Configuration-centered positional priming of visual pop-out search

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Ahu Gökçe
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General Introduction

1.1 Attention in Daily Life

We are surrounded by countless stimuli in our visual environment at every moment. Not all of these items are relevant for the specific task we want to achieve or the action we want to pursue. Attentional mechanisms play an important role in such situations where the actions shall lead to the outcome in the most beneficial way for the individual. You do not want to focus on the items which are not relevant for your goal in order to reach your goal as soon and as efficiently as possible. You (un)consciously direct your attention to only relevant features, objects or persons in your environment. A classic daily life example on the importance of selective attention is what we face in the grocery stores. Imagine yourself in a big grocery store that you have not been in before and you want to buy a shampoo. Since you lack spatial orientation cues and there is diversity in your visual environment, you would first start to search for external cues such as the label indicating the corner of the personal care products. Once finding the relevant shelf of your interest, you would start to look for the green items on the shelf as the shampoo you want to buy is in green color. If there are multiple green items, then you would start to filter out the items that differ from your shampoo in, e.g., size and form. These several steps of visual search and attention mechanisms enable us to accomplish our goals in an effective way. Having such attentional mechanisms are important because otherwise people would suffer on almost every action they make and in most of the cases, the failures would be inevitable.

The role of attention in daily life can be generalized to other fields such as car driving, detecting and preventing potential dangers in airport security, or examining x-rays as a radiologist. In the laboratory, attention behaviour is investigated using visual search. In this paradigm, observers are presented with a to-be-detected target item, embedded in a (variable) set of distractor items. There are various theories that explain mechanisms of selective attention (visual search).

1.2 Visual Search Models and Attention Control

A visual search task basically involves searching for one target among multiple distractors. Observers are asked to respond as quickly and as accurately as they can and their performance is evaluated in terms of reaction times (RT) and accuracy performance. The identity of the target and the distractors can lead to differences in the performance. If the target shares multiple features (e.g. color and orientation) with the distractors, the search for the target becomes more difficult compared to cases where target and distractors share only one feature (e.g. color), because in such cases the target is more dissimilar to the distractors thus it gets easier to detect (discriminate). These types of visual search are referred to as conjunction search and feature search respectively (Bravo & Nakayama, 1992). The search displays need not to have a target present necessarily. One type of the visual search tasks involves responding to the target's absence or presence. It has been shown that RTs in these tasks highly depend on the set size, the number of items in the search display. RT values increase as the set size increases. Additionally, the slopes of the RT x display set size functions are steeper in target-absent trials compared to target-present trials in the conjunction search tasks, indicating that observers inspect each item serially in the search display until they are certain that there is no target in the display. In target-present situations, the same checking process goes on until target is detected; after serially checking each item, search is terminated once the target is found. This kind of search is called *serial self-terminating search* (Wolfe, 1998). There are also cases where the set size has no effect on the RTs. In this *feature search*, the target and distractors share only one feature which makes the target salient, i.e., ‘pop-out’, in the display. As a result, it can be detected at a glance, i.e., in parallel, in the visual field (Duncan & Humphreys, 1989).

The dissociation between conjunction search and feature search have led to different theories trying to explain how attentional (visual) selection works. One of the most famous theories on this is the *feature integration theory* (FIT), proposed by Treisman and Gelade (1980). According to this theory, there are multiple levels of processing that are organized in a hierarchical way. In the first lower part of the hierarchy, multiple feature maps for each feature (i.e. color, orientation, location) exist. It is assumed that all these features are processed and perceived automatically in parallel. In the next stage, several features are combined (integrated) by spatial attention focusing on an area within the so called master map of locations. Spatial attention is the glue for retrieving and combining different values recorded at the attended location (in the master map) from the feature maps. The result is a temporary representation of an object, called an ‘object file’, which can be used to access / interface with stored knowledge. The critical point in FIT is the presence of the master map of locations. Even if the features are automatically processed at the pre-attentive stage (i.e., attention is ‘called’ automatically by the ‘pop-out’ target), attentional allocation is needed to combine the features, creating the object-file, and accessing long-term memory. Figure 1 depicts the FIT and its stages.

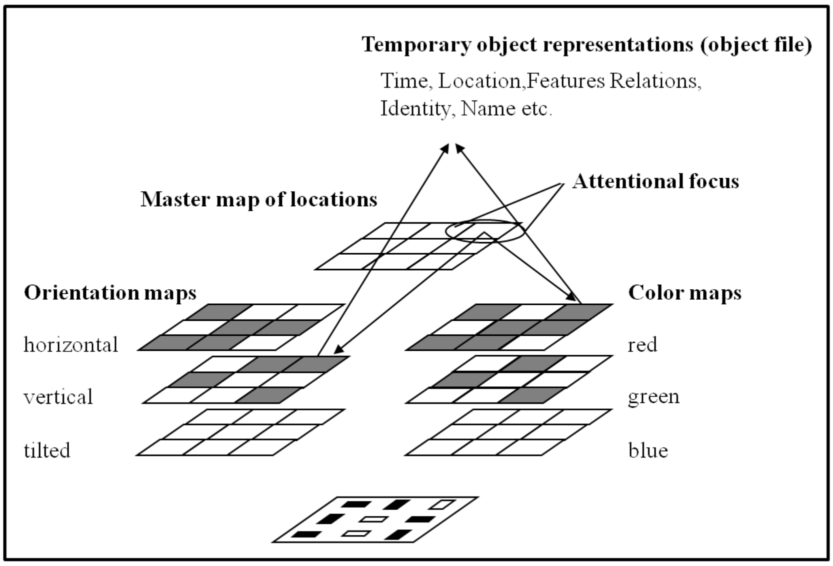

Figure 1. Feature integration theory (FIT) and the multiple levels of processing. In the first stage, feature maps (here color and orientation) are processed in parallel and then the target-relevant features are combined in the next stage to create an object file which then activates the location map of the target finally leading to localizing the target in the display. Figure adapted from Treisman & Gelade (1980).

An alternative model to FIT was proposed by Wolfe (1994, 1996, 1998, 2007): The *guided search* (GS) model. GS model has two stages, namely the pre-attentive and the attentive stages. In the first, pre-attentive stage, basic visual features (color, motion, orientation) are processed and saliency, i.e., contrast, values are computed per dimension (rather than feature-wise - as in FIT) in parallel and in automatic manner. Dimension-specific contrast signals are combined in the second, attentive stage to guide attention. Depending on the target entity, not all dimensions will have the same amount of activation (weight). For example, if the target is a red and right tilted bar, the signal of each dimension is activated or inhibited depending on the similarity between the target and the distractors. The relevant target features (color and orientation) will have more activation than the distractor features (green and left tilted bars). That is, the more salient one feature is, the larger is the weight for that feature (dimension). When this saliency computation is accomplished, the master activation map comes into play where each location specific signal is evaluated and finally attention is allocated to the location with the highest amount of activation (Wolfe, 1994, 1998; Müller, Heller & Ziegler, 1995; Itti & Koch, 2000). Figure 2 depicts the GS model.

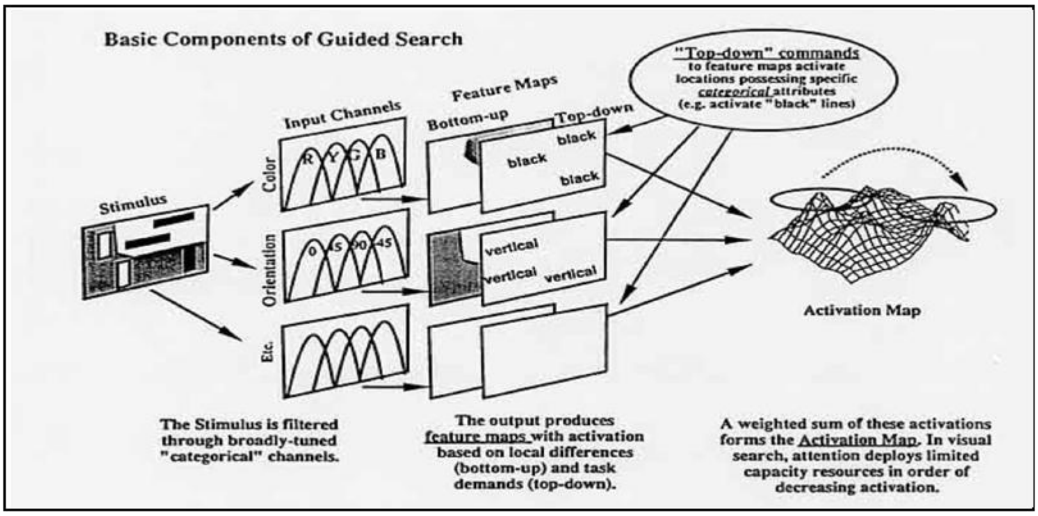

Figure 2. The Guided Search 2.0 Model. Different feature maps lead to different level of activations depending on the target and distractor similarity. The dimension with the highest activation leads to allocation of focal attention that is achieved at the master activation map stage. Figure taken from Wolfe (1994).

In both FIT and GS, there are two different processes of how saliency signals are computed and attentional selection is achieved. The first kind of attentional selection is bottom-up or stimulus-driven. Conspicuous items, in the above supermarket example a green shampoo amongst yellowish shampoos, ‘pop-out’ on the shelf and automatically draw attention (Theeuwes, 1992, 1994). The second type of attention is top-down or endogenous control (Bacon & Egeth, 1994; Folk & Remington, 1998; Geyer, Müller, & Krummenacher, 2008). That is, having certain goals or expectations about the target feature (specific color, location, size etc.) modulates the attentional selection in a way that the observers start to search for the target-specific attribute in the search display which then leads to the target selection. In other words, having in mind the feature(s) of the target, observers set-up certain expectations that influence the search process (Desimone & Duncan, 1995). Top-down influences come to the fore particularly when the target is less conspicuous, such as in conjunctive search. Another important function of top-down mechanisms is to forage search, that is: the generation of inhibition of return (e.g., Posner, 1980; Klein & MacInnes, 1999). The inhibition of return (IOR) mechanism has been introduced by Posner and Cohen (1984) in a cueing paradigm. The observers were asked to fixate on the fixation point (box). Another box either on the left/right side was cued exogenously. The target appeared in one of the cued boxes after certain period of time. The stimulus onset asynchrony (SOA) varied between 0, 50, 100, 200, 300, and 500 ms. intervals and the task was to detect the target. It has been found that exogenous cueing benefited the performance when the SOA was 150 ms and after the 300 ms SOA interval, the cueing benefit was diminished. After the 300 ms SOA, longer RTs were obtained to detect the target object when presented in a previously cued location compared to when the object was presented at a non-cued location. In other words, observers inhibited to orient to a previously attended location after 300 ms. Related to this, Klein (1988) found that the RT differences were smaller to detect the target presented at an empty location and at a distractor location in the parallel search than in the serial search. Klein (1988) claimed that inhibitory tags are created for each attended location in serial search so that IOR mechanism kicks-in and the observer orients his/her attention to somewhere else. However, it has been shown that this pattern depends on the presence of the display when the target is presented (Takeda & Yagi, 2000; Müller & von Mühlenen, 2000).

More recently Wolfe, Vo, Evans and Greene (2011) proposed a dual-path model for search guidance in complex visual scenes. This model involves both selective and nonselective pathways. Object features would be bound and recognized via the selective pathway. Given that the selective pathway has limited capacity, guidance is needed to select the relevant item. Here, both semantic and episodic guidance come into play provided by the nonselective pathway. The nonselective pathway enables to extract the needed information semantically and globally in a very short period of time by the surrounding items available in the complex scene. Thus, more recent versions of GS assume guidance of attention is based on the contextual factors (e.g., the background within which the target is embedded or meaningfulness of the array / scene), in addition to bottom-up and top-down factors.

1.3 Space-Based vs. Object-Based Attention

Selective attention can manifest for several visual attributes, such as item features, item dimensions, item locations, or the objects themselves. The debate on whether people orient their attention to space independent of the objects occupying that space or they direct their attention to specific objects regardless of where they are located in the space has been long going on. These two types of attention can be named as space-based and object-based attention respectively.

The studies favoring space-based attention claim that attention can be directed to space independent of the absence/presence of an object in that to-be-attended space. The finding on space-based attention has its roots in the 19th century when Helmholtz (1802) established his findings on covert attention. In his setup he presented himself with arrays of letters while fixating on the center of the screen. In a given trial, he directed his covert (beam of) attention to, e.g., the top-left display quadrant (while fixating on the display centre). When a spot illuminated the attended quadrant, he was able to perceive and report the letters, but not so for the non-attended quadrants. This shows that the attention selection is space-based.

Another classical study on space-based attention was done in 1980 by Posner. In the study, observers were presented with two boxes in the left and right parts of the fixation cross. The target could appear at one of these boxes and the task was to detect the target as quickly as possible. Prior to target presentation, one of the boxes was peripherally cued. The cue indicated the target location (valid cue, 80% of trials) or indicated the ipsilateral target location (invalid cue, 20% of trials). It was found that RTs were slower for invalid-cue than the valid-cue trials. This suggests that the stimulus cue attracts attention and that covert attentional shifts in space are time-dependent. Although the observers expected a valid cue in the majority of the trials, they were not able to suppress the shift to the invalidly cued box (see also Müller & Rabbitt, 1989 for an investigation of exogenous vs. endogenous shifts of attention in the ‘Posner’-task).

Studies investigating the space-based attention have led to the idea that attention can be considered as a ‘zoom lens’ that can vary in width (e.g., Carrasco & Frieder, 1997; Carrasco & Yeshurun, 1998; Carrasco, Talgar, & Cameron, 2001; Carrasco, 2011). According to Eriksen and St. James (1986), there is a trade-off between the size of the zoom lens and the resolution of spatial attention - based on the idea of a fixed gradient (capacity) of attention. When the area of the attentional focus increases, there is decrease in the amount of attentional resources, or spatial capacity, deployed. Further evidence on the spatial structure of attention comes from the study of Müller, Mollenhauer, Rösler and Kleinschmidt (2005). According to their Mexican hat model, the stimuli close to and far away from the observers’ attentional focus are better processed (relative to stimuli presented at intermediate positions) and thus performance improves as the target is located close to (or far away from) the center of an observer’s attentional field. The authors (2005) presented their participants with a Flanker task (Eriksen & Eriksen, 1974). In a typical Flanker task, response inhibition is investigated by presenting the target letter in the center among distractors that are located laterally in a row. In a given display observers are presented with 7 letters with different letter pairs (e.g. H and K or S and C) with different response mappings. Mapping different responses to each letter enabled to create displays where the target letter’s response is compatible or incompatible with the remaining distractors’ responses. It has been shown that RTs were faster for the compatible trials compared to the incompatible trials because the observers had to inhibit the response feature of the distractor letters before responding to the target’s response feature in the incompatible trials. Müller et al. (2005) located their stimuli (letters) on the right visual field on an imaginary hemicircle. The distractors could be compatible, incompatible or neutral with regard to the identity of the target. The presented letters in the array were “E”, “F”, “X”, and “O”. Task difficulty was manipulated by presenting similar letters together, making the discrimination process harder (eg, discriminating “E” and “F” is harder than discriminating “X” and “O”). The task was to respond to letter onset that is located in the square at the top of the search array and report the letter identity. In the (in)compatible trials the distractor (e.g. “X” or “O”) that interfered with the target letter (“E” or “F”) was present (incompatible) or absent (compatible). In addition, the distance between the target and the distractors was varied. The dependent variable was the RT differences calculated by the differences between the neutral and incompatible trials, as a function of the distance between the target and the interfering distractor. The results were as following: First, the difference values were largest when the distractor was presented in close spatial proximity to the target. Second, RTs were almost comparable between neutral and incompatible trials for intermediate target-distractor distances. Third, difference values increased again for distractors presented in the periphery of the target. When drawn, the difference values reflected the shape of a Mexican hat. Further experiments showed that the shape, i.e., lateral extension, of the Mexican hat function was narrower when the task was made difficult (e.g., presenting the ‘similar’ letters “E” and “F” relative to the ‘dissimilar’ letters “X” and “O”) suggesting that the spatial profile of attention depends on the task difficulty or on the availability of the attentional resources (Lavie, 1995; as cited in Müller et al. 2005).

Another study on space-based attention was conducted by Tsal and Lamy (2000) where they showed that attending to a non-spatial feature (color) entails attending to its location. In their Experiment 1, the observers were presented with six letters in different colors in a circular arrangement. Three of these letters were either enclosed by or superimposed on differently colored shapes in different experiments. In such display, one of the letters shared the same color with the target shape (color letter) and another letter was enclosed by the target shape (location letter). The task was to report the color of the target shape. In addition, they were asked to recall the maximum amount of the presented letters. It was found that the location letters were more frequently reported than the color letters. This clearly supports space-based attention. However, one can argue that the letter and the shape formed an object together and the results might be explained by object-based attentional selection. Another experiment was run to check for this possibility where the “object” was disrupted by superimposing the letter on the shape rather than enclosing it. Again, the location letters were reported much frequently than the color letters. It can be concluded that even if the spatial feature is task irrelevant, attention is still oriented to space.

Opponent views to space-based attention claim that attention is directed to objects themselves independent of where those objects are located. One study was carried out by Duncan (1984) where observers were presented with two objects (rectangular box and line grouping). Each object had two different dimensions. The box could be large vs. small (dimension 1) or contain a gap on the left vs. right side (dimension 2). The line could be dotted vs. dashed (dimension 1) or tilted to the left vs. right (dimension 2). This manipulation enabled to create two objects with two attributes each. The two objects were presented at the same location in a way that they overlapped. The objects were presented very briefly and were followed by a mask. The task was to report either one or both of the dimensions and in the latter case, they were asked the dimension(s) of one/two object(s). It was found that when two overlapping objects were presented, performance was significantly better at reporting the two dimensions of one object rather than one dimension of the two objects. This finding supports the object-based selection view. Similar findings were reported by O’Grady and Müller (2000, see also Müller & O’Grady, 2000; Müller, O’Grady, Krummenacher, & Heller, 2008; Desimone & Duncan, 1995). In their study, they investigated space- and object-based attention by using grouped spatial arrays. In Experiment 1, the displays contained little boxes occupying multiple locations at different eccentricities on different rings (e.g. Egly & Homa, 1984). These boxes were connected with lines which enabled to group several of these dots and form an object. Each display contained one of these objects served as the target object and multiple objects that were oriented vertically/horizontally/diagonally and colored differently. Prior to the presentation, the target object was cued (validly or invalidly) either on its orientation (vertical/horizontal/diagonal) or on both color and orientation features. The task was to respond to target object's absence/presence. The results suggested object-based selection and its mediation by the groupings of the spatial arrays at different target eccentricities. Furthermore, when they looked at the closure effect by having closed or unclosed grouped arrays (objects), they still found object-based representation (O'Grady & Müller, 2000). In another study Müller and O'Grady (2009) further investigated object-based attention by using modified version of Egly and Homa's (1984) ring-like displays where they tested this as a function of eccentricity effect. The observers were presented with three differently colored rings located in each other and varied in their sizes and locations with respect to the fixation cross (close/middle/distant). On all rings, there were eight potential target locations. The task was to respond to the absence/presence of the target. A cue (highlighting a ring) was used to indicate which ring the observers had to attend to. The accuracy performance, to detect the target, differed for the three rings. Fewer errors were made when the target was located in the inner ring as compared to the middle and distant ring (performance was also different between the middle and distant ring). This shows the ring-based, i.e., object-centred, distribution of attention.

