mean that observers do perceive dots that form a spatial arrangement not individually, but as part of group, that is, the presentation of a certain dot pattern activates categorically related patterns in perception. More recently, category-based processing has also been shown for vSTM (Lachmann & Geissler, 2002). In Lachmann and Geissler’s experiments, observers had to make same-different judgments to two subsequently presented “Garner” patterns. Of relevance here is the finding that RT performance was influenced by the size of the items equivalence sets—importantly, even if the to-be-judged items were physically identical (e.g., T- followed by T-pattern; RTs increased monotonically across equivalence sets of one, four, and eight items). Based on this finding, Lachmann and Geissler surmised that observers do not directly

compare (“match”) a given dot pattern with another pattern. Instead, they argued, individual patterns are automatically coded in vSTM with regard to group representations and that the comparison involves a memory search through these representations (where detection of the two patterns in the same memory set yields a “same” response and detection of the patterns in two distinct sets yield a “different” response).

In sum, prior research suggests that Gestalt effects influence vSTM as well as visual perception. Furthermore, given the evidence of overlapping vSTM and priming mechanisms (see above), it is well possible that similar principles apply to the (group-based) storage of information in vSTM and positional priming memory.

On this background, in the current study, the search items were arranged as Z- or, respectively, T-configurations, variably across trials (see Figure 1). In Garner and Clement (1963), the Z and T equivalence sets received almost identical goodness-of-pattern ratings (of 1.55 and 1.74, respectively), suggesting that the two pattern categories are comparable in terms of Gestalt properties—and task difficulty (see below). In addition, the configuration of the search items was surrounded by a white Z- or T-shaped outline, reinforcing interelement grouping. These conditions made it possible to assess positional priming of target and, respectively, distractor locations on consecutive trials of repetitions versus changes of configurations and repetitions versus changes of categories. For example, a target presented at location x in a \lrcorner -configuration on *trial* $n - 1$ could be followed by a target presented at the identical location x in the very same \lrcorner -configuration on *trial* n ; we refer to this as the *configuration-repetition condition*. Furthermore, targets presented at identical

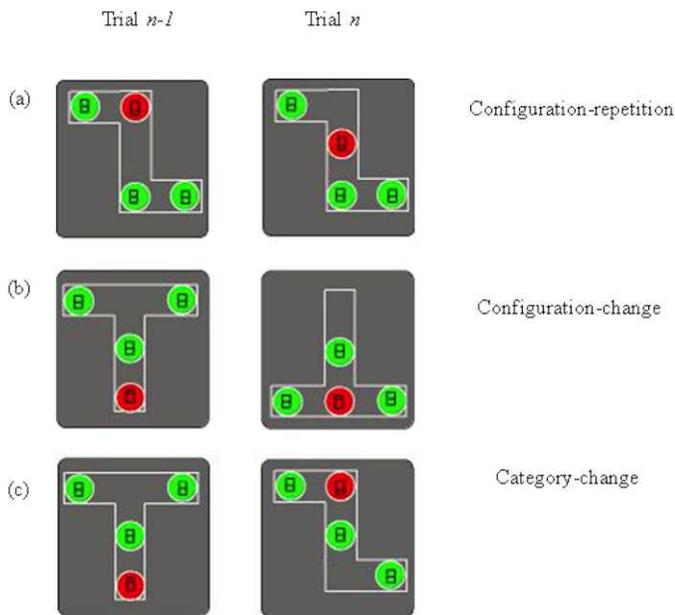


Figure 2. Illustration of the three types of display transition conditions. Panel A depicts the configuration-repetition condition, Panel B the configuration-change condition, and Panel C the category-change condition.

locations could appear in a Γ -configuration on *trial n - 1* and a different, \sqcap -configuration on *trial n*; we refer to this as the *configuration-change condition*. Finally, a target could appear at location x in a \sqcap -configuration on *trial n - 1* and at the identical location x in a Γ -configuration on *trial n*—the *category-change condition* (see Figure 2). Thus, across the three conditions, target and distractor locations could be repeated in terms of their exact screen and retinal coordinates, but be changed in terms of their placement within the overall item arrangement (except for the configuration repetition condition, which served as a baseline condition).

We hypothesized that positional priming effects (target facilitation, distractor inhibition) would be manifest in the configuration-repetition condition, because in this condition both the visuospatial category and the configuration are kept same across trials—as in almost all prior investigations of positional priming. Priming effects in the configuration repetition (baseline) condition could then be compared against those in the configuration-change and category-change conditions. In this regard, note that in each Z- and T-display, one out of five stimulus locations was left empty in order to compare RTs to targets presented at previous target and, respectively, distractor locations with RTs to targets presented at this empty—“neutral”—location. As pointed out in the Introduction, positional priming could result from a (full) match between prior and current item properties, with the match also including visuospatial attributes, in addition to the

target’s selection-defining and/or response-defining attributes. If this were the case, then introducing only partial matches in visuospatial attributes might weaken positional priming. More specifically, if positional priming memory buffers interitem configural information (Geyer et al., 2010), then the effect should be reduced in the configuration-change (and logically the category-change) condition relative to the baseline, configuration repetition condition. By contrast, if positions are stored in positional vSTM in terms of an object-centered reference frame based on more coarse item categories, positional priming should be reduced (only) in the category-change condition. Note that these predictions are neutral with regard to the locus of positional priming effects. Although the finding of partial repetition costs (e.g., Huang et al., 2004) is often considered as evidence for late—that is, episodic—priming effects, it does not necessarily rule out an early locus of position priming. For example, Krummenacher, Müller, Zeheitleitner, and Geyer (2009) have shown dimension priming (modulating processes prior to target selection; see Töllner et al., 2008) to interact with positional priming effects, particularly in “compound” tasks, where the target-defining and response-defining features are separated, as in Maljkovic and Nakayama (1996). The main finding of Krummenacher et al. was that of dimensional priming being most pronounced for *trial n* targets presented in close spatial proximity to the target on *trial n - 1*, relative to *trial n* targets presented further away from the location of the target on *trial n - 1*. This led Krummenacher et al. to conclude that dimension-based and space-based weighting processes influence a common processing stage, most likely the overall-saliency map. Applied to positional priming, it is thus possible that both repetition of target and repetition of distractor locations aid processes operating at the level of the overall saliency map (i.e., target facilitation and, respectively, distractor suppression). However, both types of memory may include visual “Gestalt” attributes as well. A reason for this might be that grouping—or object-centered coding—reduces the load on limited-capacity visual memory. An alternative, though not mutually exclusive, view is that object-centered memory representations come to the fore with small display sizes, that is, when pop-out is weak and prone to fail (e.g., Geyer et al., 2010; see also Becker, 2008, or Rangelov, Müller, & Zehetleitner, 2013, for similar ideas albeit testing feature priming). If positional priming is nested in item arrangements, partial repetition of previous trial characteristics, for instance of only the target or distractor locations, but not the configuration within which these were embedded, may reduce (abolish) spatial weighting at the overall saliency map—and / or delay the comparison between previous

and current stimulus attributes (i.e., episodic matching).