Though it is possible to find findings that favor either space- or object-based attentional selection, there are also studies showing that the type of selection depends on the task itself. For example, Vecera and Farah (1994) introduced a number of new variations to

Duncan’s (1984) task, such as separating the two objects in space or adding letter distractors to the task. But again, the results were indicative of object-based selection. However, when they changed the task to a simple detection task along the lines of Posner (1980), they observed space-based attention effects. The observers were presented either with a rectangle or a line (“separate” condition) or with both (“together” condition). In the detection task observers had to respond to target’s location (either on rectangle / line) which was cued by brightening either the rectangle or the line. The cue would be valid or invalid. RT benefits resulting from valid versus invalid cues were more pronounced for “separate” condition as compared to the “together” condition. These results of Vecera and Farah (1994) indicate that the particular attentional selection (space- vs. object-based) in a given task is contingent on the task demands or the observers’ strategic preferences.

In addition to the behavioural findings, there is neurophysiological evidence showing that there are distinct brain regions of space- and object-based attentional selection. An fMRI study on object-based attention was carried out by O'Craven, Downing and Kanwisher (1999). The authors investigated whether object-based attributes are processed at the pre-attentive stage. Observers were presented with superimposed faces and houses as objects. One of the objects was moving while the other one was stationary. The observers were asked to attend to either one of the face, house or movement features and the activity from the brain regions of interest associated with these features (fusiform face area (FFA) for faces, parahippocampal place area (PPA) for houses and the motion area (MT) for the movement respectively) were recorded. The aim was to see whether task irrelevant features of an attended object are processed in addition to the task-relevant features. It was found that when the observers attended, e.g., motion and faces were task-irrelevant; there was enhanced activation not only in MT, but also in FFA. Similar findings were obtained when houses were task irrelevant. Increased activity was observed in the attention-relevant motion region, i.e., MT area, in addition to attention-irrelevant house region, i.e., PPA. This clearly indicates that the task-irrelevant features are processed automatically and this cannot be explained by space-based attentional selection theories, attention is directed to objects independent of the task relevancy.

1.4 The Role of Memory in Visual Search

The evidence presented above suggests that attention can be both space- and object-based and under top-down or bottom-up influences depending on the stimulus and task type. This section will focus on the role of memory in visual search. Before digging the relationship between memory and visual search, it is worth to mention different forms of memory. Atkinson and Shiffrin (1968) suggested multiple components of human memory; namely the sensory memory (SM), short-term memory (STM) and long-term memory (LTM) components. The SM holds information obtained from the sensory organs and lasts around one second. Iconic memory for visual stimuli or echoic memory for the auditory stimuli are the examples for the SM components. STM has also short-lasting duration (15-30 seconds) and is limited in capacity. Both verbal and visuospatial information can be stored in STM or as others call working memory (WM) (see also Philips, 1974; Baddeley, 1966, 2003; Luck & Vogel, 1997). Due to its limited capacity, chunking 7±2 items can be efficient way to increase the memory storage. LTM on the other hand has limitless capacity and can last for years. The Atkinson-Shiffrin model has been qualified by Baddeley and Hitch (1974). In their working memory model, the STM component of the Atkinson-Shiffrin model has been replaced by a short-term storage system where three kinds of storage systems are present: The central executive, phonological loop and the visuospatial sketchpad. As the phonological loop and the visuospatial sketchpad update verbal or visual information respectively, the central executive manages the transition between these two storage systems.

Shore and Klein (2000) suggested three types of memory influences in visual search depending on their duration. The first type, longest lasting, involves implicit perceptual learning (corresponding to LTM in Atkinson & Shiffrin, 1968). At this stage, all stimulus and task related factors are encoded during visual search, registered into memory and affects future trials (enhancing performance) occurring in the time range of hours to years. The second type, trial to trial priming, can last from seconds to minutes as only the information registered to memory from previous visual search trials can influence the upcoming 5-7 trials. The last memory type involves perceptual memory components within a given trial. This kind of memory can last from milliseconds to seconds. Note that inter-trial priming and within trial memory can be considered as instances of Atkinson and Shiffrin’s STM buffer. Figure 3 depicts the schematic illustration of three different stages of memory. It should be mentioned that the processes occurring at the stages with the shorter latencies can influence the later ones. For example, the information gained from one trial (stage C) can modulate the processes in the next trial (stage B) or having a certain feature repeated over trials can modulate the perceptual learning mechanisms (stage A).

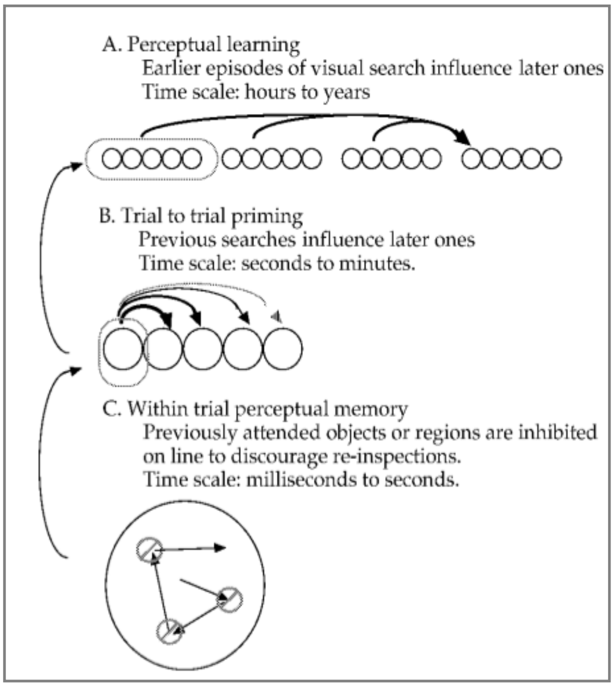

Figure 3. Different stages of memory at different time scales. Stage (A) with the longest duration depicts the perceptual learning stage. One block of trials can influence the preceding ones at the longest duration (hours to years). Stage (B) with moderate duration of seconds to minutes depicts trial to trial priming where one trial can influence the next 5-7 trials. Stage (C) within trial perceptual memory covers processes occurring from milliseconds to seconds. Such a stage enables to skip the processing of previously checked items for an efficient search within a given trial. Figure taken from Shore & Klein (2000).

There are opponent views on the role of memory in visual search. Horowitz and Wolfe (1998) claimed that the visual search is not memory-driven. They presented their observers with a visual search display consisting of Ls and target T. The task was to respond to target’s absence/presence. The set size was varied between 8, 12 and 16 items in the display. The two critical conditions were the static and the random condition. In each condition, four different frames were presented. While in the *static* condition the stimulus locations did not change, in the *random* condition, the locations of the search items changed in every 111 milliseconds. This manipulation prevented to encode the item location in the memory. When the RTs were plotted for the target present trials as a function of the set size, it became evident that the search efficiency did not differ between the static and the random conditions. According to the authors (1998), if visual search was indeed memory-driven, then the search efficiency should have been much better in the static condition.

On the other hand, there are studies showing that memory plays an important role in visual search. Geyer, von Mühlenen and Müller (2007b) investigated overt gaze shifts in different memory-based search strategies (Horowitz & Wolfe, 1998). In a given search display observers would adopt either an active search strategy or rather more passive sit and wait strategy. The authors (2007b) used two different search tasks. In the static task, the locations of the search items were kept stationary over the trials whereas in the dynamic task, the location of each item changed randomly in every 116 milliseconds. They found that oculomotor variables (number of fixations, saccade amplitude, fixation duration and latency of the first saccade) were quite different between the static and dynamic search tasks: The number of the fixations and the saccade amplitudes were larger in the static than in the dynamic condition, whereas fixation duration and the latency of the first saccade were longer in the dynamic condition. Further, the number of re-fixations was quite low in the static condition, again being an indication of memory-less search performance. The authors (2007b) took these results to mean that dynamic, but not static, search does not need to have any memory involvement (see also Theeuwes, Olivers, & Chizk, 2005; Zelinsky & Sheinberg, 1997). Similar results were also reported by McCarley, Wang, Kramer, and Irwin (2003). In a gaze-contingent search paradigm, with multiple items in the search display, memory for up to 3-4 previously inspected locations was present, even for items that disappeared across the course of the search (in their task, observers had to shift gaze serially to individual items until the target was found. In doing so, only the currently fixated and the last two fixated items were shown).

This thesis focuses on STM and how this type of memory guides attention as based on spatial vs. non-spatial, i.e., object, information (see Section 1.8 of this chapter for more details). The studies in the literature suggest that STM and selective attention are linked with each other and that memory can aid attention (Downing, 2000; Chun & Nakayama, 2000; Peterson, Kramer, Wang, Irwin, & McCarley, 2001; Soto, Humphreys, & Rothstein 2007: Soto, Hodsoll, Rothstein, & Humphreys 2008; Soto, Llewelyn, & Silvanto 2012; Olivers, Meijer, &Theeuwes, 2006b; Olivers, 2009; Woodman, Luck, & Schall, 2007; Woodman & Luck, 2007). However, before one accepts this view, it may be beneficial to distinguish different kinds of STM and how they relate to visual search.

1.4.1 Visual Working Memory

As stated previously in this section, working memory (WM) refers to maintaining information in short-term memory for limited amount of time and in limited capacity. This section will focus on more specific WM type: Visual working memory (VWM). Olivers, Peters, Houtkamp, and Roelfsema (2011) put forward the idea that VWM guides attention depending on the availability of the active attentional templates. The authors (2011) distinguish between active versus accessory WM states. While the accessory WM states have little influence on the guidance of attention, the existence of the active WM state creates attentional templates that can guide attention efficiently (see also Theeuwes, Belopolsky, & Olivers, 2009, for a review).

Awh and Jonides (2001) went a step further in claiming that attention and WM share representations (a strong version of this proposal is to assume that attention and WM are essentially similar). They presented evidence for this thesis from behavioural findings as well as from imaging studies using a variant of the Posner (1980) task. They showed that memorized locations facilitate attentional performance at that location. Further, they found that directing attention away from memorized locations led to decrements of locational WM. Lastly, their findings obtained with fMRI and EEG studies indicate that WM rehearsal led to activation in posterior areas contralateral to the visual field of the to-be-memorized locations with these effects being observable already 100 ms after the onset of the memory display.

It has been shown that saccades and attention system are tightly coupled (Deubel & Schneider, 1996; Jonikaitis & Theeuwes, 2013). With particular relevance to the Awh and Jonides (2001) work, Theeuwes, Belopolsky, and Olivers (2009) showed that maintaining a location in WM does not only involve attention rehearsal, but also engages the oculomotor system. In their experiments, observers had to maintain the location of a dot in WM while performing an eye movement in the same direction as the WM item. Under these conditions, saccades curved away from the WM location.

1.4.2 Transsaccadic Memory

At a given moment, humans make more than three saccades per second in order to perceive and process the visual environment in an efficient way. However, and despite this inconsistent input, the visual world seems stable. To account for visual stability, researchers have suggested the notion of transsaccadic memory (Irwin, 1996). Research on transsaccadic memory has used direct and indirect measures to reveal the contents of this form memory (De Graef & Verfaille, 2002). The basic approach is analyzing the performance as a function of whether a change has occurred between pre- and post-saccadic images. Of particular relevance to the present thesis is the finding that transsaccadic memory stores objects, or configural attributes, rather than the elements in point-by-point details (Carlson-Radvanski, 1999). Carlson-Radvansky (1999) investigated the relational information set by the items in a search display across different local/global spatial categories. The findings led to the evidence that the structural descriptions of certain configurations are encoded as the relational features of items and they are represented in the transsaccadic memory that is the structural descriptions can be maintained across the saccades.

Similar findings were reported for the organization of WM. Jiang, Olson, and Chun (2000) did series of experiments to investigate how the visual short-term memory is organized by using a change detection task in spatial configurations. The aim was to investigate whether the items in VWM are represented individually or is there a relational mechanism between the items in a given search display. The experimental paradigm was similar in all experiments. Observers were presented with memory and probe displays and they were asked to detect whether there was any change between these two displays. In their Experiment 2B, Jiang et al. (2000) presented their observers with a prime and probe display (in a single experimental trial) with a blank interval in between. In both displays, several green squares were presented at random locations. Prior to the presentation of the probe display, one of the squares was cued and the task was to indicate whether the location of the cued square was occupied or empty in the 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 was identical to the prime display (but there were subtle changes in the locations of the items across the two displays). 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 and thus location was completely irrelevant for solving the experimental task (Jiang et al., 2000; Experiment 1). Jiang et al., (2000; see also Chun & Jiang, 1998) took the results to mean that single items are stored in VSTM with regard to their placement in the spatial configuration (difference between minimal-change and single-item condition) and that only a partial match between prime and probe display can even hamper VSTM performance (difference between single-item and partial-change condition).

Additional studies were done on the configural organization of WM. Gmeindl, Nelson, Wiggin, and Reuter-Lorenz (2011) showed that the representation of a single stimulus location in working memory is influenced by the locations of the surrounding items. In their Experiment 2, observers performed a location change detection task in which they had to indicate whether or not a probe item (in the test display) occurred at the location of a target item (in the memory display).The memory and probe displays contained three items, arranged in a virtual triangle. This configuration could either be preserved or changed at the transition between the memory and test displays. There were three conditions. In the “black-red” condition, the items in the memory display were shown in black color, whereas one item in the test display was presented in a salient – red – color (the other two items in the test display were black). In the “red-black” condition, one item in the memory display was presented in red color, whereas all other items, in both the memory and the test displays, were colored in black. In the final “red-red” condition, one item was red in both the memory and test display (the other items were black). Across all three conditions, observers showed higher accuracy on location match trials compared to non-match trials. Further, for non-match trials, observers’ change detection performance was enhanced on trials with distorted relative to preserved configurations. This result was found in the “black-red” and even in the “red-black” condition, that is, even when (in the latter) the target was a feature singleton in the memory display, so that its location could be easily maintained in working memory. In contrast, target-location detection performance was uninfluenced by the changes of the item configuration in the “red-red” condition. This result pattern led Gmeindl et al. (2011) to surmise that target location detection is influenced by configural information (“black-red” and “red-black” conditions), specifically, that configural attributes aid information processing at a decision stage where evidence for a mismatch between item locations in the memory and test displays is evaluated. Thus, detection of a change of stimulus locations is enhanced when the configuration changes, too. Moreover, Gmeindl et al. (2011) suggested that configuration-dependent and -independent representations can be compartmentalized in working memory and that the influence of the former is attenuated when the target and the probe item are presented in salient colors (“red-red”condition) (see also Boduroglu & Shah (2009) who showed that even task-irrelevant spatial configurations can be encoded in WM in addition to the object information in a change detection task).

1.4.3 Priming Memory

McPeek, Maljkovic, and Nakayama (1999), investigating the relationship between saccades, focal attention and visual STM found that (first) saccadic latencies were shorter when the color of the target was repeated rather than changed across subsequent trials. The authors claimed that this effect is an outcome of the usage of the focal attention rather than the distributed attention mechanisms because saccades required focal rather than distributed attention (Bravo & Nakayama, 1992). The difference between the focal attention and the distributed attention lies on the spatial scale (LaBerge, 1983). While focal attention requires narrower/local scope of attention, the distributed attention requires broader/global scope. Additionally, STM mechanisms guide the focal attention system as re-fixating to a previously attended target location trial took shorter latencies than when the observers re-fixated to a new location from one trial to the next. That is, STM facilitates saccades when target feature is repeated. When target attributes are repeated from one trial to the next, performance is enhanced / facilitated compared to trials where the target attributes are changed. This effect is known as priming (Kristjánsson & Driver, 2008; Fecteau & Munoz, 2003; see also Section 1.5 of this chapter for detailed discussion). Of particular relevance here are the findings suggesting that (1) priming effects can account for large performance gains visual search that were previously attributed to top-down expectation (e.g., Kristjánsson, Wang, & Nakayama, 2002; Geyer, Müller, & Krummenacher, 2006); and that (2), there is an overlap in the representations underlying priming memory and other forms of visual memory, such as WM (Lee, Mozer, & Vecera, 2009; Kristjánsson, Saevarsson, & Driver, 2013; Chapter 5 of this thesis). Kristjánsson et al. (2002) investigated the role of priming in visual search. By using conjunctive visual search task, color and orientation features were assigned to the target. Three other conditions were created where the target had only one feature (i.e. orientation) instead of two features. In the “switch” condition the target’s orientation switched across consecutive trials. In the “streak” condition, target’s orientation switched after longer period of time compared to switching right after the current trial. Finally in the “random” condition, the target’s orientation changed randomly. The task was to respond to target’s absence/presence. In the conjunction search task, the target was always predictable (i.e. red vertical bar) whereas in the other conditions the observers were instructed to search for the red item which was oddly oriented. It was found that the reaction times were fastest in the conjunction condition where the target was same across all trials. RTs were slowest in the switch condition where the target defining feature changed across trials. In order to test for the role of priming in conjunction visual search task, the authors compared the performances in the conjunction and streak conditions where the streak condition should have the smaller priming effects due to the changes in the target defining feature and larger priming effects should be observed in the conjunction condition as the target is same across all trials. For the streak condition, those trials with the minimum priming effects (1-3 streaks) and maximum priming effects (6-8 streaks) were selected rather than pooling the data across conjunction versus streak conditions. It was found that the reaction times in the 6-8 streak and the conjunction conditions were highly similar, which indicates that the priming effects are not affected by knowing the target in advance and repeating the target defining features across a block of trials (conjunction condition) compared to the condition where only one of the target defining features was known (i.e. color) (streak condition). The authors (2002) interpreted this finding as priming per se is sufficient to explain the conjunction search mechanisms and that top-down guidance of attention does not facilitate the performance.

The longer-lasting memory effects have been shown in the priming studies as well. Kristjánsson and Nakayama (2003) investigated the primitive memory system for the deployment of transient attention in feature priming experiments. It has been shown that the feature-based relationships between the target and the cue were learned leading to rapid deployment of attention to the target based on the prior experience. More findings on the relationship between feature based priming and memory systems were shown by Geyer, Müller, and Krummenacher (2006) where target and distractor repetition effects were analyzed as a function of uncertainty and target absence/presence in a conjunction search task. In two experiments, target and distractor uncertainty varied as the number of alternatives defining target and the distractor features (orientation) were different. In Experiment 1A, the number of the distractor alternatives was the double the amount of the number of target alternatives leading to higher uncertainty for the distractors than the target. This proportion was reversed in Experiment 1B which led to higher uncertainty for the target than the distractors. This enabled to compare the target facilitatory priming effects across the conditions of repeating the orientation feature of target only / distractor only / target and distractor features across trials as well as to examine effect of uncertainty on the strength of the target/distractor based priming effects. It was found that higher target uncertainty did not affect the RT facilitation but higher distractor uncertainty caused RT facilitation for both target absent and target present cases. In addition, the distractor repetition effects caused facilitatory priming effects despite the target repetition effects. This suggests that the target and distractor repetition effects are interactive. The authors (2006) put forward the idea that the dominance of one set of (red) distractors in the display enable perceptual grouping of the distractors to discern the target singleton. This effect was more pronounced in displays with larger set size where the grouping can be achieved more easily with more items. The results indicate that the feature facilitatory priming effect heavily depend on distractor feature repetition rather than the target feature repetition.