Method

Participants

Fourteen observers participated in the experiment (female: eight, mean age: 26 years, $SD = 3.27$ years). They were recruited from the participant panel of the Department of Psychology (Units of General & Experimental Psychology and Neuro-Cognitive Psychology). All participants had normal or corrected-to-normal visual acuity as well as normal color vision, and all were right-handed. They were naive as to the purpose of the study, and were debriefed about its aims after completing the experiment. All participants gave informed consent prior to commencing the experiment. Anonymity of their recorded and stored response data was guaranteed. Participants were paid at a rate of 8 Euros (10 USD) per hour or received course credits for their participation.

Apparatus and stimuli

The search display consisted of four colored circles, presented on a gray background (22.0 cd/m^2): one target and three distractors (size: $1.59^\circ \times 1.59^\circ$ of visual angle). When the target was red, the distractors were green, and vice versa. The colors of the stimuli were near-equiluminant: red: 33 cd/m^2 ; green: 35 cd/m^2 . The items were arranged in either a Z- or a T-like pattern, with the configuration outlined by a white border (50.0 cd/m^2). Two different Z- and T-type patterns were used: “ \neg ” versus “ \neg ” (Z-patterns) and “ \neg ” versus “ \neg ” (T-patterns). They were presented in the center of the monitor on a matrix of 3×3 locations, $7.04^\circ \times 7.04^\circ$ in size. To reinforce grouping, the four individual items were enclosed in a white outline shape identical to the configuration formed by the items; this outline “touched” the margins of the search items, effectively connecting the individual stimuli. Each search item contained a black figure “8” placeholder (size: $0.33^\circ \times 0.33^\circ$). The placeholder inside the target contained a central horizontal line that was shifted 0.07° from the (virtual) horizontal midline either to the top or the bottom of the placeholder. The positioning of this line was the response-defining target feature. A black cross (size: $1.36^\circ \times 1.36^\circ$; luminance: 0.5 cd/m^2), to be fixated at the start of a trial, was located at the display center.

Stimulus presentation and response measurement were controlled by a standard PC (3.8-GHz AMD processor), equipped with a Microsoft Windows XP

Prof operating system. The experimental control software was purpose-written in C++. Stimuli were presented on a 19-in. CRT screen (AOC; Amsterdam, NL). The screen resolution was set to 1024×768 pixels, the refresh rate to 85 Hz. Observers with odd (even) participant numbers pressed the left (right) mouse button when the middle horizontal line in the target placeholder was at the top, and the right (left) mouse button when the line was at the bottom, in the first experimental session; these mappings were reversed in the second session. The participants’ distance from the screen was 57 cm; a chin rest was used to keep the head position constant during the experiment. The experimental cabin was dimly lighted.

Procedure

The experiment was performed in two consecutive sessions. Each session consisted of 8 blocks of 112 trials, yielding a total of $896 \text{ trials} \times 2 \text{ sessions} = 1,792$ trials. A session lasted approximately 50 min. Each trial started with the presentation of a fixation cross for 500–1500 ms, which was then replaced by the search items (displayed until response). Observers’ task was to detect the singleton color target and respond to the location of the line (top vs. bottom) inside the target placeholder. Participants were encouraged to respond as fast and accurately as possible. In case a participant made an erroneous response, the word “Error!!!” was presented for 1000 ms, in the display center. The target’s color and “orientation” (i.e., position of the line inside the target placeholder) varied randomly across trials. The position of the target was pseudo-randomized: Approximately 85% of targets appeared at one of three locations (28% probability each) on the vertical (“central”) midline of each stimulus pattern (“ \neg ,” “ \neg ,” “ \neg ,” or “ \neg ,” respectively). In the remaining 15% of trials (i.e., on 7.5% each), the target appeared at one of the “peripheral” locations of a given pattern; for example, in a \neg pattern, the two peripheral positions were top-left and bottom-right. As stated above, the four search items were enclosed in a white outline shape, identical to the arrangement formed by the search items. In this shape, there were a total of five stimulus locations for the items to appear. Four locations were occupied by the search items (one target, three distractors), and one was left empty—serving as neutral location. A location was left empty on the vertical midline in 85% of the trials (28% of trials for each of the three vertical midline positions), and in the periphery in 15% of trials (7.5% each for the left and right positions). Pseudo-randomization was implemented in order to increase the number of positional priming trials: only the three locations on the vertical midline of each item

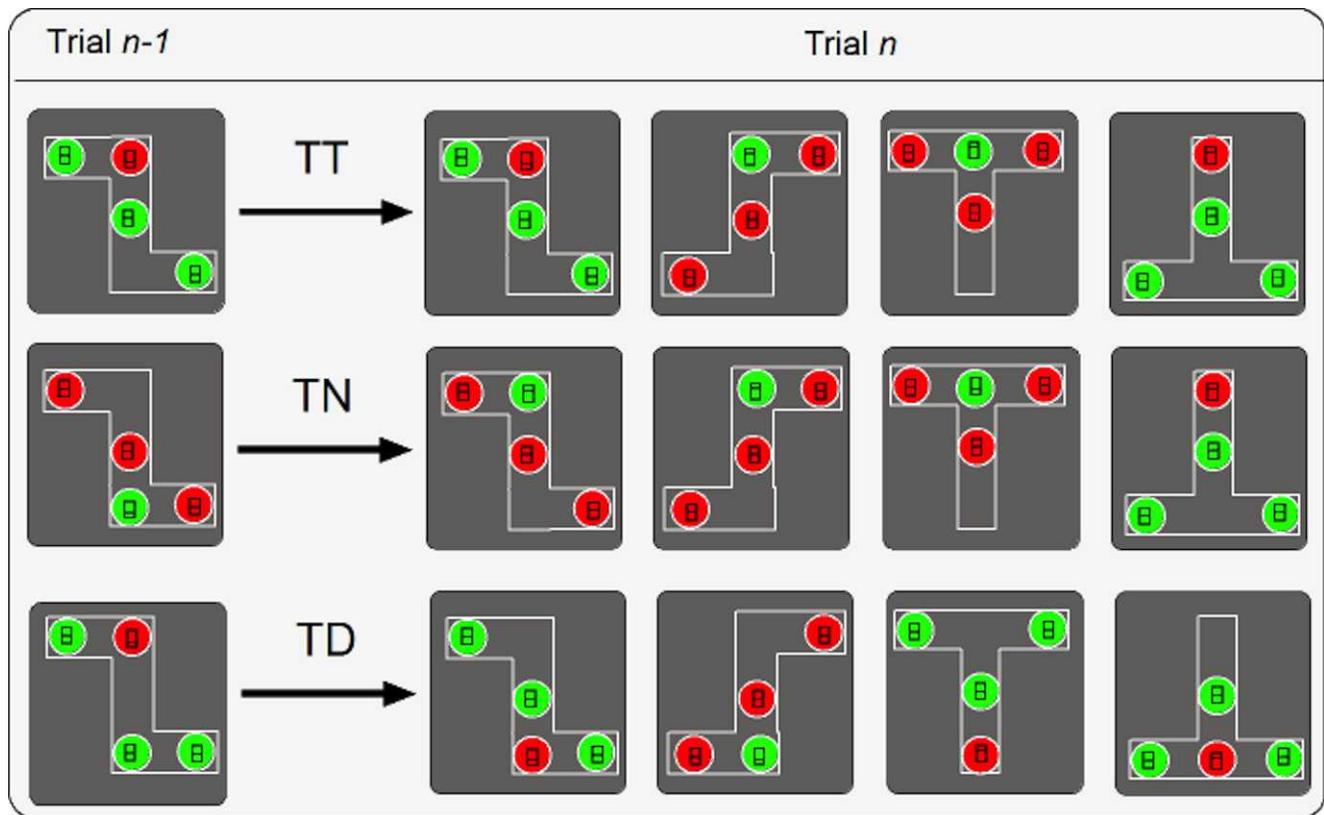


Figure 3. Illustration of the position of the target across two trials ($n - 1 \rightarrow n$). TT: *trial n* target appears at *trial n - 1* target location. TN: target appears at previously empty, i.e., neutral, position. TD: *trial n* target appears at *trial n - 1* distractor location. Across trials, the search stimuli could appear as one out of four possible arrangements (25% probability each): “ $_ _ _$ ”-configuration, “ $_ _ _$ ”-configuration, “ $_ _ _$ ”-configuration, and “ $_ _ _$ ”-configuration.

patterns (“ $_ _ _$,” “ $_ _ _$,” “ $_ _ _$,” and “ $_ _ _$ ”) were identical across patterns and could be used for the analysis of positional priming effects.

Design and analyses

On a given trial, observers were presented with one of four different stimulus patterns: “ $_ _ _$,” “ $_ _ _$,” “ $_ _ _$,” or “ $_ _ _$ ” (each on 25% of trials). These four displays were presented on the same underlying (virtual) 3×3 dot matrix. Thus, on this matrix, repetitions versus changes of absolute stimulus locations could be decoupled from repetitions versus changes of the overall object “Gestalt” within which the items were embedded. For example, the target on *trial n - 1* could appear at location x in a $_ _ _$ -pattern, and this location could be repeated on the subsequent *trial n*, however now in a $_ _ _$ -pattern (see Figure 2). The intertrial repetition effects were analyzed in terms of three conditions: (a) configuration-repetition trial (e.g., $_ _ _$ -followed by $_ _ _$ -display; approx. 25% of trials); (b) configuration-change trial (e.g., $_ _ _$ -followed by $_ _ _$ -display; $\sim 25\%$ of trials); and (c), category-change trial

(e.g., $_ _ _$ -followed by $_ _ _$ -display; $\sim 50\%$ of trials). In each of the three transition conditions, the target on *trial n* could appear at one of three different locations relative to *trial n - 1* (33% of trials each): *trial n* target at *trial n - 1* target location; *trial n* target at *trial n - 1* neutral (empty) location; and *trial n* target at *trial n - 1* distractor location (see Figure 3). The design was a within-subject design with two factors: “display transition” (configuration repetition, configuration change, category change) and “target location” (target at target, at neutral, at distractor location).

Results

Data from one participant were excluded from the analysis, because the RTs were more than 2.5 *SDs* above the group mean. Data analysis was performed using “R” (R Development Core Team, 2007), in addition to SPSS (Version 21). The first twenty trials in the first block of each session were excluded from analysis as practice trials. In addition, the first three trials in each block were excluded as warming-up trials.

| | TT | TN | TD |
|--------------------------|----------|----------|----------|
| Configuration-repetition | 718 (3%) | 745 (2%) | 762 (3%) |
| Configuration-change | 746 (3%) | 745 (2%) | 761 (3%) |
| Category-change | 740 (2%) | 743 (3%) | 747 (4%) |

Table 1. Mean RTs and response accuracy (in brackets) for *trial n* targets presented at *trial n – 1* target (TT), neutral (TN), or distractor (TD) locations, separately for the configuration-repetition, configuration-change, and category-change conditions.

Moreover, RTs to targets presented at peripheral positions in each item pattern were not entered into analysis (overall 14.2% of trials). The reason for this was that only the three vertical midline positions were identical across the four configurations, permitting the assessment of positional priming independently of repetitions versus changes of the overall configuration. In addition, trials on which the target was located at the position of the central fixation cross were also not included in the analysis (28.6% of trials), to prevent a “starting effect” and thus RT confounds in the selection of this item. Furthermore, error trials and trials following error trials (2.8%) were excluded, in addition to discarding trials with (outlier) RT values deviating by more than ± 2.5 SDs from the individual’s mean (2.5%).