Further studies in the literature point out the relationship between the STM and priming. For example Lee, Mozer, and Vecera (2009) investigated whether priming of pop-out mechanisms are represented in episodes that are under top-down control (Huang, Holcombe, & Pashler, 2004) or modulated by the feature gain mechanisms in a bottom-up manner (Wolfe, Butcher, Lee, & Hyle, 2003). In order to test the VSTM effects on priming of pop-out (PoP), the authors (2009) conducted a dual task experiment where the observers had to hold four items in their memory while performing a pop-out task. The memory array was presented before the search display which was followed by the test array. The memory task was to make a same/different judgment. The authors (2009) claimed that if the VSTM representations underlie the PoP mechanisms, then the memory load would abolish the priming effects as the target identity will exceed the memory capacity thus will not be able to enter into the VSTM to facilitate the performance. On the other hand, if the VSTM representations have no role in PoP, then the memory load should not affect the priming effects. This is exactly what was found; the memory load had no effect on the priming performance which shows that the priming effects do not arise from the VSTM representations. This finding is in favour of the feature gain view of PoP as the memory representations had no effect on PoP. This finding was further elaborated with an additional experiment where a shape discrimination task was presented between the two PoP tasks. The shape discrimination task consisted of a house shape (a triangle on top of a square) either in red or green and the task was to respond to the direction of the house (i.e. triangle pointing up/down). The shape discrimination task and the PoP tasks shared only one feature (color) in common and this led to feature priming effects as well. When the house’s color matched the PoP task target color, the RTs were significantly faster. Furthermore, the feature priming effects were present between the two PoP tasks. However Lee et al.'s (2009) findings were challenged by Kristjánsson, Saevarsson, and Driver (2013) by having task-relevant WM load in feature PoP task (Maljkovic & Nakayama, 1994). There were two color pairs of target and distractors: red-green and blue-yellow. The red/blue target could be presented among green/yellow distractors respectively. In each pair, the target color was randomized. Each display was surrounded by a white or black circle that indicated the task for that display. The task could be either to memorize the search items and report if there is a change (WM task) or just respond to the notch of the target stimulus (search task). The WM task could only be performed by holding the search items' color and location in memory until another trial with the same surrounding circle was presented. Having two different target-distractor color pairs enabled to have task-relevant and task-irrelevant conditions. In cases where the red-green display is WM-relevant, the blue-yellow displays would be irrelevant and vice versa. It has been found that task-irrelevant color items, disrupting the WM, led to stronger priming effects compared to the priming of the task-relevant items.

1.5 Inter-trial Priming Effects

Visual search experiments consist of several hundreds of trials each. Repeating certain features of the target from one trial *(n-1)* to the next trial (*n*) facilitates RT and accuracy performance relative to a change of these features. So, the stimulus attributes selected and/or the actions performed in trial *n-1* accelerate performance in trial *n*. Inter-trial priming effects can arise at the level of stimulus features, dimensions, modalities, manual responses – including eye movements, or the particular task performed by the observers (Maljkovic & Nakayama, 1994, 1996, 2000; Goolsby & Suzuki, 2001; Hillstrom, 2000; Kristjánsson & Driver, 2008; Kristjánsson & Campana, 2010; Lamy & Kristjánsson, 2013; Thomson & Milliken, 2011; Geyer et al., 2006, 2007a,b, 2009, 2010; Müller, Heller, & Ziegler, 1995; Found & Müller, 1996; Rangelov et al., 2011, 2012; McPeek et al., 1999) and can even depend on the goals of the observers (Fecteau, 2007, Müller, Reimann, & Krummenacher, 2003; see also next point).

There are different views regarding the sources of inter-trial priming. The discussion centers mainly on the level of the representation – or performance – that is primed by the repeated targets. According to the *early-selection* view, inter-trial priming effects facilitate early perceptual processes, such as the selection of the target by focal attention (Müller et al., 2003; Wolfe et al., 2003; Goolsby & Suzuki, 2001; Maljkovic & Nakayama, 2000). In contrast, the *late-selection* view stresses that inter-trial priming effects facilitate processes after the target selection, such as the response selection (Cohen & Magen, 1999; Mortier Theeuwes, & Starreveld, 2005; Theeuwes, Reimann, & Mortier, 2006). A variation of the post-selective view are the accounts that assume the RT gains in visual search are due to the operation of an episodic memory mechanism, buffering information about the target's perceptual- (i.e., attention) and response-defining features as well (Huang & Pashler, 2005). But do these accounts really exclude each other? The available evidence suggests that they do not. For example, by using electrophysiological measures Töllner, Gramann, Müller, Kiss, and Eimer (2008) investigated the processing stage of dimension and response repetition effects. They found that when the dimension of the target was repeated from one trial to the next, the allocation of attention was facilitated, importantly, independent of whether the response-defining target attributes were repeated or not. In addition, the lateralized readiness potentials (LRP) were influenced by the repetitions / changes of the target's response defining features independently from the repetitions / changes of the target dimension. This suggests that "early" attention and "late" response priming can occur independently. Related to this claim, Lamy, Yashar, and Ruderman (2010, see also Yashar & Lamy, 2011) put forward the idea of a *dual-stage account* of inter-trial priming, in which both early attentional and late response priming effects can co-occur, but differ with regard to their temporal characteristics (with perceptual priming building up fast – within 100 – 300 ms following the onset of the probe trial – and response priming building up slow – starting only around 400 ms after probe trial onset). The idea of independent attention and response priming is also at the heart of Olivers and Meeter’s (2006a; see also Meeter & Olivers, 2006) *ambiguity* hypothesis, which states that inter-trial priming is determined by the degree of ambiguity – or uncertainty – regarding the target’s perceptual- or response-defining features. For example, Meeter and Olivers (2006) showed that featural priming (Maljkovic & Nakayama, 1994) is larger with 3-item relative to 12-item displays – an effect which they attributed to reduced target pop-out, and thus larger ambiguity, with 3- relative to 12-displays. (In a sense, ambiguity refers to the efficiency of feature contrast – or saliency – computations. Assuming that these are spatially scaled (see e.g., Nothdurft, 1991, and Krummenacher, Müller, & Heller, 2002) saliency coding is improved with denser inter-item spacing – as in Meeter and Olivers’s 12-item condition).

1.6 Priming of Pop-out Paradigm

One of the most commonly used paradigms in research on inter-trial priming is the *priming of pop-out* paradigm. Just like in a typical priming task, keeping previous trial’s feature identities same in the current trial lead to speeded RTs for the repeated target feature. On the other hand, switching between the two identities across the subsequent trials slows down the RTs. It is important to note that although in visual search typically the target and distractor features either remain the same or switch with one another from one trial to the next, Lamy Antebi, Aviani, and Carmel (2008; see also Kristjánsson & Driver, 2008), using a set of elegant presentation techniques, provided suggestive evidence in favor of RT benefits and costs representing independent mechanisms (of attention facilitation and inhibition). Other studies showed that featural priming is more evident in sparse displays than in the dense displays (Rangelov, Müller, & Zeheitleitner, 2013). Moreover, if the primed feature is perceptually distinct from the other features, the priming effects can last twice as long as the usually reported duration (extending maximum 8 trials back). Thomson and Milliken (2012) found feature priming effect for the n-16 trial when the perceptually distinct feature was primed 15 trials before.

The repeated target feature could be color, orientation or position; each leading to different forms of priming effects (color priming, response priming and positional priming respectively, Maljkovic & Nakayama, 1994, 1996; Lamy et al., 2010). Geyer and Müller (2009) showed that the color and positional priming effects are independent from each other. In their experiments (2009) when the likelihood of target position repetitions were higher than the color repetitions, (Experiment 2) the magnitude of the positional priming effect was much larger than the color priming effect. The same pattern was replicated when the likelihood of the target color repetition was higher than the position repetition (Experiment 3). In addition, the positional and color priming effects in Experiments 2 and 3 respectively were comparable with those of Experiment 1 that served as the baseline.

The nature of priming effects being implicit or being under top-down control has been investigated as well. In a priming of pop-out task, Maljkovic and Nakayama (1994, Experiment 4) presented their observers with predictable sequences of target colors (e.g. red, red, green, green and so on). The aim was to investigate whether the valid predictability of the target defining feature would affect the priming performance (especially target facilitation). There were two critical conditions: active and passive viewing conditions. In the passive condition, the observers performed the standard task. In the active condition, they were asked to subvocalize the color of the target that will be presented in the next trial. The authors (1994) hypothesized that if the observers can manage to perform the task in the active condition, then there should be a reduction in the priming magnitude in the active condition which would count as evidence for priming being under conscious control. The results showed that the priming effects were not smaller in the active condition than the passive condition; in fact the priming magnitude was larger in the active condition. This indicates that priming is not under conscious control, it is implicit.

Contradictive results to that of Maljkovic and Nakayama (1994) were reported by Müller, Reimann, and Krummenacher (2003) who showed that priming effects are top-down modulable. The authors (2003) used the method of trial by trial cueing in a pop-out task. The target defining feature (color or orientation) was cued (validly or invalidly) prior to the display onset by presenting the cue word “color” or “orientation”. In various experiments, the authors obtained results in favour of dimension-specific cueing effects leading to RT benefits in pop-out tasks. This shows that the priming is the top-down modulable. The top-down processes modulate the priming performance in a way that when attentional resources are allocated to a certain dimension (i.e. color), all dimension related features are activated across subsequent trials. In other words, knowing that the target defining feature is color in advance and setting certain expectations on this, independent of the target’s actual color, the valid pre-cueing modulates the priming performance.

1.7 Positional Priming of Pop-out Paradigm

Systematic analyses of the target location in the current relative to the previous trial lead evidence for positional priming. In their pioneering study, Maljkovic and Nakayama (1996) let their observers perform a pop-out search task, with the displays consisting of three diamond shaped stimuli (1 target, 2 distractors). The three items were presented on an elliptical layout and arranged by means of an apparent equilateral triangle, which phenomenally appeared to rotate across trials. The target was defined by its color relative to the distractors: when it was red, the distractors were green and vice versa. Each stimulus had a cut-off section either at the left or right side. Observers’ task was to respond to the cut-off side of the target stimulus (left versus right – henceforth referred to as the target’s orientation). Across trials, the color, orientation, and position of the target could change randomly. Maljkovic and Nakayama (1996) analyzed RTs to the current target as a function of its location in the previous trial(s). There were three different inter-trial transitions: Target at previous target location (TT), target at previous distractor location (TD), and target at previously empty (i.e., neutral) location (TN) (See Figure 4). The latter served as a baseline condition against which RTs were compared in the TT and TD conditions. It was found that RTs were fastest for trial n targets presented at n-1 target locations, intermediate for trial n targets presented at n-1 neutral locations, and slowest for trial n targets presented at n-1 distractor locations. Further experiments by the authors showed that both the *facilitatory priming* effect (RT_{TN} minus RT_{TT}) and *inhibitory priming* effect (RT_{TD} minus RT_{TN}) extended back up to 5-8 trials. Maljkovic & Nakayama (1996) attributed their findings to the operation of a ‘primitive’ priming memory system, which was surmised for storing item locations – and associated valence tags (positive or negative), and which function is to aid attention deployments. In their Experiment 3, Maljkovic and Nakayama (1996) investigated the spatial coordinate frames of positional priming effects. 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 trials. Both conditions yielded significant priming effects, suggesting that positional facilitation minimally requires that the target is presented at the relative-same location within a given visuospatial configuration (i.e., object-based frame).

Further studies on the spatial coordinates of positional priming effects showed that positional priming is supported also by an observer-centered reference frame. Ball, Smith, Ellison, and Schenk (2009) asked their observers to discern the presence/absence of an orientation singleton: a left-tilted target line amongst right-tilted distractor lines (the display size was kept constant at 12 elements; the target was present in 80% of the trials). There were four priming conditions: egocentric, allocentric, combination of allocentric and egocentric, and control condition. In the egocentric condition, the target appeared at the very same display (and retinal) location across two successive trials. Note that in this condition, the target was positioned at different locations relative to a ‘landmark’ distractor (a distractor item consisting of two lines, instead of only a single line). In the allocentric condition, the target was presented at the very same location relative to the ‘landmark’ distractor, but at a different display (and retinal) location. In the combined condition, the target location was same in display and ‘landmark’ coordinates. In the control condition, the target appeared at a novel location; this served as a baseline against which priming effects were compared in the other three conditions. The results were that of significant priming in all conditions. However, the effect was reliably larger in the combined and egocentric relative to the allocentric condition. This pattern led Ball et al. (2009) to conclude that target positions are represented in positional short-term memory by means of a body-centered (i.e., retinotopic and / or spatiotopic) code.

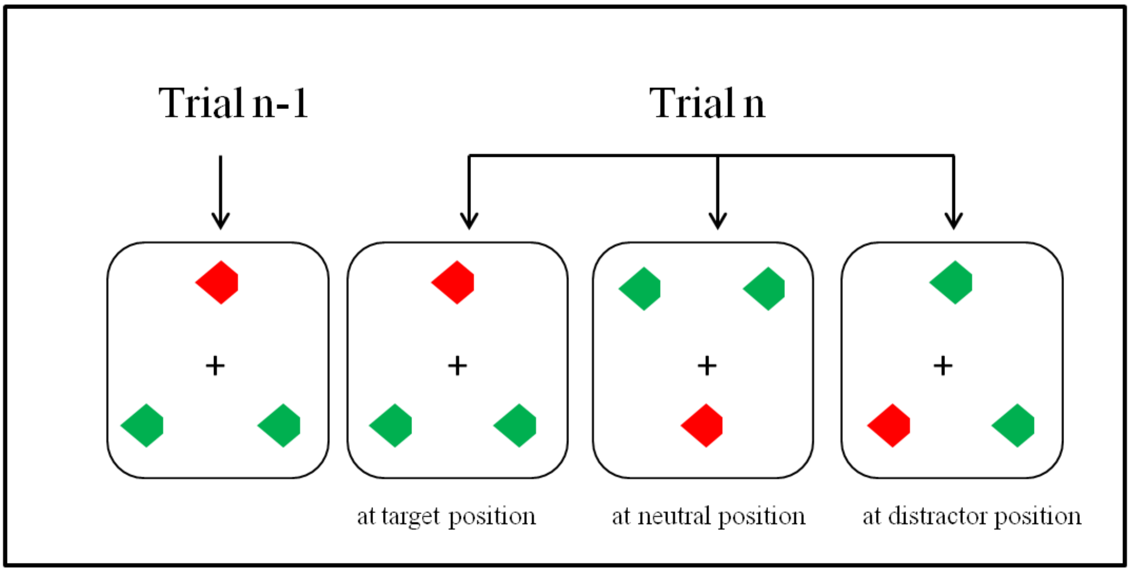

Figure 4.The illustration of the positional priming of pop-out paradigm (Maljkovic & Nakayama, 1996). In the current trial *n*, the target (here in red) could be located at the trial *n-1* target neutral (empty) / target / distractor locations. Presenting the target at the previous target / distractor position leads to the facilitation of the target location or inhibition of the distractor location respectively compared to the condition where target is presented at previous neutral (empty) position. Figure adapted from Maljkovic & Nakayama (1996).

Further studies were conducted by Geyer and colleagues (2007a, 2009, 2010) on the relationship between object-centered representations and positional priming effects. In one of the studies, Geyer, Müller, and Krummenacher (2007a) showed that the predictability of the triangular arrangement of the stimulus configuration can affect the positional priming effects. Of relevance here is Experiment 2B where the overall arrangement of the items was modulated by separating the distances between the target and the distractors which disrupted the near-equilateral triangular configuration. This made it possible to make the target and distractor locations unpredictable and also enabled to compare the priming performances across regular and irregular configurations. In the control experiment (2A) only regular triangular arrangements were used. It was found that there was no reliable inhibitory priming for the distractor locations in Experiment 2B whereas the facilitatory priming effect was almost unaffected by the variations of the inter-item distances. This indicates that in order to obtain reliable inhibitory priming effects across trials, regular triangular arrangements must be used. Moreover, distractor inhibition, but not target facilitation, was influenced by the observers’ practice on the task: The inhibitory effect was larger – i.e., extended longer back in time – with practiced relative to unpractised performance (Geyer et al., 2007a). Related to this, Geyer, Zeheitleitner, and Müller (2010) put forward the idea of relational encoding account. Again a similar version of Maljkovic and Nakayama’s task (1996) was used. Here, displays with 2 items (1 target, 2 distractors) were mixed with 3-item displays (1 target, 2 distractors). The 3-item displays had the majority of the overall trials (80%). The target color was kept constant; otherwise the task could not be performed in the 2-item display conditions. The relevant inter-trial transition would be from 2-item displays to 3-item displays (trial *n-1* to trial *n*). In this case, the target would appear at a previously visible or empty location. The empty location here would substitute the location of a distractor in the majority of trials. The interesting result was that the inhibition of the distractor in this condition was still present although there was no visible distractor stimulus. On the basis of this, it can be concluded that the distractor locations are inhibited in relation to the target (‘anchor’) location or the center-of-mass of sets of items (Alvarez & Oliva, 2008).

The distinction between the facilitatory and inhibitory priming effects were also demonstrated in a neuropsychological study (Finke, Bucher, Kerkhoff, Keller, von Rosen, Geyer, Müller, & Bublak, 2009). In their study, patients with left-sided visual neglect and healthy controls performed the priming of pop-out task (Maljkovic & Nakayama, 1996). Interestingly, while the facilitatory priming effect was present in both groups, the inhibitory priming effect was reduced in the neglect compared to the control group. Additionally, two patients with lesions close to the frontal eye field showed almost no inhibitory priming (but reliable facilitation).

The main conclusions that could be drawn from the series of these studies about the nature of the positional priming effects are as follows: (1) Facilitatory and inhibitory are distinct phenomena (Finke et al., 2009); (2) Distractor location are tracked in positional short-term memory with regard to the object (‘triangle’) configuration of the search items (3) Target locations in contrast, are stored in priming memory in space-based coordinates, through a substantial amount of target location priming be attributed to the object (i.e., configural) representations (see, e.g., Maljkovic & Nakayama, 1996; Experiment 3).

1.8 Overview of the Thesis

The evidence presented in the previous sections shows that spatial memory components play an important role in visual search and selective attention mechanisms. The repetition of target features from one trial to the next can facilitate RT performance in the current trial, the effect known as priming of pop-out. Repeating/changing the target’s position across trials lead to target facilitation and distractor inhibition effects. This thesis focuses on how target facilitation and distractor inhibition priming effects are represented in visuospatial memory (Chapters 2 and 3) and how they are expressed in the brain using electrophysiological measures (Chapter 4). Chapter 5 provides a more direct test for the thesis that position priming memory and WM share representations.

Chapter 2 investigated the representations(s) underlying positional priming of visual pop-out search (Maljkovic & Nakayama, 1996). Three search items (1 target and 2 distractors) were presented at different locations, arranged at the horizontal display axis (Experiment 1.1), at the vertical axis (Experiment 1.2) or both along the horizontal and vertical axes (Experiment 1.3). In these experiments the number of the display regions to present the fixation cross and the search display varied. In Experiments 1.1 and 1.3, 3 display regions were used creating either horizontal (Experiment 1.1) or vertical (Experiment 1.3) shifts. In Experiment 1.2, 7 display regions were used which enabled to make both horizontal and vertical shifts. While the presentation of the search display was predictable in Experiments 1.1 and 1.3, it was unpredictable in Experiment 1.2.

By these manipulations it was possible to disentangle retinotopic, spatiotopic, and object-centered priming representations separately for facilitatory and inhibitory priming effects. Previous findings suggest that position priming is supported by both spatiotopic (Maljkovic & Nakayama, 1996; Ball et al, 2009; Jonikaitis & Theeuwes, 2013 and object-centered (Geyer et al., 2010; Tower-Richardi, Leber, & Golomb, 2012) representations. The main question of this chapter is whether there are differences in the relative contributions of one over the other reference frame in the positional priming of pop-out effects. It was found that the target locations were coded in positional short-term memory with reference to both spatiotopic and object-centred, representations (Experiments 1.1, 1.3 vs. 1.2). In contrast, distractor locations were maintained in an object-centred reference frame (Experiments 1.1, 1.2, and 1.3). This finding suggests that the uncertainty induced by the experiment manipulation (2 vs. 6 peripheral display regions in Experiments 1.1, 1.3, and 1.2 respectively) is the underlying cause of the transition from spatiotopic to object-centered representation.