Separate 3 (display transition) \times 3 (target location) repeated-measures ANOVAs were performed for response accuracy and RT performance (see also Table 1). For response accuracy, the ANOVA revealed no effects (all F s < 2). For RTs, the ANOVA revealed the main effects of target position, $F(2, 24) = 12.81$, $\eta^2 = 0.51$, $p < 0.01$, and display transition, $F(2, 24) = 5.36$, $\eta^2 = 0.30$, $p < 0.05$, to be significant. Furthermore, the interaction was significant, $F(4, 48) = 4.26$, $\eta^2 = 0.26$, $p < 0.01$ (see Figure 4). Tukey’s Post-hoc (LSD) tests were conducted to further explore these effects. The main effect of target position occurred because RTs were fastest for targets presented at previous target locations, intermediate for targets presented at previous neutral locations, and slowest for targets at previous distractor locations (734, 744, and 757 ms, respectively; 734 vs. 744 ms: $p < 0.05$; 744 vs. 757 ms: $p < 0.05$). The main effect of display transition occurred because RTs were faster in the configuration-repetition and category-change conditions relative to the configuration-change condition (742, 743, and 751 ms, respectively; 742 vs. 751 ms: $p < 0.05$; 743 vs. 751 ms: $p < 0.05$). As can be seen from Figure 4 (and Table 1), this effect is driven by the significant interaction: Separate analyses of position repetition effects in the three display conditions revealed that targets were detected faster in the target-at-target and slower in the target-at-distractor-location relative to the target-at-neutral-location condition in the configuration-repetition condition (718

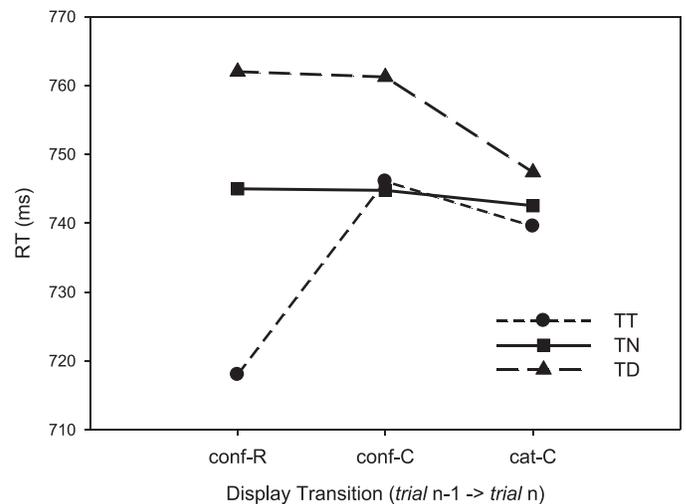


Figure 4. Mean RTs (ms) to targets presented at previous target (TT), neutral (TN), and distractor (TD) locations as a function of the repetition versus change of the visuospatial arrangement of the items across two consecutive trials: configuration-repetition condition (conf-R), configuration-change condition (conf-C), and category-change condition (cat-C).

vs. 745 ms: $p < 0.01$; 745 vs. 762 ms: $p < 0.01$). However, RTs to target-at-target- and RTs to target-at-neutral-location conditions were statistically indistinguishable in the configuration-change condition (746 vs. 745 ms; $p = 0.86$), whereas RTs to targets at previous distractor locations were still slower than RTs to targets at neutral locations in this condition (761 vs. 745 ms; $p < 0.05$). Finally, no facilitation of target and inhibition of distractor locations were found in the category-change condition (target-at-target- vs. target-at-neutral-location RTs: 739 vs. 743 ms, $p = 0.68$; target-at-neutral- vs. target-at-distractor-location RTs: 743 vs. 747 ms, $p = 0.50$). Taken together, the significant interaction marks the facts that (a) target facilitation and distractor inhibition were reliable in the configuration-repetition condition (27- and 17-ms effects, respectively); (b) distractor inhibition, but not target facilitation, was reliable in the configuration-change condition (16- and –1-ms effects); and (c) neither target facilitation nor distractor inhibition was reliable in the category-change condition (3- and 5-ms effects). Given that RTs to targets at neutral locations were almost comparable across the display transition conditions (745, 745, and 743 ms in the configuration-repetition, configuration-change, and category-change conditions, respectively), the display transition main effect is likely due to variations of RTs in the target-at-target- and target-at-distractor-location conditions, that is the pattern of RT facilitation (present only in the configuration-repetition condition) and RT inhibition (present in the configuration-repetition and configura-