Given the fact that inhibitory priming – and facilitatory priming –is object-centered (Chapter 2 of this thesis; Geyer et al., 2010), Chapter 3 investigated which object (configural) attributes are stored in positional priming memory. Chapter 3 distinguishes between spatial configurations versus categories. By using a variant of Maljkovic and Nakayama’s (1996) priming of pop-out task, the singleton target and the distractors were be presented in different visuospatial contexts across trials, permitting positional priming based on individual locations to be disentangled from priming based on inter-item configural relations. Individual display items are perceptually organized into (object-like) groupings (Wertheimer, 1950). An object category is formed by a set of unique geometrical elements which 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; see Garner & Clement (1963)). The search items were arranged as Z- or, respectively, T-configurations, varying across the trials. In addition, the configuration of the search items was surrounded by a white Z- or T-shaped border, reinforcing the inter-element grouping. These conditions made it possible to assess the positional priming of target and distractor locations on consecutive trials of repetitions vs. changes of the configurations and repetitions vs. changes of the categories. Three inter-trial transitions were possible: configuration-repetition, configuration-change, and category-change. The configuration-repetition condition served as a baseline (providing maximum priming effects). In the configuration-change 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. Finally in the category-change condition, different displays were presented across consecutive trials (e.g. Z-type display was followed by T-type display) which changed the visuospatial categories and configurations across the trials. Facilitatory and inhibitory priming effects were found to be evident and substantial in the baseline – configuration repetition – 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 VSTM – as individual items, but rather as elements of an encompassing configuration.

This chapter also focused on investigating at which stage the positional priming of pop-out contributes to the information processing chain. Namely the pre-attentive or post-selective processes would attribute the priming effects in visual pop-out search that speed-up processes that occur prior to or, respectively, after the selection of the target by focal attention. Regarding the latter accounts, it has been suggested that priming can act on various (post-selective) processes, including (1) 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); (2) response selection (e.g., Yashar & Lamy, 2011; Töllner et al., 2008); and/or (3) response preparation (or production; Töllner et al., 2008, 2012). Although the present investigation cannot ultimately decide among these three processes, the evidence obtained suggests that target verification (Huang et al., 2004) is the likely cause of positional repetition effects in visual pop-out search. It was hypothesized that positional priming would aid stimulus verification process and that this would involve visuospatial stimulus attributes as well. However, given that only facilitatory priming of target locations was found to be dependent on repetitions vs. changes of the previous target's response feature, it is suggested 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 vs. changes of the previous target's response feature. This may be taken to indicate that the distractor features are maintained in a memory that, rather than impacting the speed of the verification process, influences other processes involved in search.

Chapter 4 investigated the electrophysiological correlates of the positional priming of pop-out. The ERP components of interest were the Ppc component, posterior contralateral negativity (PCN) component, contralateral delay activity (CDA) component and finally the stimulus- and response-locked lateralized readiness potentials (LRP). In order to test the lateralization effects, a variant of Maljkovic and Nakayama's (1996) task was used with four, instead of three, stimuli presented on a circular layout. A 4-item layout was necessary in order to equalize signal strength between the two hemifields. The sensory-driven ERP components were modulated as a function of target position change. Processing of targets occurring at previous distractor, relative to previous neutral and target, locations modulated the elicitation of the Ppc and PCN waves, indicating that distractor positions are suppressed at early stages of visual processing. Processing of targets occurring at previous target, relative to previous neutral and distractor locations, by contrast, modulated the elicitation of the CDA wave, indicating that post-selective target identification processes are facilitated if the target occurred at the same position as on the previous trial.

Chapter 5 investigated whether spatial WM contents influence the facilitatory and inhibitory priming effects.Observers were presented with a to-be-memorized item (Experiment 4.1: triangle, Experiment 4.2: circle) at the beginning of each block and were asked to recall the to-be-remembered item among the three test items at the end of a block. In Experiment 4.3, the memory test was conducted prior to the start of a block. This experiment, without a memory condition, served as a control condition. It was found that inhibitory priming effects were larger in the memory condition (Experiment 4.1) than in the no memory condition (Experiment 4.3). Moreover, the effects were comparable in Experiment 4.2 (‘circle’ memory) and Experiment 4.3 (no memory baseline), suggesting that increased distractor inhibition in Experiment 4.1 (triangle memory) is due to an overlap in the contents of WM and priming memory (triangle), and not because the secondary WM and search task share executive WM capacity.

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Chapter 2:

Positional priming of visual pop-out search is supported by multiple spatial reference frames

Abstract

This chapter investigated the representations(s) underlying positional priming of visual 'pop-out' search (Maljkovic & Nakayama, 1996). Three search items (1 target and 2 distractors) were presented at different locations, arranged at the horizontal display axis (Experiment 1.1) or both at the horizontal and vertical axes (Experiment 1.2). By these manipulations it was possible to disentangle retinotopic, spatiotopic, and object-centered priming representations. Two forms of priming were tested: Target location facilitation (i.e., faster reaction times – RTs– when the trial *n* target is presented at a trial *n-1* target relative to *n-1* blank location) and distractor location inhibition (i.e., slower RTs for *n* targets presented at *n-1* distractor compared to *n-1* blank locations). It was found that target locations were coded in positional short-term memory with reference to both configuration-independent, i.e., spatiotopic / retinotopic, representations and configuration-dependent, i.e., object-centered, representations (Experiments 1.1 vs. 1.2). In contrast, distractor locations were maintained in an object-centered reference frame (Experiments 1.1 and 1.2). It is claimed that the uncertainty induced by the experiment manipulation (2 vs.6 peripheral display regions in Experiments 1.1 and 1.2 respectively) is the underlying cause of the transition from spatiotopic to object-centered representation.

Keywords: Visual search, positional priming of pop-out, spatial reference frames, working memory

Introduction

In visual search, observers select, identify, and act upon a target item which is embedded in a set of distractor items. Previous research has shown that multiple mechanisms contribute to search (in particular reaction time – RT) performance. These mechanisms can broadly be classified into stimulus- and expectation-based, that is, bottom-up and top-down guidance of selective attention (e.g., Wolfe, 1998). A third form of guidance is based on visual memory, with one form operating short-term across search episodes and producing 'repetition priming' (Kristjánsson & Driver 2008; Zehetleitner & Müller, 2010). Conceptually, priming effects in visual search can be attributed to the operation of visual short-term memory (VSTM) influencing the speed of attentional selection (Fecteau & Munoz, 2003) – though priming might aid post-selective processes, too (Hillstrom, 2000, Yashar & Lamy, 2011, Töllner, Gramann, Müller, Kiss, and Eimer, 2008). In visual search, priming effects have been reported for a number of stimulus attributes, including specific features (Chun & Nakayama, 2000; Maljkovic & Nakayama, 1994), whole feature dimensions (Found & Müller, 1996; Müller, Heller, & Ziegler, 1995, Töllner, Zeheitleitner, Gramann, and Müller, 2010), locations (Maljkovic & Nakayama, 1996), and the search objects themselves (Huang, Holcombe, and Pashler, 2004).

The current set of experiments was designed to further examine memory-based guidance of attention in 'pop-out' (singleton) feature search, in particular, how selected target and de-selected distractor items are tracked across trials in implicit VSTM for item locations, giving rise to facilitatory and inhibitory positional priming effects, respectively (Maljkovic & Nakayama, 1996). The specific questions were: (i) When a target is selected at a certain location in singleton feature search, is the attended location coded with respect to the observer – in a retinotopic or spatiotopic VSTM representation – or, alternatively, relative to the environment – in an object- or configuration-centered representation? (ii) Likewise, when distractors are filtered from search, are their locations coded in exact screen (eye) or object-centered coordinates? Concerning these two questions, prior investigations of the memory-based guidance of attention have shown target and distractor location priming to be distinct phenomena, in both functional and neuronal terms (Maljkovic & Nakayama, 1996; Finke, Bucher, Kerkhoff, Keller, von Rosen, Geyer, Müller, and Bublak, 2009; Kristjánsson Vuilleumier, Schwartz, Macaluso, and Driver, 2007).

The question of the spatial coordinate frames supporting facilitatory priming of target and inhibitory priming of distractor locations is not new. Several previous studies have attempted to address this issue (Maljkovic & Nakayama, 1996; Ball, Smith, Ellison, and Schenk, 2009; Tower-Richardi, Leber, and Golomb, 2012; Geyer, Zehetleitner, and Müller, 2010; these studies will be reviewed in more detail below). However, their results are mixed with regard to the exact reference frame(s) of VSTM for item locations. Arguably, to understand why results – and conclusions – are divergent, it is worth evaluating any differences in paradigms between the critical studies. This is the approach taken in the present study, namely, to re-investigate the reference frames of both target and distractor location priming using a set of different spatial manipulations (see Figure 3). To preview the results, it was found that the target locations are maintained in positional-priming memory by means of both viewer-dependent (i.e., spatiotopic / retinotopic) and viewer-independent (i.e., object-centered) representations, with the latter coming to the fore particularly under conditions of variable, and thus unpredictable, placement of the item across trials. In contrast, distractor locations are tracked in position priming memory almost entirely by means of object-centered representations.

Multiple reference frames support position priming in visual pop-out search

The representation of items in positional priming memory requires a spatial reference frame for ‘pinpointing’ the element locations. Previous work suggests that memory items can be represented in a number of reference frames, for instance, observer-centered or world-centered frames. For example, Ball, Smith, Ellison, and Schenk (2009) reported evidence that positional priming is supported by an observer-centered reference frame. In their study, observers had to discern the presence (vs. absence) of an orientation singleton: A left-tilted target line amongst right-tilted distractor lines (the display size was kept constant at 12 elements; the target was present in 80% of the trials). There were four priming conditions: Egocentric, allocentric, combination of allocentric and egocentric, and control condition. In the egocentric condition, the target appeared at the very same display (and retinal) location across two successive trials. Note that in this condition, the target was positioned at different locations relative to a ‘landmark’ distractor (a distractor item consisting of two lines, instead of only a single line). In the allocentric condition, the target was presented at the very same location relative to the ‘landmark’ distractor, but at a different display (and retinal) location. In the combined condition, the target location was same in display and ‘landmark’ coordinates. In the control condition, the target appeared at a novel location; this served as a baseline against which priming effects were compared in the other three conditions. The results were that of significant priming in all conditions. However, the effect was reliably larger in the combined and egocentric relative to the allocentric condition. This pattern led Ball et al. (2009) to conclude that target positions are represented in positional short-term memory by means of a body-centered (i.e., retinotopic and / or spatiotopic) code.

However, this result – and conclusion – was only partially supported by subsequent studies (Geyer, Zeheitleitner, and Müller, 2010; Tower-Richardi, Leber, & Golomb, 2012; see also Maljkovic and Nakayama, 1996). For instance, Geyer et al. (2010) investigated the spatial reference frame(s) underlying cross-trial memory for distractor locations, instead of target locations. Their findings support the view that distractor location priming is supported by object-centered representations. Geyer et al. (2010) used a task adapted from Maljkovic and Nakayama (1996): on a given trial, there were three search items (1 target, 2 distractor diamonds) that were arranged in a (near-) equilateral triangle configuration. The target was a feature (i.e., color) singleton that was either red amongst green distractors or vice versa (the target's color changed unpredictably across trials). Observers' task was to respond to the cut-off side of the target diamond (left vs. right; varying randomly). Across trials, the target and the distractors could also change their locations, which phenomenally made them appear as a rotating triangle. RTs were analyzed as a function of the location of the target across consecutive trials. Two effects were observed. First, targets presented at previous target locations elicited faster RTs (i.e., target facilitation); second, targets presented at previous distractor locations led to slower RTs (i.e., distractor inhibition) – with both facilitatory (target location) and inhibitory priming (distractors locations) assessed relative to targets presented at previous empty locations (i.e., a neutral – 'baseline' – condition). Of particular relevance here is Experiment 3 of Geyer et al. (2010), in which they mixed 3-item displays (presented on the majority of trials) with 2-item displays (presented on the minority of trials; in these displays, there was 1 target and only 1 distractor, rather than the usual 2 distractors); target color was kept constant across trials so that observers could unequivocally discern the target even in 2-item displays. The critical manipulation was the location of the target in a 3-item display preceded by a 2-item display. In such transitions, the target (in the 3-item display) appeared either at a previously (in the 2-item display) occupied or at a previously empty distractor location – in the latter case, at a location where observers would have expected a distractor within the overall triangular item configuration presented on the majority of trials. Of note, targets presented at a previously empty distractor location led to RT slowing (i.e., distractor inhibition) – even though the target position had contained no distractor on the previous trial. And, the RT disadvantage for previously empty distractor locations was of same magnitude as that found for previously visible distractors.

The finding of inhibition arising even from empty distractor locations led Geyer et al. (2010) to conclude that the inhibitory effect is represented in an object-centered (i.e., triangle) reference frame. Geyer and colleagues (Geyer et al., 2010; Geyer, Krummenacher, & Müller, 2007) referred to this as 'relational encoding account' of inhibitory positional priming (see also Jiang, Olson, & Chun, 2000, or Kunar, Humphreys, Smith, & Hulleman, 2003, for related proposals, albeit using different paradigms). Similar findings were obtained by Tower-Richardi et al. (2012), who tested whether target position priming survives eye movements – a question that is similar to the issue of object-centered priming in visual search. Their findings suggest that target location priming is indeed supported by configural representations. Nevertheless, they also found indications that a substantial proportion of the facilitatory effect is mediated by spatiotopic representations.

Effects of spatial uncertainty on the reference frame coding

The evidence reviewed above suggests that items in positional short-term memory can be represented in multiple reference frames. However, the studies presented so far have also some limitations. For example, Tower-Richardi et al. (2012), Ball et al. (2009), and Maljkovic and Nakayama (1996) investigated only the reference frame(s) underlying target location priming. Ball et al. (2009) found evidence for egocentric target position priming. However, on the basis of Ball et al.'s (2009) egocentric condition, it is impossible to disentangle retinotopic from spatiotopic target position priming. Furthermore, Tower-Richardi et al. (2012), as well as Maljkovic and Nakayama (1996; Experiment 3), were missing an appropriate baseline condition in their design. Tower-Richardi et al. measured priming in a retinotopic (i.e., trial *n* target at identical trial *n-1* retinal position), a spatiotopic (i.e., trial n target at identical trial *n-1* display location), and an object-centered condition. In the latter, the trial *n* target reappeared at the identical trial *n-1* location within the 'square' object configuration (in Tower-Richardi et al., the search displays consisted of four elements

– 1 target and 3 distractors – arranged in a virtual square). Critically, priming effects in these conditions were assessed relative to a control condition in which the target, across trials, was presented at a previous distractor location. However, as mentioned above, there is good evidence that target location facilitation and distractor location inhibition reflect independent mechanisms (e.g., Maljkovic and Nakayama, 1996; Geyer et al., 2010; Finke et al., 2009; see also Lamy, Antebi, Aviani, Carmel, 2008; and Kristjánsson & Driver, 2008, for similar evidence pertaining to featural priming). Thus, it is not clear whether position repetition effects in Tower-Richardi et al. (2012) reflect attentional facilitation of the target location and / or inhibition of distractor locations. Restated, it is unclear whether the target and / or the distractor locations are represented in an object-centered, in addition to a spatiotopic, reference frame. And the problem associated with Geyer et al. (2010) is that the analysis of position repetition effects was limited to inhibitory distractor priming (the results were that of object-centered distractor inhibition). Thus, it remains an open issue whether item locations in positional priming of singleton feature search are represented in viewer-dependent (spatiotopic / retinotopic) or environment-centered (object-centered) reference frames and whether there are differences in the coordinate systems underlying the priming of target and distractor locations.

Experiments 1.1, 1.2, and 1.3

On this background, the aim of the present experiments was to re-investigate the reference systems underlying target and distractor location priming. Previous findings suggest that positional priming is supported by both viewer-dependent and viewer-independent representations. The main question addressed in the current study was whether there are differences in the relative contributions of viewer-centered and environment-centered reference frames to positional priming, and – if so – which conditions would promote the transition from one to the other reference frame.

Maljkovic and Nakayama's (1996) findings are consistent with the target location priming being supported by environment-centered representations. In their Experiment 3, they presented the array of three search items in, across trials, systematically varying quadrants of the display screen. Ball et al. (2009), by contrast, reported evidence suggesting that target locations are stored in positional priming memory with regard to a viewer-centered reference frame. In their study, though, the search items appeared always in the center of the display (with the target's absolute screen location varying, across trials, within in the overall array of search items). Thus, an apparent difference between these two studies lies in the placement of the stimuli across trials. While in Ball et al.'s (2009) study, it was certain for observers to expect, and subsequently search for, the target in the center of the display, in Maljkovic and Nakayama's (1996) study, the items were presented off-center. Across the trials, the displays were shown in randomly chosen screen quadrants. If this is the crucial difference generating the differential results, it would suggest that the reference frame underlying positional priming is influenced by certainty (or the lack thereof) with regard to the placement of the search items across trials. A relatively high degree of certainty – or predictability – in item placement may lead to the adoption of a viewer-centered reference frame. By contrast, conditions of unpredictable stimulus placements may foster the adoption of configuration-centered priming representations. – The experiments reported in this chapter were designed to test this hypothesis.

In Experiments 1.1 and 1.2, the search displays were presented systematically in the left and right visual hemifields, relative to the fixation, or vice versa across the trials (an exception was the baseline condition in which the search items were presented always at the screen center). In Experiment 1.1, the search items appeared in only one – and thus predictable – display region in the left or, respectively, the right visual hemifield (this approach was similar to Ball et al., 2009; the prediction was that of viewer-centered, i.e., spatiotopic / retinotopic, target location priming). In Experiment 1.2, by contrast, the stimuli were presented in either the upper, central, or lower– that is, an uncertain – display region in the left or, respectively, the right visual hemifield (an approach similar to Maljkovic and Nakayama, 1996; the prediction was that of configuration-centered target location priming). In contrast, distractor location priming was expected to be relatively uninfluenced by the experimental manipulations and supported largely by object-centered representations. The latter prediction derives from Geyer et al. (2010), who reported evidence for object-centered distractor location priming, even under conditions of predictable stimulus placements (in Geyer et al., the search items were shown always at the screen center).

Method

The general set-up was identical for Experiments 1.1 and 1.2. Participants performed a version of the ‘priming of pop-out’ visual search task first introduced by Maljkovic and Nakayama (1996). Across trials, the target-defining feature (color) and the response-defining feature (left/right ‘orientation’ of the cut-off section) were manipulated independently, in addition to the location of the target (transition from preceding trial *n-1* to current trial *n*): target-at-target, target-at-distractor, or target-at-neutral location, respectively.

Participants

14 different observers participated in two experiments (28 observers in total; female: 20; mean age = 25 years, *SD* = 3.18 years). They were recruited from the subject panel of the Psychology Department (Units of General & Experimental Psychology / Neuro-Cognitive Psychology). All participants had normal or corrected-to-normal (color) vision and, except for one participant, all were right-handed. They were naïve as to the purpose of the study (but debriefed afterwards about its aims) and gave informed, written consent prior to their participation. Anonymity of their recorded and stored response data was guaranteed.

Participants were paid at a rate of 8 Euro (10 USD) per hour or received course credits for their participation.

Apparatus & Stimuli

Stimulus generation / presentation and response recording were controlled by a standard Intel PC equipped with Microsoft Windows XP Prof operating system; the experimental control software was purpose-written in C++. An LG Plasma TV was used for stimulus presentation, with screen resolution set to 1440 x 900 pixels. Participants responded via the computer keyboard placed in front of them. The distance between the participant and the screen was approximately 68 cm. Head positions were maintained by the use of a chin rest. The experimental cabin was dimly lighted.

In both experiments, eye movements were recorded using an SR Research EyeLink II system (software version: 2.22), so that trials on which observers made saccades in the critical (spatiotopic, object-centered) conditions could be detected and excluded. Table 1 presents the proportion of the trials excluded due to the occurrence of eye movements; separately for the two experiments (Table 1 also shows the results from a third – control – experiment, which will be introduced in the Results Section). Eye movements were classified as saccades using EyeLink II's standard settings (i.e., speed > 35°/s; acceleration $9500°/s^2$). A trial was considered as an eye movement trial if the eyes departed from the fixation cross and landed within an imaginary square frame, of side lengths 7.92°, centered on the search stimuli. The proportion of eye movements was comparable across the two experiments [7.3% and 9.2% in Experiments 1.1 and 1.2, respectively; *t*(1, 26)=.33, *p*=.74]. Further, the stimuli were presented at the central region of a relatively large Plasma TV monitor (screen diagonal: 107 cm) to prevent edge effects in the determination of reference frames, such as cross-trial tracking of the search items relative to the monitor edges, which would be equivalent to operating in an object-centered frame.

The search display consisted of three diamond-shaped stimuli presented on a white background (30.0 cd/m²): one target and two distractors (size 2.21° x 1.88°). When the target was red, the distractors were green, and vice versa. The colors were chosen to be near-equiluminant: red, 7.7 cd/m²; green, 8.0 cd/m². All stimuli had a cut-off section (size: 0.78° x 0.70°) either on the left or the right side, which was determined randomly (see Figure 1). The black fixation cross had a size of 1.49° x 1.34° and a luminance of 0.5 cd/m². The fixation cross remained on the screen until the response was given, to make it easier for participants to suppress eye movements (they were instructed to maintain gaze at the fixation cross; see Figure 1). Pilot testing showed that with stimulus sizes of about 2.0° and cut-off section sizes of about 0.7° (the retinal eccentricity was approximately 10.0°), the target's orientation could be discriminated without gaze shifts.

	Exp. 1.1	**Exp. 1.2**	**Exp. 1.3**
Proportion of trials excluded due to eye movements	7.3%	12.8%	9.2%
Proportion of trials excluded due to extreme RTs	2.8%	2.0%	2.3%

Table 1. Proportion of trials in Experiments 1.1 through 1.3 excluded due to eye movements (only spatiotopic, object-centered condition) and extreme RTs (i.e., individual trial RT±2.5 *SD*'s from the mean RT).

The search items were arranged on an elliptical layout with horizontal and vertical axes of 7.14° and 6.77°, respectively. There were six possible target and distractor locations on the virtual ellipse. With respect to the previous trial *n-1*, targets on the current trial *n* appeared at one of three types of position: At the same position as the target on the previous trial (probability: 1/6), at the position of a distractor on the previous trial (probability: 2/6), or at a position where there had been no stimulus on the previous trial (i.e., neutral condition: probability: 3/6).

In Experiment 1.1, there were three possible display regions, arranged on the horizontal display axis, for the fixation cross and the search items to appear: On the left side, in the center, and on the right side of the screen. These display regions were separated by a (center-to-center) distance of 9.63°. Observers' task was to press the Y-key (on a German keyboard) when the target's cut-off side was on the left and the N-key when the cut-off side was on the right, while responding as fast and accurately as possible. The dependent variables were the RTs, response errors, and the oculomotor measures (i.e., saccade locations – used to detect and eliminate critical eye movement trials). In Experiment 1.2, the three search items appeared at one out of a total of seven display regions, arranged across the horizontal and vertical display axes. Three regions were on the left side, another three on the right side, and one region in the center of the display (see Figure 3; this figure also contains an illustration of the 'control'-Experiment 1.3, presented in the Results Section).

Procedure

Each experiment consisted of a practice session (4 blocks x 20 trials; data not recorded) and an experimental session (10 blocks x 96 trials). In the experimental session, 40% of all trials (i.e., 4 blocks) were control trials. In the remaining 60% of the trials (i.e., 6 blocks), observers performed the retinotopic, spatiotopic, or object-centered conditions (20% or 2 blocks each). These conditions were kept constant within a block, but their order was randomized across blocks. The relative dominance of the control condition trials over the other (retinotopic, spatiotopic, object-centered, condition) trials was intended to provide observers with practice on the positional priming task (Geyer, Müller, & Krummenacher, 2007, who showed that at least inhibitory priming is practice-dependent). The fixation cross was presented on a white background for 1000 ms and followed by the search items (1 target, 2 distractors) which remained on the screen until the observers executed their response. The inter-trial interval was 1000 ms. No error feedback was given. Each experiment lasted approximately 1.5 hours.

Design

Across the two experiments, positional priming effects (target facilitation, distractor inhibition) were investigated in four different conditions: (1) a baseline condition; (2) a retinotopic condition; (3) a spatiotopic condition; and (4) an object-centered condition (see Figure 1).

In the *baseline* condition, the fixation cross and the three search stimuli were presented in the center of the screen on each trial. The aim of this condition was to provide a full measure of positional priming as the search stimuli appeared at the very same (retinotopic, spatiotopic, and object-centered) locations across trials. Note that the term ‘object’ refers the triangle configuration of the three search stimuli, which was identical, too, across trials. In the *retinotopic* condition, the fixation cross and the search display would be located on, say, the left side of the screen on trial *n-1*, and on the right side on the subsequent trial (*n*). This would require participants to shift gaze from the left (i.e., the fixation cross on trial *n-1*) to the right (the fixation cross on trial *n*), and vice versa across other doublets of trials. Thus, in this condition, only the retinotopic (and object-centered), but not the spatiotopic coordinates were identical across trials. In the *spatiotopic* condition, the fixation cross was located on either the left or the right side of the screen, but the search display was located always in the center of the screen. For example, when the fixation cross was left on trial *n-1*, it was right on trial *n* (and vice versa). Again, this condition would require participants to shift gaze from the left to the right (or vice versa) across trials, but the search items would appear always in the center of the screen. Thus, in this condition, only spatiotopic (and object-centered), but not retinotopic, information was repeated across trials. Finally, in the *object-centered* condition, the fixation cross was always located in the center of the screen, but the three search items changed their absolute locations from left to right and vice versa across trials. For example, when the items were located on the left side of the screen on trial *n-1,* then they were located on the right side on trial *n*. Importantly, in the object-centered condition, only the information relating to the arrangement of the three search items (the ‘triangle object’), but neither the retinotopic nor the spatiotopic coordinates were repeated across trials.

In Experiment 1.2, the search items could appear in seven display regions (instead of three regions as in Experiment 1.1), arranged along both the horizontal and vertical display axes (see also Figure 2). The baseline condition of Experiment 1.2 was identical to Experiment 1.1: The fixation cross and the three search items appeared in the central display region. In the retinotopic condition of Experiment 1.2, both the central fixation cross and the three search items changed their locations from left to right, and vice versa, across trials while appearing, on a given trial, always in the same peripheral region (the critical region on the left or right side was determined randomly on a given trial). This was identical in the spatiotopic and object-centered conditions. However, in the spatiotopic condition, only the fixation cross was presented in one of the six peripheral regions, while the search items appeared always in the center of the display. In the object-centered condition, the fixation cross was presented in the central region, while the search items appeared in one randomly chosen region out of the six peripheral regions. Thus, in the object-centered condition of Experiment 1.2, the target on a given trial was equally likely to appear in one out of three possible display regions (upper, central, lower) in either the left or the right half of the screen, thus engendering uncertainty as to the exact placement of the search items across trials. This was not the case in Experiment 1.1, where the items were presented in only a single (central) region in the left or the right screen half, providing 100% certainty as to the placement of the search items. Figure 3 illustrates the variable cross-trial re-placements of the search items in the object-centered conditions of Experiments 1.1 and 1.2 (and in the ‘control’ Experiment 1.3).

The logic of these conditions was as follows: Cross-trial priming effects should be largest in the baseline condition – because in this condition, retinotopic, spatiotopic, and object-centered coordinates are repeated across trials (assuming that the effects of the three reference frames are additive, at least to some extent). And, by comparing cross-trial effects between the baseline and the other three conditions, one would be able to determine the reference frame(s) underlying target facilitation and distractor inhibition. For example, if priming effects are comparable between the baseline and the spatiotopic condition, but are reduced in the other conditions, then this would count as evidence for spatiotopic priming – because only in this (and the baseline) condition, locational information, in terms of exact X / Y stimulus coordinates, would be repeated across trials. In contrast, if positional priming is object-centered, then facilitation of target locations and / or inhibition of distractor locations should be equivalent between the baseline and all other conditions. This is because in all conditions, the three search items are ‘linked’ within the same triangular configuration and this pattern would be repeated across the trials.

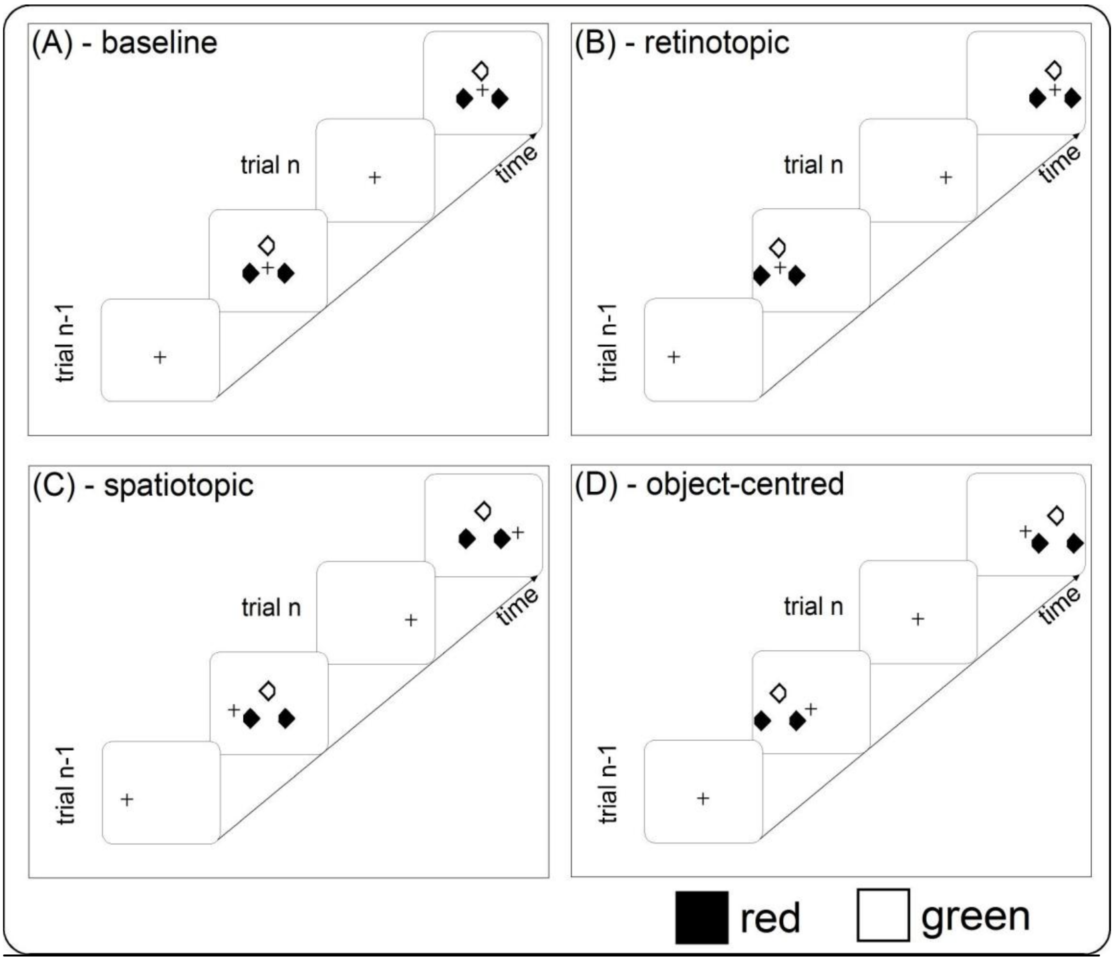

Figure 1. Illustration of the baseline (A), retinotopic (B), spatiotopic (C), and object-centered (D) conditions used in Experiments 1.1 – 1.3.

Results

Oculomotor data were pre-processed using SR Research's 'Data Viewer' software (version 1.8.221). Subsequent data analysis was performed using 'R' (R Development Core Team, 2007) and SPSS (version 19). In all experiments, the first three (warm-up) trials in each block were excluded from the analysis. Further, besides error trials and trials on which eye movements occurred, RTs values ±2.5 *SD*'s from the individual condition mean were discarded as outliers (see Table 1).

Mixed-design ANOVAs were computed to test for the effect of target location (target at target, at neutral, at distractor location; within-subject factor), reference frame condition (baseline, retinotopic, spatiotopic, object-centered; within-subject variable), and experiment (1.1, 1.2; between-subject variable) on response accuracy and RTs (see Table 2). The mixed-design ANOVA on response accuracy revealed significant main effects of experiment [*F*(1,26)=15.29, *p*<.001; response accuracy was higher in the ‘easy’ 3-region Experiment 1.1 than the ‘difficult‘ 7-region Experiment 1.2; 3.7 vs. 4.7%] and target location [*F*(2,52)=73.95, *p*<.001; response accuracy was higher for targets at previous target relative to targets at previous neutral and distractor locations; 3.4 vs. 4.2 and 4.4%]. No further effect was significant (all *F*’s<2).

For the RTs, the ANOVA revealed significant main effects of target location [*F*(2,52)=226.39, *p*<.001] and reference frame condition [*F*(3,78)=37,87, *p*<.001]. Further, the experiment x target position [*F*(2,52)=7.52, *p*<.01] and reference frame x target position [*F*(6,156)=3.08, *p*<.01] interactions were significant. The main effect of reference frame condition was due to RTs being slower in the spatiotopic and object-centered, relative to the baseline and retinotopic conditions (657 and 625 vs. 730 and 715 ms.). This effect is likely due to the fact that in the spatiotopic and object-centered conditions, the fixation cross and search stimuli were presented in spatially separated display regions, requiring the target to be detected / discriminated in the periphery, rather than being presented around fixation, as in the baseline and retinotopic conditions. This would have influenced the time required for sensory evidence (as to the target cut-off side: left vs. right) to accumulate to threshold. The main effect of target location occurred because RTs were fastest for targets at previous target locations, intermediate for targets at previous neutral (i.e., empty) locations, and slowest for targets at previous distractor locations (656, 684, and 706 ms, respectively). Thus, in line with prior research (e.g., Maljkovic & Nakayama, 1996), there was both reliable target facilitation and distractor inhibition (28- and 22-ms effects). The two significant interactions suggest that position priming effects (target location facilitation, distractor location inhibition) were more pronounced overall in Experiment 1.2 than in Experiment 1.1 (34- and 25-ms effects vs. 21- and 21-ms effects; experiment x target position interaction) and that position effects were overall larger in the baseline (target facilitation: 37-ms effect; distractor inhibition: 26-ms effect) compared to the retinotopic (22- and 21-ms effects), spatiotopic (32- and 17-ms effects), and object-centered conditions (19- and 19-ms effects).

	Exp. 1.1			**Exp. 1.2**			**Exp. 1.3**		
	TT	TN	TD	TT	TN	TD	TT	TN	TD
Baseline	614 (2.3)	648 (2.9)	670 (4.6)	634 (3.9)	673 (4.4)	702 (5.4)	639 (2.5)	676 (3.4)	701 (4.3)
Retinotopic	626 (3.3)	644 (3.3)	662 (4.1)	578 (3.5)	609 (4.2)	631 (4.1)	667 (3.2)	687 (3.1)	706 (4.0)
Spatiotopic	692 (1.7)	717 (4.2)	737 (3.5)	712 (4.9)	749 (6.6)	775 (6.4)	716 (3.3)	745 (4.9)	769 (3.6)
Object-centered	711 (4.5)	719 (5.3)	737 (5.0)	682 (4.2)	711 (4.2)	731 (4.6)	765 (3.7)	774 (4.0)	792 (3.7)

Table 2. Mean RTs (in ms) and, in brackets, error rates (%) for trial *n* targets presented at trial *n-1* target (TT), neutral (TN), or distractor (TD) locations, separately for the baseline, retinotopic, spatiotopic, and object-centered conditions in Experiments 1.1 - 1.3.

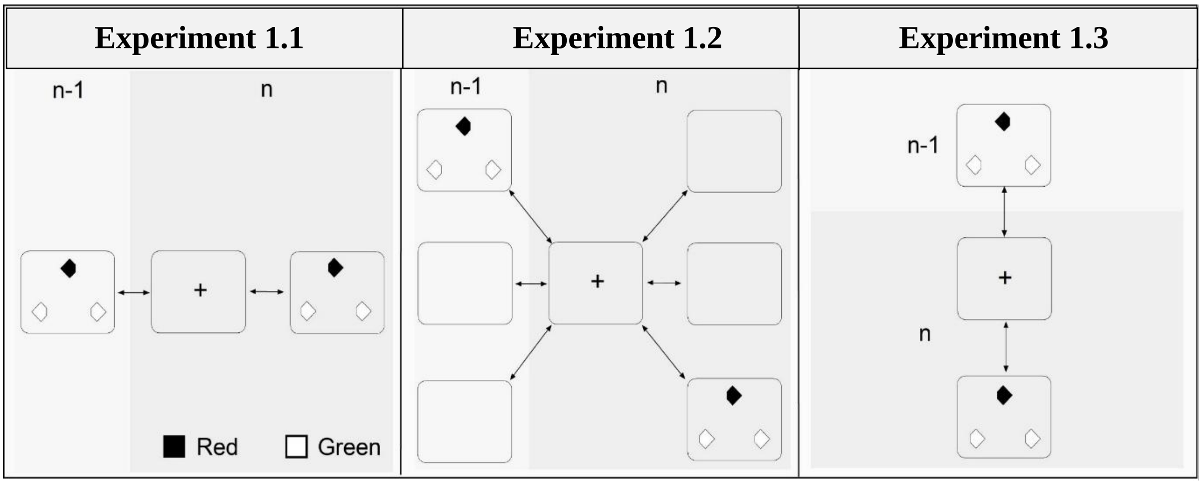

Figure 2. Placement of the three search items (1 target, 2 distractors) and the fixation cross in pairs of trials (*n-1* → *n*) in the object-centered condition. In Experiments 1.1 and 1.3, the search items changed their locations predictably from the left to the right (Experiment 1.1) or the top to the bottom (Experiment 1.3). In Experiment 1.2, the items were presented peripherally at an uncertain location (i.e., at one out of six possible regions in left and right display half).