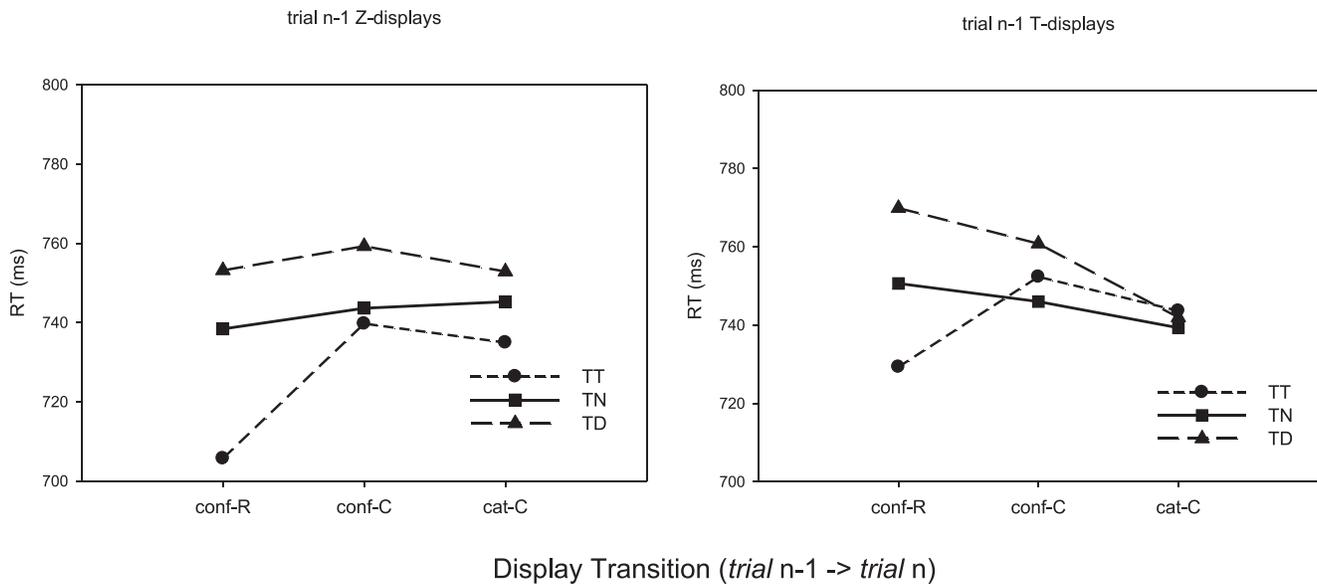


Figure 5. Mean RTs (in ms) to *trial n* targets presented at *trial n – 1* target (TT), empty (TN), or distractor (TD) locations in the configuration-repetition (conf-R), configuration-change (conf-C), and category-change (cat-C) conditions. The data are shown separately for *trial n – 1* Z-shaped displays (left panel) and T-shaped displays (right panel).

tion-change conditions) explains the display transition main effect.

Next, we analyzed RT performance separately for *trial n – 1* Z- and T-displays. Following Garner and Clement (1963), we expected the two types of display to form independent visuospatial categories. Given this, the effects of repeated versus changed layouts should be comparable for the two types of prime displays. The results suggest that Z- and T-displays were indeed processed as independent categories. RT analysis for *trial n – 1* Z-displays revealed a significant target location \times display transition interaction, $F(4, 48) = 2.75$, $\eta^2 = 0.18$, $p < 0.05$. As illustrated in Figure 5, and confirmed by LSD tests, both target facilitation and distractor inhibition were reliable ($ps < 0.05$) in the configuration-repetition condition (706, 738, and 753 ms in the target-at-target-, at target-at-neutral-, and target-at-distractor-location conditions, respectively). However, only the inhibitory ($p < 0.05$), but not facilitatory effect ($p = 0.62$) was significant in the configuration-change condition (740, 744, and 759 ms, respectively). And neither facilitation ($p = 0.20$) nor inhibition ($p = 0.34$) was significant in the category-change condition (735, 745, and 753 ms, respectively). A similar result pattern was obtained for *trial n – 1* T-displays (two-way interaction target position \times display transition: $F(4, 48) = 2.58$, $\eta^2 = 0.17$, $p < 0.05$: target and distractor location priming was significant in the configuration-repetition condition (729, 751, and 770 ms in the target-at-target-, at target-at-neutral-, and target-at-distractor-location conditions, respectively; 729 vs. 751 ms: $p < 0.05$; 751 vs. 770 ms: $p < 0.05$). Further, the inhibitory ($p < .05$), but not the

facilitatory ($p = 0.54$), effect was significant in the configuration change condition (752, 746, and 761 ms, respectively). And no effect was significant in the category-change condition (743, 739, and 742 ms in the target-at-target-, at target-at-neutral-, and target-at-distractor-location conditions, respectively; 743 vs. 739 ms: $p = 0.67$; 739 vs. 742 ms: $p = 0.80$).

In another analysis, we compared RTs to each of the four display configurations, “ \neg ” “ \neg ” “ \neg ” and “ \neg ” to rule out any confounds in the above two-way interactions due to variations in mean response speed for the four configurations. And indeed, the results of this analysis confirmed mean response speed to be comparable across the four configurations: 741, 740, 749, and 746 ms, respectively, $F(3, 36) = 1.39$, $\eta^2 = 0.10$, $p = 0.25$.

Furthermore, we examined the effects of repetition versus change of other target attributes, too (besides repetition vs. change of the position). That is, we re-analysed the data as a function of target position (target-at-target, at-neutral, at-distractor location), target color (same, different on *trial n* relative to *trial n – 1*), and target orientation (same, different on *trial n* relative to *trial n – 1*). According to prior research, the repetition of other target attributes, too (besides position), can facilitate RT performance (e.g., Kristjánsson & Campana, 2010). However, our main interest in this analysis was confined to possible interactions, specifically those involving target orientation (the response-defining feature), which, at least in behavioral studies, have been interpreted as evidence for “late” priming effects influencing processes after the selection of the target by focal attention (e.g., Hill-

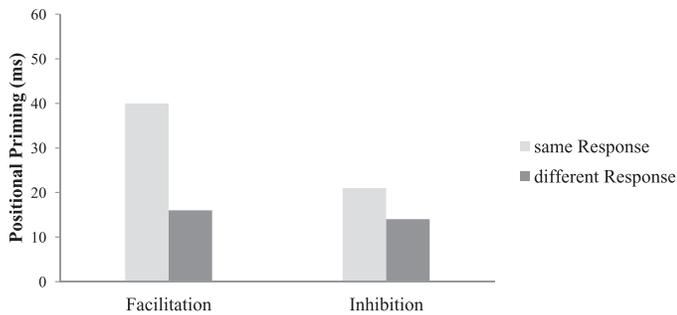


Figure 6. Target location facilitation (RT target-at-previously-empty location minus RT target-at-previously-target location) and distractor location priming (RT target-at-distractor minus RT target-at-empty-location condition), separately for same versus different response trials (light gray vs. dark gray bars, respectively) in the configuration-repetition condition.

strom, 2000; Huang et al., 2004; Yashar & Lamy, 2011)—the idea being that repetitions versus changes of the target’s response features can influence the processing of other target features (position, color) only after the target is selected by focal attention.

The 3 (target position) \times 2 (target color) \times 2 (target orientation) repeated-measures ANOVA revealed all main effects to be significant: target position ($F(2, 24) = 26.49$, $\eta^2 = 0.68$, $p < 0.01$; RTs were faster for targets at target and slower for targets at distractor locations, relative to targets at neutral locations, respectively; see above), target color ($F(1, 12) = 14.96$, $\eta^2 = 0.56$, $p < 0.01$; RTs were faster for same- relative to different-colored targets, 724 vs. 757 ms), and target orientation ($F(1, 12) = 39.01$, $\eta^2 = 0.34$, $p < 0.01$; RTs were faster for same- relative to different-orientation targets, 730 vs. 751 ms). Furthermore, and of the greatest interest here is that the target position \times target orientation interaction was significant, $F(2, 24) = 3.47$, $\eta^2 = 0.22$, $p < 0.05$. Post-hoc LSD tests showed that target facilitation was dependent on repetition versus change of the targets’ response-defining feature: The effects was larger for same- relative to different-oriented targets (40 vs. 16 ms; $p < 0.05$). In contrast, inhibitory priming for targets presented at previous distractor locations was comparable between same- and different-oriented targets (21 vs. 14 ms; $p = 0.58$). See also Figure 6, which shows target position facilitation and distractor position inhibition separately for same- versus different-response trials.