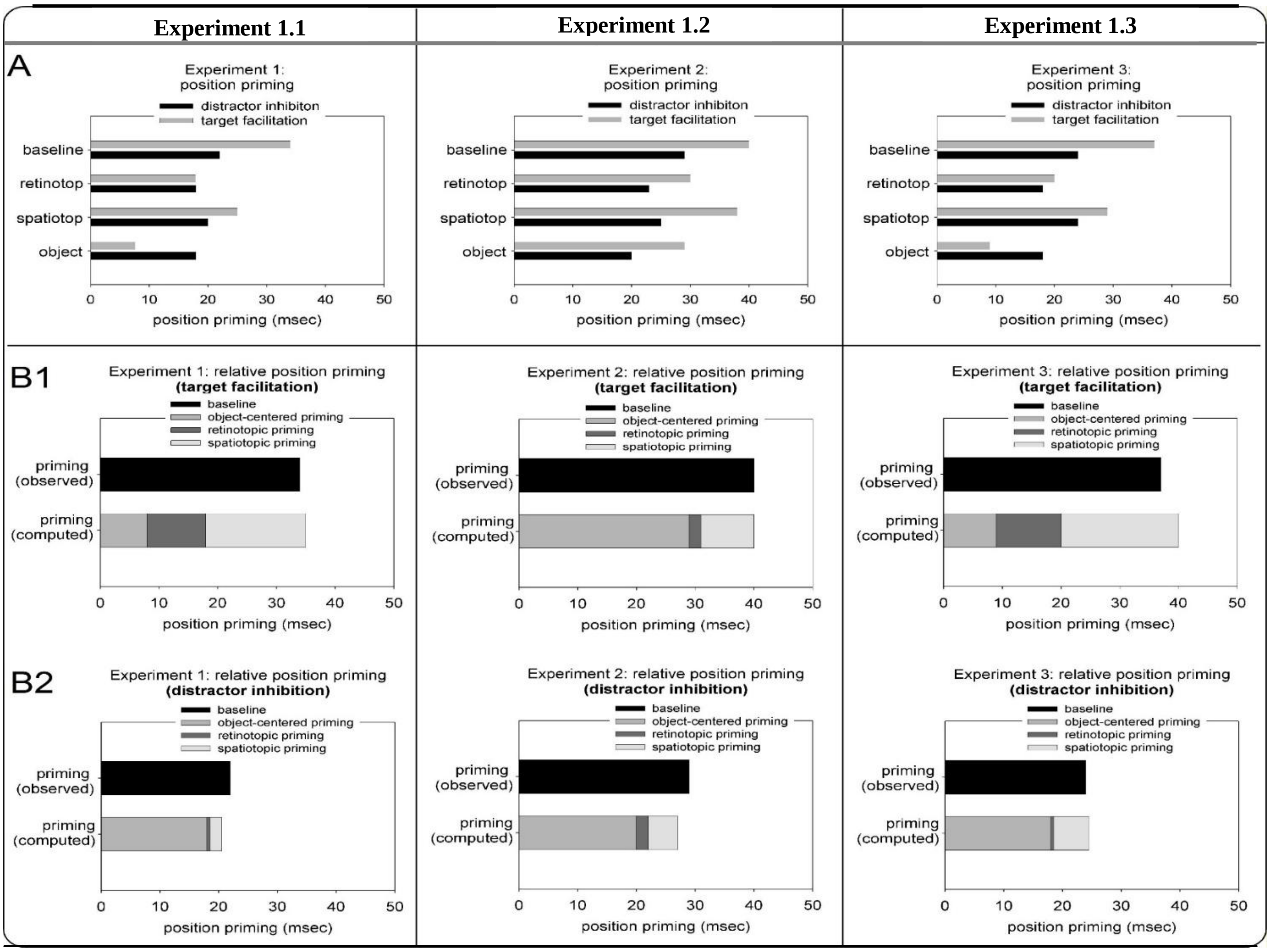

Figure 3. Results in Experiments 1.1 through 1.3. Panel A depicts mean positional priming, i.e., target facilitation and distractor inhibition, in the baseline, retinotopic, spatiotopic, and object-centered conditions. Panels B1 and B2 show the relative contributions of object-centered, retinotopic, and spatiotopic representations to target location priming (B1) and distractor location priming (panel B2). Note that priming effects in the baseline condition (black bars in B1 and B2) were additive, i.e., they could be predicted as the sum of retinotopic, spatiotopic, and object-centered priming effects (stacked gray bars in B1, B2). Further, the contribution of object-centered representations to target location priming varied as a function of the predictability of stimulus locations: object-centered target priming was more marked in Experiment 1.2 than in Experiments 1.1 and 1.3.

As a next step, the relative contributions of retinotopic, spatiotopic, and object-centered representations to target and distractor position priming were quantified, assuming that the effects of the three reference frames are additive (e.g., Tower-Richardi et al., 2012). To this end, the target facilitation (RT target-at-neutral minus target-at-target location condition) and distractor inhibition (RT target at distractor minus target-at-neutral location) were computed and the effects in the retinotopic and, respectively, spatiotopic with that in the object-centered condition were compared. The difference in priming between the retinotopic and object-centered condition is a measure of pure retinotopic priming (priming in the object-centered condition can logically only be influenced by configuration-centered representations; cf. Figure 1). Likewise, the difference between the spatiotopic and object-centered condition provides a measure of pure spatiotopic priming. If (un)certainty in the placement of the search items determines the use of one over the other reference frames, then position priming should be largely viewer-centered, that is, retinotopic and / or spatiotopic, in Experiment 1.1, but configuration-centered in Experiment 1.2. The results of this analysis support this assumption. A 3 x 2 mixed-design ANOVA on target facilitation with the factors priming type (retinotopic, spatiotopic, object-centered; within-subject variable) and experiment (1.1, 1.2; between-subject variable) revealed a (borderline) significant interaction [$F(2,52)=2.10$, $.05 < p < .10$]. Post-hoc (LSD) tests showed that object-centered target priming was larger in Experiment 1.2 than in Experiment 1.1 (29 vs. 8 ms-effects, $p<.05$). In contrast, retinotopic and spatiotopic target priming effects were comparable across the two experiments (10- and 2-ms vs. 17- and 9-ms effects in Experiment 1.1 and 1.2, respectively; both *p*'s > .47). Another way to look at the data is to compute the relative contributions of retinotopic, spatiotopic, and object-centered reference frames to priming in the baseline condition. This is illustrated in Figure 4 (panel B1). For Experiment 1.1, object-centered priming accounted for approx. 20% of priming in the baseline condition (retinotopic priming: ~30%; spatiotopic priming: ~50%). However, for Experiment 1.2, the contribution of object-centered target location priming increased up to ~70% of total priming in the baseline condition (retinotopic priming: ~10%; spatiotopic priming: ~20%).

For distractor priming, on the contrary, the 3 x 2 mixed design ANOVA only revealed a (borderline) significant effect of priming type [$F(2,52)=2.65$, $.05 < p < .10$]. Post-hoc tests revealed the object-centered component of distractor priming to be larger than the retinotopic and spatiotopic components (19-ms vs. 1- and 3-ms effects; both *p*'s < .05). This result was reinforced by an estimation of the relative inhibitory priming values, showing that object-centered distractor inhibition accounted for approx. 70% of the overall priming effect in the baseline condition (retinotopic priming: 10%; spatiotopic priming: 20%; panel B2 in Figure 3).

However, one might argue that the contribution of an object-centered reference frame to positional priming was different across the two experiments simply due to the Experiments 1.1 and 1.2 generating priming effects that were different in magnitude (with overall larger effects in Experiment 1.2 than in Experiment 1.1). While this argument does hardly apply to distractor location priming (the inhibitory effect was larger in Experiment 1.2 than Experiment 1.1, but not so its object-centered component – which was comparable between the two experiments; see panel B2 in Figure 4), it could at least explain the contribution of object-centered representations to target position priming. To rule this out, the amount of the object-centered, retinotopic, and spatiotopic target priming (Δo, Δr, Δs) was divided by 'base' RTs, that is, RTs to targets presented at neutral locations in the baseline condition – $\Delta o/RT$, $\Delta r/RT$, and $\Delta s/RT$. A 3 x 2 mixed-design ANOVA revealed the relative magnitude of object-centered target priming ($\Delta o/RT$) to be larger in Experiment 1.2 than in Experiment 1.1 [04 vs. .01; $p< .05$]. No differences were found for $\Delta r/RT$ and $\Delta s/RT$ between Experiments 1.1 and 1.2 [$\Delta r/RT$: 02 and .01; $\Delta s/RT$ .03 and .02 in Experiments 11. and 1.2, respectively; both *p*'s > .41; these post-hoc tests were based on a priming type x experiment mixed-design ANOVA, which revealed a borderline-significant priming type x experiment interaction: [$F(2,52)=2.03$, $.05 < p < .10$]. A similar analysis on the relative inhibitory distractor priming revealed this effect essentially stable across Experiments 1.1 and 1.2 [$\Delta o/RT$: .029 and .030; $\Delta r/RT$: .00 and .00; $\Delta s/RT$: .00 and .01; interaction priming type x experiment $F <.10$; as in the above analysis, on the relative impact of object-centered, retinotopic, and spatiotopic representations to ‘baseline’ priming, this analysis showed Δo/RT to be larger overall than Δr/RT and Δs/RT; main effect of priming type, [*F*(2,52)=2.75, *p*< .05].

A final analysis examined whether the differences in the coordinate systems underlying target location priming are due to differences in stimulus presentation. Specifically, in Experiment 1.1, the three search items were re-positioned only along the horizontal screen axis (meridian), whereas in Experiment 1.2, the search items appeared in one out of a total of seven different regions arranged along both the horizontal and vertical display axes. In other words, there is a difference between Experiments 1.1 and 1.2 in terms of the number of meridians (axes) across which the three items could be re-positioned across trials. Given this, it is conceivable that changes in item placement across a (i.e., the horizontal) field meridian – required in the ‘environment-centered’ Experiment 1.2, but not the ‘viewer-centered’ Experiment 1.1 – led to the adoption of an object-centered reference frame (see, e.g., Rizzolatti, Riggio, Dascola, & Umiltá, 1987, who suggested that shifts within hemifields engage different pre-motor mechanisms of attentional re-orienting compared to shifts across hemifields). To examine this, a control experiment (Experiment 1.3; 14 new observers, mean age: 29 years, *SD:* 9.33, 11 females) was conducted that was identical to Experiment 1.1, except that the stimuli and the fixation cross were presented in three regions on the vertical, rather the horizontal, display axis (see also Figure 3). Thus, similar to Experiment 1.1, observers could well predict the locations of the upcoming stimuli. If predictability is a crucial factor for adopting a viewer-centered (and non-predictability for adopting an object-centered) reference frame, target location priming was expected to be spatiotopic (retinotopic) in Experiment 1.3. A 4 (reference frame) x 3 (target location) repeated-measures ANOVA revealed significant effects of reference frame [*F*(3,39)=15.06, *p*<.001; RTs were faster in the baseline and retinotopic relative to the spatiotopic and object-centered conditions, 672 and 687 ms vs. 744 and 778 ms) and target location [*F*(2,26)=63.00, *p*<.001; RTs were fastest in the target-at-target, intermediate in the target-at-neutral, and slowest in the target-at-distractor location condition, 697, 721, and 742 ms]. Of most importance is the significant interaction [*F*(6,78)=3.39, *p*<.01], reflecting the fact the facilitatory priming was reliably smaller in the object-centered condition relative to the baseline, retinotopic, and spatiotopic conditions (9 vs. 37, 20, and 29 ms, all *p*'s < .05). In contrast, distractor inhibition was comparable across the four conditions (24, 18, 24, and 18 ms, all *p*'s>.37). The reduced facilitatory priming in the object-centered condition of Experiment 1.3 rules out that viewer-centered coding is limited to the upper vs. lower visual hemifield. Instead, it suggests that priming is primarily viewer-centered when the observers have certainty regarding the placement – whether horizontal (Experiment 1.1) or vertical (Experiment 1.3) – of the stimuli across trials.

Discussion

The current set of experiments investigated the spatial reference frame(s) underlying positional priming of pop-out (Maljkovic & Nakayama 1996). In two experiments, the three search items appeared at various locations on the horizontal display axis (Experiment 1.1), or on both the horizontal and vertical axes (Experiment 1.2). It was found that target locations (facilitation) were encoded in terms of a viewer-centered (Experiment 1.1) or an environment-centered reference frame (Experiment 1.2). In contrast, Experiments 1.1 and 1.2 both showed that distractor locations (inhibition) are coded exclusively in an environment-centered representation. The diversity in the spatial reference frames underlying target facilitation is in line with previous results (viewer-centered priming: Ball et al., 2009; environment-centered priming: Maljkovic & Nakayama, 1996). However, it raises the question as to the cause of this transition from viewer-centered to environment-centered representation of target locations. The present experiments indicate that spatial uncertainty, introduced by the use of three (Experiment 1.1) vs. seven (Experiment 1.2) possible display regions for the target and distractor to appear, plays an important role for the transition from a viewer-centered to an object-centered reference frame. In the next section, the issue that configuration-dependent and configuration-independent reference systems are separate in position priming memory and that both are used to represent target locations in positional VSTM are discussed.

Configural processing in priming and spatial working memory

A number of previous studies investigated the representation(s) underlying the maintenance of multiple item locations in visual memory across shorter and longer time spans (Golomb & Kanwisher, 2012; Jiang, Olson, and Chun, 2000; Chun & Jiang, 1998; Boduroglu & Shah, 2009). As the present study is similar to some of these, it is worth to compare the current repetition effects to recent work, in particular, on the organization of spatial working memory (Jiang et al., 2000, Gmeindl, Nelson, Wiggin, and Reuter-Lorenz, 2011). A review of these studies suggests that spatial working memory and positional priming share common mechanisms.

For example, Gmeindl et al. (2011) showed that the representation of a single stimulus location in working memory is influenced by the locations of the surrounding items. In their Experiment 2, observers performed a location change detection task. The memory and probe displays contained three items, arranged in a virtual triangle. This configuration could either be repeated or changed (in the latter condition, two of the three items were displaced in random directions in the test display; the memory and test displays were separated by a gap of 3000 ms). There were three conditions. In the “black-red” condition, the three items in the memory display were shown in black, whereas one (i.e., the probe) item in the test display was presented in a salient – red – color; the other two items in the test display were black. Observers were told to indicate whether the probe item occurred at the location of a stimulus in the memory display. In the “red-black” condition, one (the ‘target’) item was a red singleton in the memory display, whereas all other items (in both the memory and the test display) were black. In this condition, participants had to indicate whether a memory item was presented at the target’s location. In the final “red-red” condition, one item was red in both the memory and test display; the other items were black. The observers’ task was to indicate whether the probe singleton appeared at the location of the target singleton. In all three conditions, observers showed higher accuracy performance on the location match trials compared to non-match trials. Furthermore, for non-match trials, observers’ performance was higher for trials with changed relative to repeated configurations. This result was found in the “black-red” condition – and even in the “red-black” condition, that is, even when the target was a feature singleton in the memory display, so that its location could easily be maintained in working memory. In contrast, target location detection performance was uninfluenced by the changes of the item configuration in the “red-red” condition, that is, when the target and the probe item were color singletons. This result pattern led Gmeindl et al. (2011) to surmise that target location detection is influenced by configural information (“black-red” and “red-black” conditions), specifically, the configural attributes aid information processing at a decision stage where evidence for a mismatch between item locations in the memory and test displays is evaluated – the idea being that detection of a change in stimulus locations is enhanced when the configuration changes, too. This builds upon evidence, reported by Hyun, Woodman, Vogel, Hollingworth, and Luck (2009), that observers, in WM tasks, encode both task-relevant (here: item locations) and task-irrelevant (here: item configuration) information and that the latter can bias observers’ (location) change detection performance. Moreover, Gmeindl et al. (2011) suggested that configuration-dependent and configuration-independent representations can be compartmentalized in working memory, with the influence of the former being reduced when both the target and the probe item are shown in salient colors (“red-red” condition).

Applied to the present visual ‘pop-out’ search task, with one salient target and two distractors, this could mean that in ‘default’ mode, observers maintain target locations by means of a configuration-independent code in positional short-term memory (Experiment 1.1). The reason for this might be that saliency of target features is sufficient to segregate relevant from non-relevant information and thus to reduce visual memory load – assuming that observers, either strategically or automatically, intend to reduce memory load in position priming (as they do in working memory tasks). However, configuration-based coding, or ‘Gestalt’ grouping, can also reduce memory load. As a result, configuration-centered representations in positional VSTM can aid target location priming. The evidence obtained in the present chapter suggests that the latter may come to the fore particularly under conditions of variable placement, and associated with this the spatial uncertainty of the search items across trials; recall that in the object-centered condition of Experiment 1.2, the target on a given trial could appear in either the upper, central, or lower region, whereas in Experiment 1.1, it was presented in only a single (central) region of the left or right visual hemifield. Alternatively, or in addition, spatial uncertainty may lead to a wider setting of the attentional ‘zoom lens’, which may reduce the capacity for resolving individual item locations (Castiello & Umiltà, 1990). Whatever the precise mechanism, the key point is that although high target saliency can attenuate (reliance on) configuration-centered location coding by reducing the load on priming memory, information about the configuration within which the target is embedded is still available in positional priming memory and can thus aid performance, especially under conditions of variable stimulus placement.

This notion of configuration-dependent and configuration-independent representations in position priming memory was further investigated in a control experiment with a separate group of 12 observers (10 female, mean age: 27 years, *SD*: 7.62; participants performed two separate sessions of 784 trials each). In this experiment, the search displays contained three or four elements, arranged in ‘triangle’, ‘square’, or ‘diamond’ configurations (50% of trials contained 3-item and 50% 4-item displays; the stimuli were always shown at the monitor center). Importantly, the 3- or 4-element configurations were presented on the very same underlying (virtual) ellipse, which consisted of a total of eight locations. For example, the target on trial *n-1* could appear at the top position of a 3-item ‘triangle’ display, whereas on trial *n* it could appear at the very same (top) position – however, in a 4-item ‘diamond’ display. This setup made it possible to disentangle repetitions vs. changes of absolute stimulus locations (target at target, at neutral, at distractor location) from repetitions vs. changes of the overall search configuration (triangle, square, diamond display). Positional cross-trial priming was analyzed for transitions of 3-3 and 4-4 displays (i.e., same configuration trials; trial *n-1* → trial *n*, respectively) and 3-4 and 4-3 displays (i.e., different configuration trials; trial *n-1* → trial *n*, respectively). It was hypothesized that both target location facilitation and distractor location inhibition would be influenced by the configural manipulation – however, with the effects of changes vs. repetitions of configural attributes being more marked for inhibitory priming, given that this effect is almost entirely configuration-centered, as demonstrated in Experiments 1.1 and 1.2. In contrast, Experiment 1.1 had shown target facilitation to be supported mainly by configuration-independent (i.e., spatiotopic / retinotopic) representations. Given that in the control experiment, the stimuli were always presented at central fixation (and observers had certainty in the placement of the items across trials), target location priming should be largely supported by configuration-independent representations. However, if configuration-dependent representations are available in positional VSTM, then target location repetition effects should nevertheless be more marked on same- relative to different-configuration trials. Thus, the control experiment using predictable stimulus placements and, accordingly, fostering spatiotopic (retinotopic) representations, provides a conservative test of the idea that configuration-dependent representations are available in positional priming memory.

A repeated-measures ANOVA with the factors configuration (same vs. different; trial n-1 → trial n) and target position (target at target, at neutral, at distractor location) revealed a main effect of target position [$F(2,22)=48.58$, $p< .001$]. This effect was due to RTs being fastest for targets at previous target locations, intermediate for targets at neutral locations, and slowest for targets at distractor locations (598, 619, and 633 ms, respectively). Of theoretical relevance is the significant two-way interaction [$F(2,22)=6.00$, $p<.01$]. Target position priming (RT target at neutral minus RT target at target location) was numerically larger for same- relative to different-configuration trials: 24- vs. 17-ms effects; a one-tailed t-test revealed this difference to approach significance [$t(12)=1.75$, $p=.05$]. In contrast, the difference in distractor location priming (RT target at distractor minus RT target at neutral location) between same- and different-configuration trials was significant: 18- vs. 11-ms effects [$t(13)=2.31$, $p<. 01$]. This pattern of results suggests that inhibitory distractor priming – and, importantly, to large extent also target location priming – is configuration-centered.

Working memory =Positional priming?

Visual priming may be considered as reflecting a form of implicit sensory memory that automatically buffers information for the task at hand. Working memory, 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 working memory 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; cf. Soto, Llewelyn, and Silvanto, 2012; see also Soto, Humphreys, and Rothstein, 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, Gokce and Müller (2011) showed that the maintenance of a triangular shape in working memory enhanced positional priming in 3-item ‘triangle’ displays. Similarly, Kristjánsson, Saevarsson, and Driver (2013) found that featural priming was attenuated when observers had to maintain featural (i.e., color) information in working memory. Kristjánsson et al. (2013) took the latter to mean that working memory and priming, in addition to selective attention, are supported by a common resource pool (see also Kristjánsson et al., 2007; Anderson, Vogel, & Awh, 2013). Given these demonstrations, it is well possible that similar principles apply to the storage of (configural) information in positional priming and spatial working memory.