It is worth noting that the target position \times target color interaction was far from significance ($F < 1$). Further, comparing target and distractor location priming separately for repetitions versus changes of item color failed to reveal any differences: Target position priming was comparable between same- and different-color trials (28 vs. 29 ms; LSD post-hoc test: $p = 0.97$); likewise, distractor location priming was uninfluenced by the repetitions versus changes of the

target color: 18 versus 18 ms ($p = 0.99$). These results argue in favor of positional priming and color priming being independent memory phenomena—in line with prior fMRI, neuropsychological, TMS, and behavioral studies (fMRI: e.g., Kristjánsson, Vuilleumier, Schwartz, Macasulo, and Driver, 2007; neuropsychological: e.g., Kristjánsson, Vuilleumier, Malhotra, Husain, & Driver, 2005; TMS: e.g., Campana, Cowey, Casco, Oudsen, & Walsh, 2007; and behavioral: e.g., Geyer & Müller, 2009).

Note that the above analyses were limited to the configuration-repetition condition, in which position priming effects were most marked. However, we found an almost identical result pattern when taking into account RTs across all three display configuration conditions. Of most relevance here is the finding of a significant target position \times target orientation interaction, $F(2, 24) = 3.61$, $\eta^2 = 0.23$, $p < 0.05$, coupled with a nonsignificant target position \times target color interaction, $F(2, 24) = 0.78$, $\eta^2 = 0.06$, $p = 0.46$. The implication is that positional priming effects in the current study, while being independent of the target color manipulation, are significantly influenced by repetitions versus changes of the items’ configuration across trials.

However, caution is indicated in interpreting the effects of the configural manipulation. Specifically, it is possible that RTs in the three configuration conditions were affected, at least in part, by factors inherent in the way the search displays were constructed. Recall that the individual search items were grouped into a single configuration (“ $_$ ”-, “ $_$ ”-, “ $_$ ”-, or “ $_$ ”) by coloring the edge of each of the search stimuli and surrounding shapes white. In doing so, a given (subjectively grouped) configuration could either be repeated or changed, as it was the case for the outer white shape. Given this, it is possible that the pattern of position priming effects obtained reflects manipulations of the outer white frames, rather than repetitions versus changes of the item configuration. To rule this out, we conducted a control experiment with nine additional observers (female = 7, mean of age = 27, $SD = 6.55$ years). This control experiment was almost identical to the “main” experiment, except that we removed the outer white frames from the stimulus displays. Thus, each search display consisted of four individual search items, arranged to form a “ $_$ ”-, “ $_$ ”-, “ $_$ ”-, or “ $_$ ”-configuration (again, one location was left empty, permitting the estimation of baseline RTs). If the above result—of a decline of position priming from the configuration-repetition through the configuration-change to the category-change condition—is owing to repetitions versus changes of the outer white frames, one would expect position priming to be relatively uninfluenced by the display transition manipulation in the control experiment. However, at variance with this view, positional priming exhibited a strong dependency

on repetitions versus changes of the overall (virtual) configuration. A 3 (target location) \times 3 (display transition) ANOVA revealed a significant main effect of the factor target position, $F(2, 16) = 12.04$, $\eta^2 = 0.60$, $p < 0.05$, in addition to a significant interaction, $F(4, 32) = 3.76$, $\eta^2 = 0.32$, $p < 0.01$. The interaction was due to the facts that (a) both facilitatory target and inhibitory distractor priming were reliable in the configuration-repetition condition (43- and 24-ms effects, respectively); (b) only distractor inhibition, but not target facilitation, was reliable in the configuration-change condition (2- and 16-ms effects); and (c) neither target facilitation nor distractor inhibition was reliable in the category-change condition (4- and 6-ms effects). These results fully replicate those obtained in the main experiment.

In sum, target location repetition effects exhibited partial repetition costs in that they were modulated by repetitions versus changes of the targets' orientation response feature. However, distractor inhibition was uninfluenced by the repetition versus change of the target's response-defining feature. Furthermore, position priming was not affected by repetitions versus changes of the target's color-defining feature or factors inherent in the design (visual grouping) of the search displays. Taken together with the above dissociation of the effects of repetitions versus changes of configural attributes (target facilitation) and categorical attributes (distractor inhibition), this suggests that target and distractor location priming are independent phenomena that modulate distinct processes in visual pop-out search (considered further below).

Discussion

The present study investigated whether positional priming (Maljkovic & Nakayama, 1996), specifically target location facilitation and distractor location inhibition, is influenced by changes of the visuospatial layout and, if so, whether visuospatial attributes differ between facilitatory target and inhibitory distractor priming. In the current experiment, target position repetitions and changes occurred in three different cross-trial transition conditions with respect to the overall pattern layout. (a) Configuration-repetition condition: This condition served as a baseline (providing maximum priming effects). (b) Configuration-change condition: In this novel condition, the specific visuospatial pattern formed by the search items changed across trials, with the search items still presented in the same general Z- or, respectively, T-pattern (category) as on the preceding trial. (c) Category-change condition: In this condition, a Z-type display was followed by T-type display; for example,

that is, the visuospatial categories (and configurations) changed across trials. The latter two manipulations were based on the idea that positions are not encoded in priming memory in isolation (e.g., Maljkovic & Nakayama, 1996, p. 988), but rather with regard to their placement within the overall item arrangement (e.g., Geyer et al., 2010; Jiang et al., 2000; Tower-Richardi, Leber, & Golomb, 2012). By introducing the configuration-change and category-change conditions, it was possible to disentangle configuration- and category-based contributions to positional priming.

Processing stages of positional priming

Facilitatory and inhibitory priming effects were found to be evident and substantial in the configuration-repetition (baseline) condition, but diminished in the configuration-change and category-change conditions (though the inhibitory effect was reliable in the configuration-change condition, too). This finding supports the hypothesis that the items arranged in certain visuospatial layouts are not perceived—and subsequently buffered in positional priming memory—as individual items, but rather as elements of an encompassing configuration. This is a noteworthy finding, given that target and distractor locations were repeated in exact screen—and eye—coordinates in all three display transition conditions. Thus, one central conclusion from the present results is that positional priming is supported by configural representations, further strengthening the view that the memory underlying (positional) priming and (configuration-centered) vSTM share functions (e.g., Kristjánsson et al., 2013).

As pointed out in the Introduction, several explanations have been proposed to account for intertrial priming. These accounts can be classified broadly as “pre-attentive” versus “postselective” (see, e.g., Rangélov, Müller, & Zeheitleitner, 2011), attributing priming effects in visual pop-out search to the speeding-up of processes that occur prior to or, respectively, after selection of the target by focal attention. Regarding the latter accounts, it has been suggested that priming can act on various (postselective) processes, including (a) target verification (which assumes that the current target is matched against prior, stored instances of the target in a checking—or verification—process; e.g., Huang et al., 2004); (b) response selection (e.g., Töllner et al., 2008; Yashar & Lamy, 2011); and/or (c) response preparation (or production; Töllner et al., 2008; Töllner et al., 2012). Although the present investigation cannot ultimately decide among these three processes, the evidence obtained suggests that target verification (Huang et al., 2004) is one likely cause of positional repetition effects

in visual pop-out search. On this account, a checking mechanism comes into play following the selection of the target (or even during the search process; Hillstrom, 2000), which matches the currently encoded stimulus to the (episodic) memory representation(s) established on the previous trial(s)—where the memory for the immediately preceding trial is assumed to have a higher likelihood to be retrieved and dominate the checking process compared to trials further back in time (Hillstrom, 2000; Thomson & Milliken, 2011). The function of this checking mechanism is to verify whether the selected item is indeed the target (Huang et al., 2004), a process that may come to the fore particularly with sparse displays (as target pop-out is usually weak in these displays; see Rangelov, Müller, & Zeheitleitner, 2013) and/or when visual pop-out search is relatively slow (e.g., Ásgeirsson & Kristjánsson, 2011). Another assumption of this account is that matching is not limited to the target’s selection-relevant feature(s), but involves also other target information, such as its response-relevant feature(s) or even irrelevant features, such as the target’s position in the present study. The verification account assumes that the RT benefits on the current trial result from either a full (consistent) match or a full nonmatch of target attributes relative to the preceding trial(s), including attention-relevant, response-relevant, and irrelevant target features—the idea being that when all to-be-checked target attributes are either the same as or different from the preceding trial, a decision regarding the status of the selected item as being the target is relatively fast. In contrast, RT disadvantages arise when only some, but not all, target features match (or nonmatch)—in which case, additional time is required for target verification.

Other, more complex accounts of the present results are also feasible. Of particular interest in this context is Töllner et al.’s (2008) study of priming in pop-out search, which revealed perceptual priming—in their case, priming of the target-defining dimension—to interact with repetition (vs. change) of the response-relevant target attribute and thus the response (note that Töllner et al. also used a compound search task, like the present study). In contrast to the *episodic-matching account* of priming (an exclusively postselective account), they put forward the idea that priming can occur at both early (pre-attentive) and late (postselective) stages, with late priming being subject to observers’ implicit assumptions about the coupling of the target’s search-critical and response-critical attributes. They showed this by analyzing the timing of two components of the event-related potential (ERP) that together permit postselective processes of target analysis and response selection to be separated from pre-attentive processes leading up to target selection, namely: the stimulus-locked Lateralized Readiness

Potential (sLRP, which encompasses all processes prior to response production; see Hackley & Valle-Inclán, 2003) and the posterior contralateral negativity (PCN—also referred to as N2pc—which is thought to reflect the pre-attentive coding processes leading up to focal-attentional selection; see Töllner et al., 2012). Töllner et al. (2008) found that (a) the time attributable to pre-attentive processing was shorter for a repetition versus a change of the search-critical attribute, independently of whether the response-critical attribute was repeated or changed; (b) however, the time attributable to postselective stimulus analysis and response selection was shorter if the search-critical and the response-critical target attribute either both repeated or both changed, but longer if one attribute repeated and the other one changed. Töllner et al. (2008) explained this by assuming that, although repetition/change of the search-critical attribute was completely uncorrelated with repetition/change of the response-critical attribute, the first attribute checked, whether the search-critical attribute repeats or changes, sets up an implicit, “linked expectancy” (cf. Kingstone & Klein, 1991) as to a repetition versus a change of the second attribute checked, the response-critical attribute. If this expectancy is violated (e.g., when the search-critical attributes repeats but the response-critical attribute changes), the total priming effect (pre-attentive effect plus postselective effect) is reduced. In other words, although (dimension) priming influences early processing stages equally, as indicated by the PCN wave, priming effects arising at postselective processing stages are modulated by observers’ implicit assumptions about the coupling of the target’s search- and response-relevant attributes, as indexed by the combined analysis of the PCN and sLRP waves.

Applied to the current study, it is possible that positional RT priming effects have both an early locus and a postselective component, but the total RT gains owing to the repetition of the target’s position may be diminished if implicit expectancies about the coupling of perceptual and response attributes are violated. However, based on RT data alone, one can only indirectly infer the processing stages of priming, whereas more direct, ERP measures can help to differentiate early and late components of positional priming. Indeed, in a very recent study that examined ERPs in addition to manual RTs, Gokce, Geyer et al. (2013) found that target position priming only influenced the dynamics of postselective ERPs, such as the Contralateral Delay Activity (CDA), relating to focal-attentional analysis of the (already selected) target (cf. Mazza, Turatto, & Umiltá, 2007; Töllner, Conci, Rusch, & Müller, 2013). Distractor position priming, by contrast, only influenced the dynamics of pre-attentive ERPs, in particular the PCN, relating to the processes leading up to the selection of the target (cf.

Töllner et al., 2008; Töllner et al., 2012). Note that both pre-attentive and postselective ERP effects were assessed relative to the neutral location (baseline) condition.