Summary

In summary, the current chapter supports the view that target location priming is governed by both viewer-centered and environment-centered reference frames. Distractor location priming, by contrast, is supported only by environment-centered representations. Stimulus-independent representations may become functional particularly under the conditions of the unpredictable placement of the search items across the trials.

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Chapter 3:

Positional priming of pop-out is nested in visuospatial context

Abstract

This chapter 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 inter-item 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 vs. changes of stimulus arrangement: While facilitation of the 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 t hrepetitions vs. 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, Bucher, Kerkhoff, Keller, von Rosen, Geyer, Müller, and Bublak, 2009) and that both effects are sensitive to subtle information about the arrangement of the display items (Geyer, Zeheitleitner, and Müller, 2010). The results are discussed with respect to the stage(s) of visual pop-out search that are influenced by positional priming.

Keywords: Pop-out search, positional priming, context effects, Gestalt principles

Introduction

Trial-based memory guided attention

The role of memory in visual search has been of great interest to researchers over the last 1-2 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 (Soto, Hodsoll, Rothstein, and Humphreys, 2008) and across search trials (Chun & Nakayama, 2000). The third form, of longer-lasting memory effects, has been attributed to configural learning, such as contextual cueing (Rosenbaum & Jiang, 2013). The present study is concerned with one of these mechanisms: Cross-trial priming of item locations (Maljkovic & Nakayama, 1996). Specifically, whether positional priming in visual pop-out search is influenced by the factors related to the visuospatial arrangement of the search items and, if so, whether these factors differ between priming of target and distractor locations is the main investigation of this chapter.

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). Intertrial priming refers to the fact that reaction times (RTs) are faster for repeated relative to non-repeated item attributes (Maljkovic & Nakayama, 1994, 1996; Goolsby & Suzuki, 2001; Fecteau & Munoz, 2003; Kristjánsson & Driver, 2008; Kristjánsson & Campana, 2010; Olivers & Meeter, 2006; Lamy, Antebi, Aviani, and Carmel, 2008; Müller, Heller, and Ziegler, 1995; Found & Müller, 1996; see also Chapter 1 of this thesis for more details). Such priming effects have been reported for several stimulus attributes, such as features (which includes target and distractor features; e.g., Lamy, Yashar, and Ruderman, 2010; Geyer, Müller, and Krummenacher, 2007), dimensions (e.g., Found & Müller, 1996; Töllner, Rangelov, and Müller, 2012), and locations (Geyer, Zeheitleitner, and Müller, 2010). Additionally, priming can also manifest for the search objects themselves (Huang, Holcombe, and 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 vs. 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 non-match can facilitate processing, whereas a partial match can hinder the 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 and Meeter, 2006, for a discussion). The alternative view is that priming facilitates the selection of the target by focal attention (Kristjánsson & Nakayama, 2003; Müller et al., 1995; Töllner, Gramann, Müller, Kiss, and Eimer, 2008). In recent years, a consensus has emerged that priming can aid processes of response selection and target selection, too (Töllner et al., 2008, 2012; Lamy et al., 2010, Yashar & Lamy, 2011).

Positional priming of pop-out

In Maljkovic and Nakayama's study (1996), the search displays contained three diamond-shaped items (1 target, 2 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-centred reference frame. The crucial finding was that positional facilitation was still evident even when the targets' "relative", as opposed to "absolute", location changed 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 trials. 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 (i.e., object-based frame).

The finding of object-centred 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 3-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 2-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, and Müller, 2011) to propose that distractor locations are maintained in VSTM within a “triangular” (object) reference frame. This view was recently expanded by Gokce et al. (submitted) to target position priming. In their experiments, the fixation cross and / or the search stimuli was / were repositioned from one to the other side of the display across trials, e.g., from the left to the right (see Chapter 2 of this thesis for more details). Under these conditions, it was possible to disentangle retinotopic, spatiotopic, and object-centred priming (see also Ball, Smith, Ellison, and Schenk, 2009; Tower-Richardi, Leber, & Golomb, 2012). It was found that while inhibition of distractor locations was object-centered, target facilitation was supported by both spatiotopic and object-centered representations. Gokce et al. took these results to mean that both ego- and object-centered reference frames can form the basis for positional priming.

Configural effects in Visual Short-Term Memory

The notion of configural processing in visual short-term memory (VSTM) is also supported by the studies that have used sequential presentation techniques (Phillips, 1974), rather than positional priming. 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 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.

Experiment 2.1

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 chapter was to further evaluate the roles of position vs. configuration in facilitatory and inhibitory positional priming, by disentangling the effects of repetitions vs. changes of the individual item locations from those of the repetitions vs. changes of their spatial context relations. To preview the results, it was found that target and distractor locations are stored in positional VSTM with regard to their placement in the item configuration, rather than their placement, in terms of exact screen locations, in the visual search display. It is concluded that 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 (Wertheimer, 1950) and, conceivably, may subsequently be maintained in object-based reference frames. For the present study, the distinction is made between the reference frames based on visuospatial ‘categories’ vs. frames based on ‘configurations’. An object category is formed by a set of unique geometrical elements which 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 (1963) goodness-of-pattern measure). For this task, Garner and Clement (1963) created 90 different patterns on a 3 x 3 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 refection). Garner and Clement (1963) found a negative correlation between observers' goodness-of-pattern ratings and the size of the equivalence set (besides a set size of 4 elements, as in the Z- and T-groups, there were equivalence sets consisting of 1 and, respectively, 8 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 (2002) experiments, observers had to give 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 1, 4, and 8 items). Based on this finding, Lachmann and Geissler (2002) 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).

Although VSTM, or working memory, and priming memory reflect qualitatively distinct phenomena (the latter being a form of implicit sensory memory which automatically buffers information for a given task, and the former an explicit system that actively maintains information for a given task), a number of recent studies suggest that working memory and priming may nevertheless share functions and neural resources (Soto et al., 2007, 2012; Geyer et al. 2011; Kristjánsson et al., 2013). Given these demonstrations, it is well possible that similar principles apply to the storage of information in VSTM and in positional priming. Specifically, it is possible that the presentation of a certain search configurations activates categorically related representations (Garner & Clement, 1963) and, as a result, target and distractor locations may be represented in positional VSTM with regard to various, categorically-related object reference frames (Lachmann & Geissler, 2002).

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 (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 border, reinforcing inter-element grouping. These conditions made it possible to assess positional priming of target and, respectively, distractor locations on consecutive trials of repetitions vs. changes of configurations and repetitions vs. changes of categories. For example, a target presented at location *x* in a ¯|_-configuration on trial n-1 could be followed by a target presented at the identical location *x* in the very same ¯|_-configuration on trial n; this is referred as the *configuration repetition condition*. Furthermore, targets presented at identical locations could appear in a ¯|_-configuration on trial n-1 and a different, _|¯-configuration on trial n; this is referred as the *configuration change condition*. Finally, a target could appear at location *x* in a ¯|_-configuration on trial n-1 and at the identical location *x* in a –|-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).

It was 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 inter-item configural information (Maljkovic & Nakayama, 1996; 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, Holcombe, Pashler, 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 that dimension priming (modulating processes prior to target selection; see Töllner et al., 2008) to interact with positional priming effects, particularly in the compound search tasks, where the target-defining and response-defining features are separated, as in Maljkovic and Nakayama (1996). The main finding of Krummenacher et al. (2009) 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. (2009) 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, Zehetleitner, & Müller, 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 salience map – and / or delay the comparison between previous and current stimulus attributes (i.e., episodic matching).

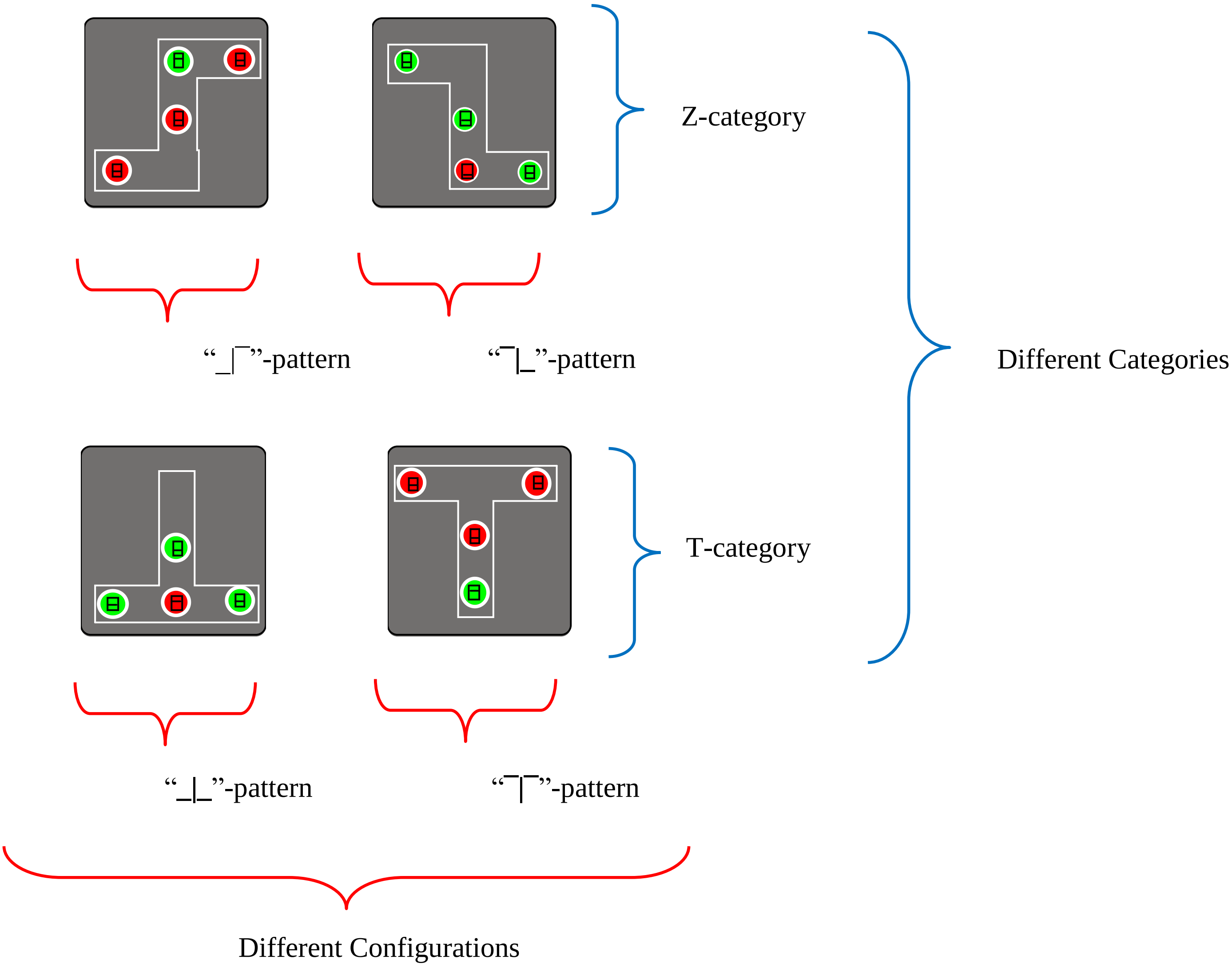

Figure 1. Examples of the four different visuospatial layouts used in the present study.

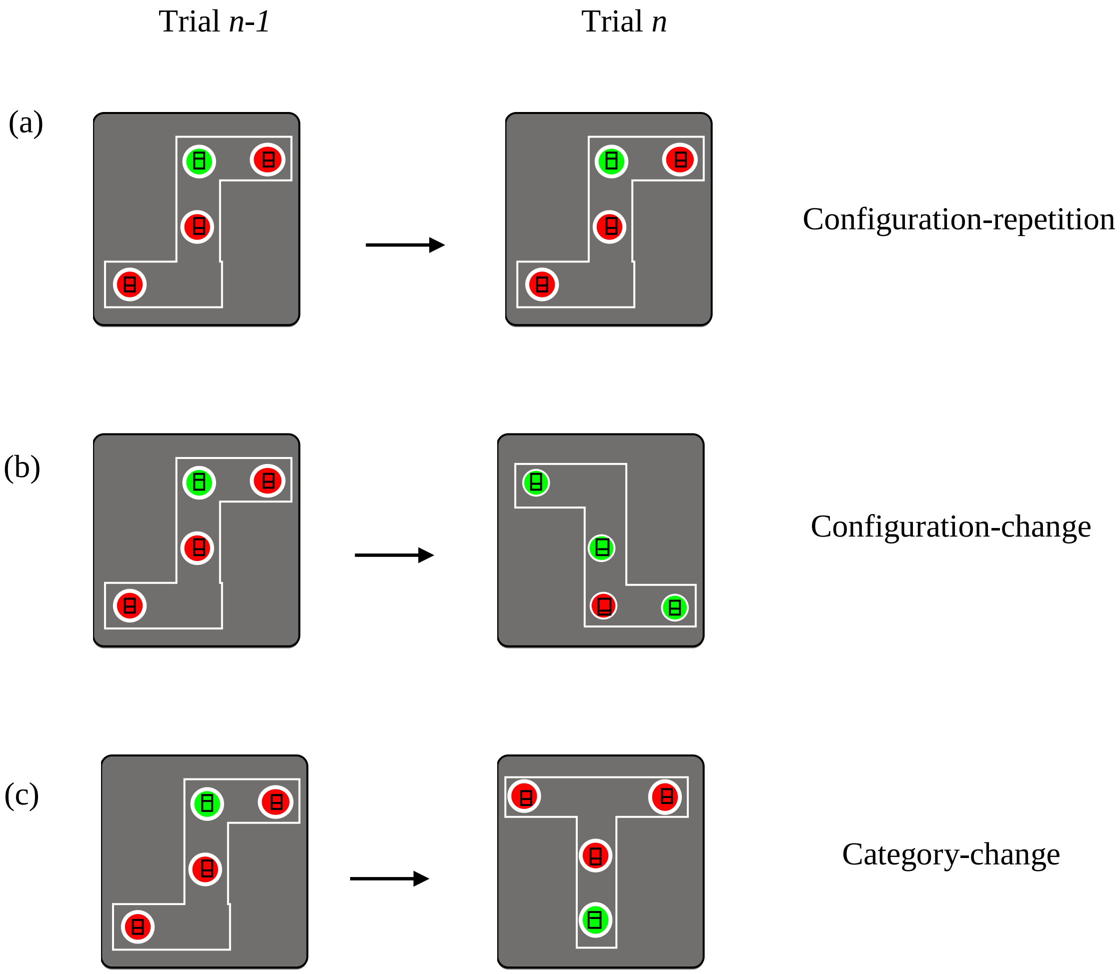

Figure 2. Illustration of the three types of display transition conditions. Panel (a) depicts the configuration-repetition condition, panel (b) the configuration-change condition, and panel (c) the category-change condition.

Method

Participants

14 observers participated in the experiment (female: 8, 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 naïve 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 & 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° x 1.59° 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: “¯|_” vs. “_|¯” (Z-patterns) and “¯|¯” vs. “_|_” (T-patterns). They were presented in the center of the monitor on a matrix of 3 x 3 locations, 7.04° x 7.04° 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 of “8” placeholder (size: 0.33° x 0.33°). 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° x 1.36°; 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-inch CRT screen (AOC; Amsterdam, NL). The screen resolution was set to 1024 x 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 revered in the second session. The participant's 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

Experiment 2.1 was performed in two consecutive sessions. Each session consisted of 8 blocks of 112 trials, yielding a total of 896 trials x 2 sessions = 1,792 trials. A session lasted approximately 50 minutes. 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, s/he was alerted to this by the presentation of the word "Error!!!" 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 the trials. The position of the target was pseudo-randomized: 75% of targets appeared at one of three locations (25% probability each) on the vertical ("central") midline of each stimulus pattern ("¯|_", "_|¯", "¯|¯", or "_|_", respectively). In the remaining 25% of trials (i.e., on 12.5% each), the target appeared at one of the "peripheral" locations of a given pattern; for example, in a ¯|_-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 (1 target, 3 distractors), and one was left empty – serving as neutral location. A location was left empty on the vertical midline in 75% of the trials (25% of trials for each of the three vertical midline positions), and in the periphery in 25% of trials (12.5% 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 patterns (“¯|_”, “_|¯”, “¯|¯”, and “_|_”) were identical across patterns and could be used for the analysis of positional priming effects.

Design

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 x 3 dot matrix. Thus, on this matrix, repetitions vs. changes of absolute stimulus locations could be decoupled from repetitions vs. 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: (1) configuration-repetition trial (e.g., _|¯-followed by _|¯-display; approx. 25% of trials; (2) configuration-change trial (e.g., _|¯-followed by ¯|_-display; ~ 25% of trials); and (3), category-change trial (e.g., _|¯- followed by _|_-display; ~ 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).

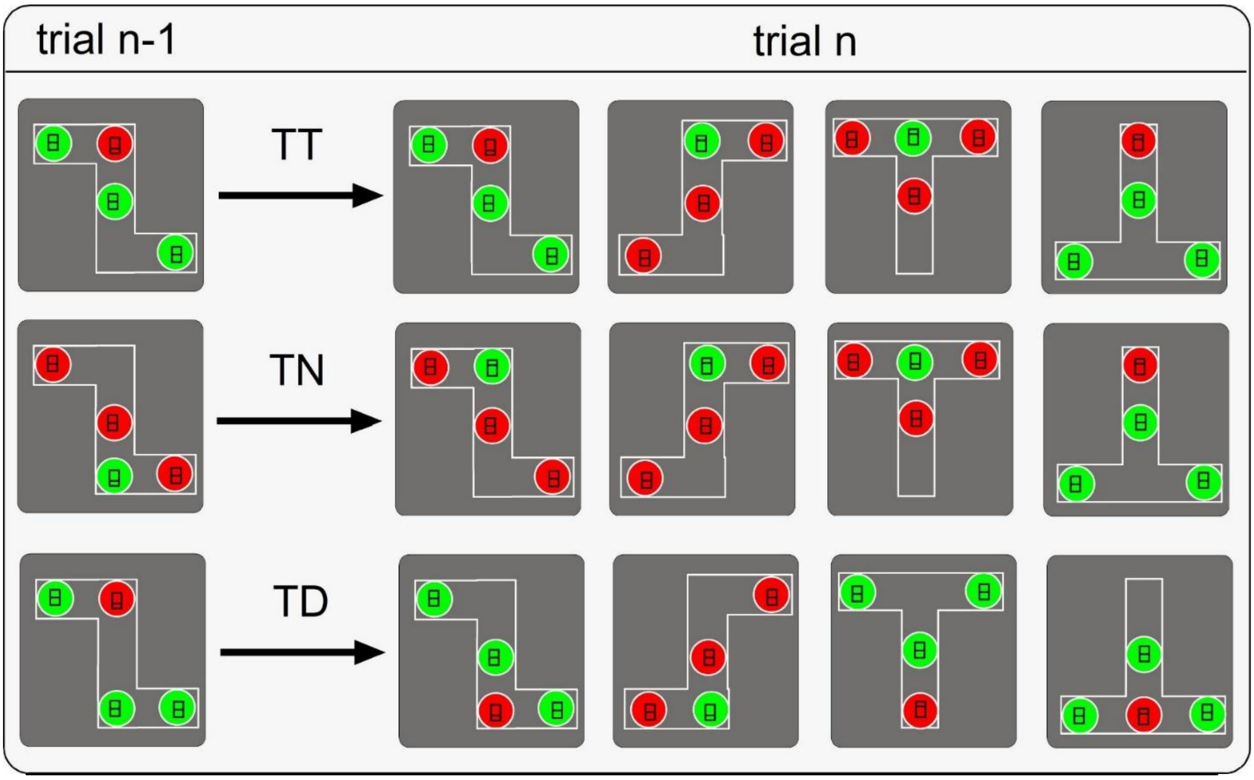

Figure 3. Illustration of the position of the target across two trials (n-1 → n). TT: trial n target appears at trial n-1 target location. TN: target appears at previously empty, i.e., neutral, position. TD: trial n target appears at trial n-1 distractor location. Across trials, the search stimuli could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

Results

Data from one participant were excluded from the analysis, because his/her RTs were more than 2.5 *SD*s above the group mean. Data analysis was performed using ‘R’ (R Development Core Team, 2007), in addition to Statistica (version 5). 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. Further, error trials and trials following error trials (2.77 %), in addition to trials with RTs values deviating by more than ±2.5 *SD*’s from the individual’s mean (2.49 %) were discarded as outliers. Further, RTs to targets presented at peripheral positions in each item pattern were not entered into analysis.