This double dissociation would have direct implication for the present results. A second central conclusion is that positional priming influences target verification and that this process involves configural attributes as well. However, given that only facilitatory priming of target locations was found to be dependent on repetitions versus changes of the previous target's response feature (see Figure 6, and consistent with the CDA effect in the target-at-target-location condition observed by Gokce, Geyer et al., 2013), we further suggest that the verification process is limited to target features, with this process being faster when the target is repeated—that is, matches an episodic memory trace—relative to when it is changed. In contrast, inhibitory priming was largely unaffected by the repetitions versus changes of the previous target's response feature (see Figure 6). This may be taken to indicate that distractor features are maintained in a memory that, rather than impacting the speed of the verification process, influences other processes involved in search.

For example, as mentioned in the Introduction, Krummenacher et al. (2009) reported that “early” dimension priming (spatially parallel) interacted with positional priming (region-specific). Related to the present findings, it is thus possible that memory for distractor locations aids saliency computation processes on the level of the selection-guiding, overall-saliency map (consistent with the PCN effect in the target-at-distractor-location condition of Gokce, Geyer et al., 2013). For example, following target selection, distractor locations may be assigned negative (positional) weights on the overall-saliency map. Thus, when the target appears at a distractor location on the next trial, accumulation of bottom-up feature contrast information is delayed at these map locations, slowing target selection. The idea advanced by Krummenacher et al. (2009) is that bottom-up computed and dimensionally weighted feature contrast signals (derived in parallel across the field and in multiple dimensions) are multiplicatively combined with (i.e., scaled by) spatially weighted, within-map signals. Accordingly, negative spatial weights for previous distractor locations would increase the time required by a subsequent target at such a location to activate the corresponding overall-saliency unit above threshold (this assumes that, following display onset, saliency information accumulates gradually over a period of time; for a formal model of saliency accumulation and saliency-based selection, see, e.g., Zehetleitner, Koch, Goschy, & Müller, 2013). However, of prime importance in the present context is that, within this scheme, negative

inhibitory weights may be assigned with regard to a categorical, object code (Z- vs. T- configuration), rather than being determined by a purely spatial weighting function centered on the target location (as assumed by Krummenacher et al., 2009, for search displays with unstructured item arrangements).

Significance of the present findings

The present findings are *theoretically* important in at least three respects. First, they provide evidence that item locations in pop-out search are stored in position priming memory not in isolation, but rather with regard to their placement within the overall search configuration—a clear indication of world-centered location priming (e.g., Tower-Richardi et al., 2012). On the other hand, the findings pose problems for accounts assuming viewer-centered (i.e., spatiotopic, retinotopic) location priming (e.g., Ball, Smith, Ellison, & Schenk, 2009; but see Gokce, Müller, & Geyer, 2013b, for a synthesis of the two discrepant views). A more general, albeit speculative, conclusion is that position priming and vSTM share (configural) representations (see, e.g., Kristjánsson, Vuilleumier, Schwartz, Macaluso, & Driver, 2013, for evidence pertaining to this view from feature priming).

Second, the present results have implications as to the locus of the position priming effects. Repetition versus change of the target position interacted with repetition versus change of the target's response-critical feature—importantly, however, only for target (but not distractor) location priming. In other words, the results suggest that positional priming is not a unitary mechanism; rather the RT costs and benefits due to position priming arise at different processing stages: While target location priming most likely modulates postselective processes of stimulus analysis and response selection, distractor location priming modulates pre-attentive processes of saliency coding at the (master map) level of the integrated priority signals (see also Gokce, Müller et al., 2013b).

Third (implicit in the two points above), the present findings add to the evidence of a dissociation between facilitatory and inhibitory priming effects. In particular, the discrepancy in “Gestalt” properties maintained in target and, respectively, distractor memory, as well as the difference in the processing stages at which target location and distractor location priming influence pop-out search, suggest that target facilitation and distractor inhibition are dissociable phenomena. This is in line with recent investigations of (featural and positional) priming effects in pop-out search, which have revealed dissociations not only at the behavioral level, but also in terms of the brain mechanisms that support the effects (e.g., Finke et al., 2009; Kristjánsson et al.,

2005; Kristjánsson et al., 2007). For instance, Finke et al. (2009) showed that positional priming was intact in 14 patients with (left) visual hemi-neglect. Interestingly, positional inhibition, but not facilitation, was almost absent when the analysis was limited to patients who exhibited lesions in the vicinity of the (right) frontal eye field (rFEF). This result also suggests that rFEF is an important neural structure for positional inhibitory priming (see Campana et al., 2007 and Kristjánsson et al., 2007, for similar conclusions based on findings from functional-imaging and TMS).

The present study has also *methodological* significance. First, to our knowledge, the present study is the first one to demonstrate reliable spatial priming effects with displays other than the triangular, circular, or horizontal item arrangements used hitherto in priming of pop-out or spatial cueing paradigms (e.g., Maljkovic & Nakayama, 1996; Mangun & Hillyard, 1991). Second, in previous investigations of positional priming, RTs to targets-at-previous-target and, respectively, distractor locations were compared against a neutral location “baseline” condition, in which the target appeared at a previously empty location. Importantly, in this baseline, the target appeared not only at a previously empty location, but also within a novel (i.e., rotated) configuration. It is thus possible that positional and configural changes were confounded in previous baseline conditions, leading to an overestimation of target and an underestimation of distractor location priming (the idea being that changes of configural attributes in the neutral condition lead to RT slowing). Thus, arguably, the present investigation is a methodological improvement over previous attempts, because configural changes were completely decoupled from positional changes in all conditions: target at target, at distractor, and at empty location, providing a univocal measure of the effects of positional priming.

Conclusion

In conclusion, the present results show that positional priming represents the placement of the items within an overall item configuration. Furthermore, there is a dissociation in terms of the “Gestalt” attributes maintained in position priming memory between target and distractor locations. These findings point to an overlap of (configuration-centered) priming and vSTM mechanisms. Moreover, target location priming is likely to facilitate verification processes after the target selection. Distractor location priming, by contrast, is likely to influence saliency computations at the attention-guiding “master” map of integrated priority signals.

Keywords: pop-out search, positional priming, configural representations, working memory

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