Finally, trials on which the target was located at the central position of the fixation cross were also not included in the analysis to eliminate the starting benefit.

Separate 3 (display transition) x 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, *p*<.01] and display transition [*F*(2,24)=5.36, *p*<.05] to be significant. Furthermore, the interaction was significant [*F*(4,48)=4.26, *p*<.01; see Figure 4]. Tukey 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 vs. 744 vs. 757 ms; both p's <.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 and 743 vs. 751 ms; both *p*'s <.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 vs. 745 vs. 762 ms; both *p*'s<.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*=.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*<.05). Finally, no facilitation of target and inhibition of distractor locations were found in the category change condition (739, 743, and 747 ms in the target-at-target, target-at-neutral, and target-at-distractor-location conditions, respectively; both *p*>.28). Taken together, the significant interaction marks the facts that (1) target facilitation and distractor inhibition were reliable in the configuration repetition condition (27- and 17-ms effects, respectively); (2) distractor inhibition, but not target facilitation, was reliable in the configuration change condition (16- and minus 1-ms effects); and (3) neither target facilitation nor distractor inhibition was reliable in the category change condition (3- and 5-ms effects). Given that RTs of 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 only in the configuration repetition and configuration change conditions) explains the display transition main effect.

Next, RT performance was analyzed 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 vs. 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 x display transition interaction [$F(4,48)=2.75$, $p<.05$]. As illustrated in Figure 5, and confirmed by LSD tests, both target facilitation and distractor inhibition were reliable (p’s<.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 ($p<.05$), but not facilitatory effect ($p=.62$) was significant in the configuration change condition (740, 744, and 759 ms, respectively). And neither facilitation ($p=.20$) nor inhibition ($p=.34$) 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 x display transition: [*F*(4,48)=2.58, *p*<.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; both *p*’s<.05). Further, the inhibitory (*p*<.05), but not the facilitatory (*p*=.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, respectively; both *p*’s>.67).

In another analysis, the RTs of each four display configurations, “¯|_”, “_|¯”, “¯|¯”, and “_|_”, were compared 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, *p*=.25].

	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 (in ms) 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.

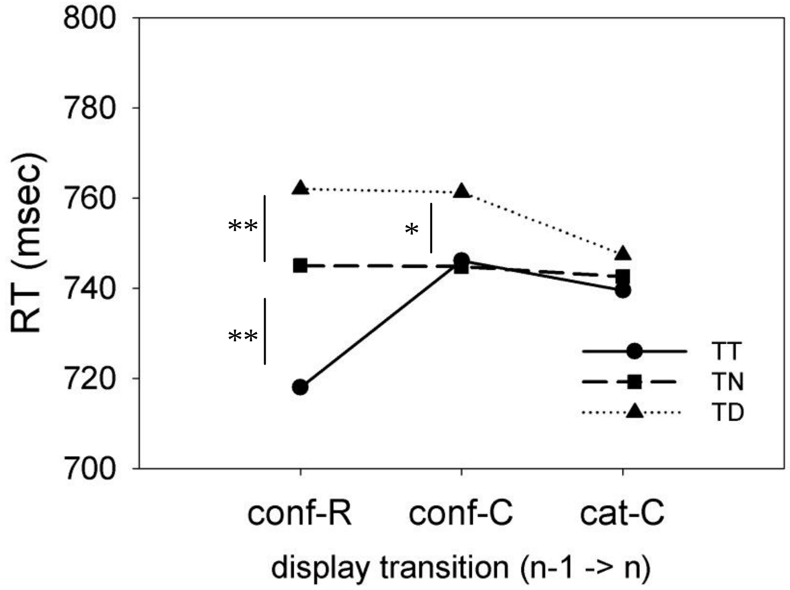

Figure 4. Mean RTs (ms) to targets presented at previous target (TT), neutral (TN), and distractor (TD) locations as a function of the repetition vs. change of the visuospatial arrangement of the items across two consecutive trials: Configuration-repetition condition (conf-R), configuration-change condition (conf-C), and category-change condition (cat-C). Asterisks indicate the significant facilitatory and inhibitory priming effect differences across the different conditions (*: *p*<.05, **: *p*<.01).

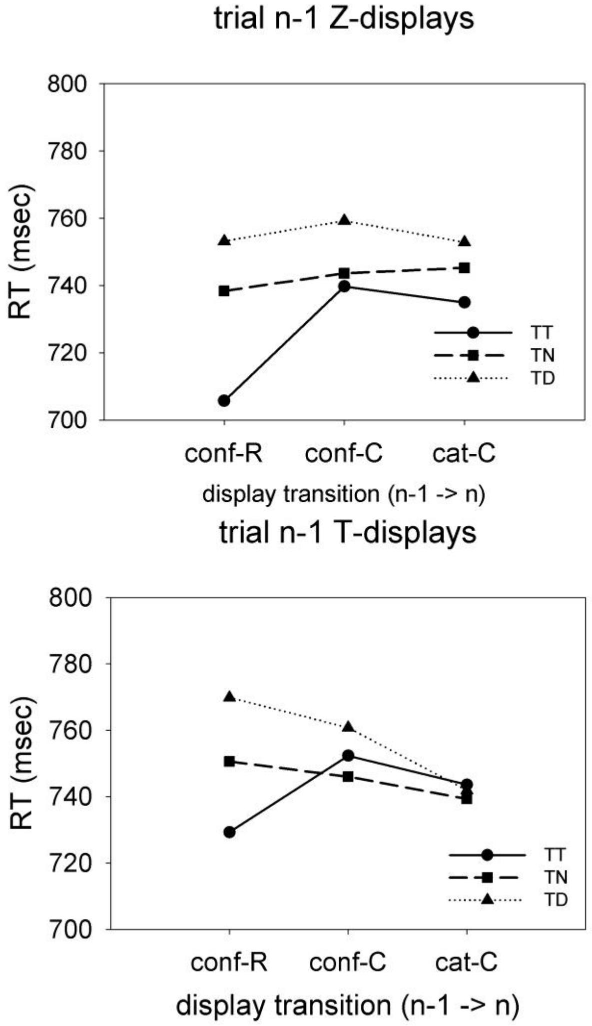

Figure 5. Mean RTs (in ms) to trial n targets presented at trial n-1 target (TT), empty (TN), or distractor (TD) locations in the configuration-repetition (conf-R), configuration-change (conf-C), and category-change (cat-C) conditions. The data are shown separately for trial n-1 Z-shaped displays (upper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

In a final ANOVA, the effects of repetition vs. change of other target attributes were examined (in addition to repetition vs. change of the position). In other words, 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) was re-analyzed. According to prior research, the repetition of other target attributes, too (besides position), can facilitate RT performance (Kristjánsson & Campana, 2010). However, the 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., Hillstrom, 2000; Huang et al., 2004; Yashar & Lamy, 2011) – the idea being that repetitions vs. changes of the target’s response features can influence the processing of other target features (position, color) only after the target was selected by focal attention.

The 3 (target position) x 2 (target color) x 2 (target orientation) repeated-measures ANOVA revealed all main effects to be significant: Target position [*F*(2,24)=8.27, *p*<.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)=118.78, *p*<.01; RTs were faster for same- relative to different-colored targets, 720 vs. 756 ms], and target orientation [*F*(1,12)=58.41, *p*<.01; RTs were faster for same- relative to different-orientation targets, 719 vs. 757 ms]. Furthermore, the target color x target orientation interaction was significant [*F*(1,12)=15.99, *p*<.01]. This interaction marked the color priming effects (i.e., RTs different color target minus RTs same color target were more pronounced for same relative to different oriented targets: 46 vs. 25 ms; see Lamy et al. 2010). Most importantly, the target color x target orientation x target location interaction was significant [*F*(2,24)=3.61, *p*<.05]. This interaction was further explored by separate ANOVAs, with target color and target orientation as factors, on target location priming (target-at-neutral-location RT minus target-at-target-location RT) and distractor location priming (target-at-distractor-location RT minus target-at-neutral-location RT). For target facilitation, this ANOVA revealed a significant target color x target orientation interaction [*F*(1,12)=3.94, *p*<.05]. LSD post-hoc tests showed that target facilitation was reliably smaller in the same-color—different-orientation condition relative to the other three transitions: same-color—same-orientation, different-color—same-orientation, and different-color—different orientation conditions (-6 vs. 18, 10, and 5 ms, respectively). In contrast, for distractor inhibition, the ANOVA revealed no significant effects, including the theoretically important two-way interaction [$F<1$]. LSD tests confirmed that RTs were comparable across the four cross-trial transition conditions: same-color—same-orientation, same-color—different-orientation, different-color—same-orientation, and different-color—different orientation conditions (6, 10, 6, and 15 ms, respectively).

Note that these results were replicated when limiting RT analysis to the configuration-repetition condition, in which position repetition effects were most marked overall. Of the greatest interest here is that the target position x target orientation interaction was significant [$F(2,24)=3.47$, $p<.05$, in addition to main effects of target position, color, and orientation]. Post-hoc LSD tests showed that target facilitation was dependent on the repetition vs. change of the targets' response-defining feature: The effects was larger for same- relative to different-oriented targets (40 vs. 16 ms; $p<.05$). In contrast, inhibitory priming for targets presented at previous distractor locations was comparable between the same- and different-oriented targets (21 vs. 14 ms; $p=.58$). See also Figure 6, which shows target position facilitation and distractor position inhibition separately for same- vs. different-response trials.

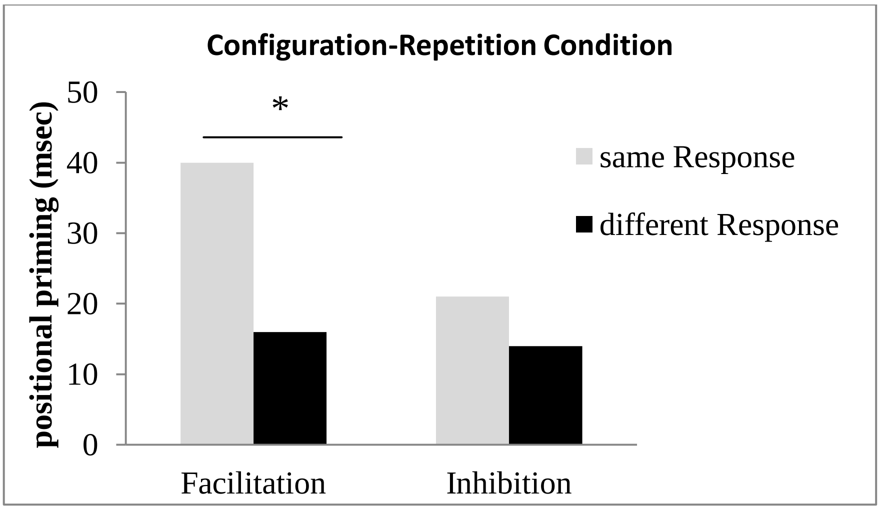

Figure 6. Target location facilitation (RT target-at-previously-empty location minus RT target-at-previously-target location) and distractor location priming (RT target-at-distractor-minus RT target-at-empty-location condition), separately for same vs. different response trials (gray vs. black bars, respectively) in the configuration-repetition condition. The asterisk indicate the significant difference between the same versus different response trials for facilitation priming (*:*p*<.05).

In sum, target location (and target color) repetition effects exhibited partial repetition costs in that they were modulated by the repetitions vs. changes of the target's response feature (orientation). However, distractor inhibition was uninfluenced by the repetition vs. change of the target's response-defining feature. Taken together with the above dissociation of the effects of repetitions vs. changes of configural attributes (target facilitation) and categorical attributes (distractor inhibition), this suggest that target and distractor location priming are independent phenomena that modulate distinct processes in visual pop-out search (considered further below).

Discussion

The present chapter investigated whether positional priming (Maljkovic & Nakayama, 1996), specifically target facilitation and distractor inhibition, is influenced by the 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. (1) Configuration repetition condition: this condition served as a baseline (providing maximum priming effects). (2) 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. (3) Category change condition: in this condition, a Z-type display was followed by T-type display, for example; the visuospatial categories (and configurations) changed across trials. The latter two manipulations were based on the idea that positions are not encoded in isolation (a view originally proposed by Maljkovic & Nakayama, 1996, p. 988), but rather with regard to their placement within the overall item arrangement (Jiang et al., 2000; Geyer et al., 2010). By introducing the configuration change and category change conditions, it was possible to disentangle configuration- and category-based contributions to positional priming.

Facilitatory and inhibitory priming effects were found to be evident and substantial in the baseline – configuration repetition – 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 VSTM – as individual items, but rather as elements of an encompassing configuration. This is a remarkable finding, given that target and distractor locations were repeated in exact screen – and eye – coordinates in all three display transition conditions.

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 vs. post-selective (Rangelov, Müller, Zeheitleitner, 2011), attributing priming effects in visual pop-out search to the speeding-up of processes that occur prior to or, respectively, after the selection of the target by focal attention. Regarding the latter accounts, it has been suggested that priming can act on various (post-selective) processes, including (1) 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); (2) response selection (e.g., Yashar & Lamy, 2011; Töllner et al., 2008); and/or (3) response preparation (or production; Töllner et al., 2008, 2012). Although the present investigation cannot ultimately decide among these three processes, the evidence obtained suggests that target verification (Huang et al., 2004) is the 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; see also Rangelov et al., 2013). 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 non-match 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 non-match) – in which case, additional time is required for target verification.

Applied to the present findings, it is proposed that positional priming aids stimulus verification and that this process involves visuospatial stimulus attributes as well. However, given that only facilitatory priming of target locations was found to be dependent on repetitions vs. changes of the previous target's response feature, it is further suggested 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 repetitions vs. 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) have 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 (see also Gokce et al., in preparation, for evidence in favor of 'early' distractor location inhibition and 'late' position facilitation using electrophysiological measures; see also Chapter 4 of this thesis for more details). 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. 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).

Finally, the discrepancy in ‘Gestalt’ properties maintained in target and, respectively, distractor memory as well as the differences in the processing stages at which the two effects influence visual pop-out search suggests that target facilitation and distractor inhibition are dissociable phenomena. This proposal is in line with recent investigations of (featural and positional) priming effects in visual pop-out search, which revealed dissociations not only at the behavioural level, but also in terms of the brain mechanisms that support the effects (e.g., Kristjánsson et al., 2005, 2007; Finke et al., 2009). For example, 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 FEF is an important neural structure for positional inhibitory priming (see Kristjánsson et al., 2007, for similar conclusions based on functional-imaging findings).

Summary

In summary, the results of the present chapter suggest that the positional VSTM, rather than simply buffering individual item locations (as assumed by Maljkovic & Nakayama, 1996, p.988), can represent the placement of the items within an overall item configuration. Furthermore, there is dissociation in terms of the ‘Gestalt’ attributes maintained in VSTM between target and distractor locations. Target location priming is likely to facilitate verification processes after target selection. Distractor location priming is likely to influence saliency computations at the attention-guiding master map of the integrated priority signals.

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Chapter 4:

Positional priming of pop-out: A neurochronometric analysis

Abstract

In visual pop-out search, it is well established that reaction time (RT) performance is influenced by cross-trial repetitions vs. changes of target-defining attributes. Positional priming of pop-out allows to compare target processing as a function of whether the target occurred at a previously occupied target, distractor, or neutral (i.e., empty) position and, thus, to disentangle the processes of target facilitation vs. distractor inhibition. By combining the RT data with sensory-driven and response-driven event-related EEG lateralizations, the levels of perceptual and motor processing for the facilitatory and inhibitory effects were investigated. The distinction was made between processes related to focal-attentional selection of the target (indexed by the Posterior-Contralateral-Negativity—PCN), post-selective target identification (Contralateral-Delay-Activity—CDA), response selection (stimulus-locked Lateralized-Readiness-Potential—sLRP), and response execution (response-locked Lateralized-Readiness-Potential—rLRP). The findings show that processing of targets occurring at previous distractor, relative to previous neutral and target, locations modulated the elicitation of the PCN waves, indicating that distractor positions are suppressed at early stages of visual search. Processing of targets occurring at previous target, relative to previous neutral and distractor locations, by contrast, modulated the elicitation of the CDA and sLRP waves, indicating that post-selective target identification (CDA) and response selection (sLRP) processes are facilitated if the target occurred at the same position as on the previous trial. Overall, the current chapter presents electrophysiological evidence for the somewhat unexpected argument that only distractor location priming, but not target location priming, influences processes that occur prior to visual selection (Maljkovic & Nakayama, 1996, 2000).

Keywords: Positional priming of pop-out, event-related potentials, lateralized readiness potentials

Introduction

Inter-trial priming effects

Visual inspections are guided not only by the current stimulation, but also by the sensory experience or actions performed in previous trials, an effect referred to as inter-trial priming. Priming effects in visual search can arise at the level of stimulus features, stimulus dimensions, the search stimuli (‘objects’) themselves, modalities, manual responses, or the particular task performed by observers (Maljkovic & Nakayama, 1994, 1996, 2000; Goolsby & Suzuki, 2001; Hillstrom, 2000; Kristjánsson, Ingvarsdóttir, & Teitsdóttir, 2008b; Kristjánsson & Campana, 2010; Geyer & Müller, 2009; Müller, Heller, & Ziegler, 1995; Found & Müller, 1996; Rangelov et al., 2011, 2012). The common finding is that repetition of target attributes expedites visual search and this effect is due to both facilitation of previous target and inhibition of distractor attributes – such as their colors or positions (Lamy, Antebi, Aviani, & Carmel, 2008; Kristjánsson & Driver, 2008a; Maljkovic & Nakayama, 1996). However, previous investigations have produced mixed evidence regarding the underlying mechanisms of priming effects (see next paragraph). Further, and to the best of our knowledge, no study has ever tested the *early locus of position priming effects*, as originally proposed by Maljkovic and Nakayama (1996). Therefore, in the current work both reaction times (RT) and electrophysiological variables were measured in order to identify the stage(s) of visual processing that is (are) influenced by position priming.

Information processing chain and inter-trial priming effects

There are different views regarding the sources of inter-trial priming. The discussion centers mainly on the level of the representation – or performance – that is primed by the repeated targets. According to the “early-selection” view, inter-trial priming effects facilitates early perceptual processes, such as the selection of the target by focal attention (Müller, Reimann, & Krummenacher, 2003; Wolfe, Butcher, Lee, & Hyle, 2003; Goolsby & Suzuki, 2001; Maljkovic & Nakayama, 2000). In contrast, the "late-selection" view stresses that inter-trial priming facilitates processes after target selection, such as response selection (Cohen & Magen, 1999; Mortier, Theeuwes, & Starreveld, 2005; Theeuwes, Reimann, & Mortier, 2006). A variation of the "post-selective" view are the accounts which assume that RT gains in visual search are due to the operation of an episodic memory mechanisms, buffering information about both the target's perceptual- (i.e., attention) and response-defining features (Huang, Holcombe, & Pashler, 2004). The available evidence suggests that these accounts do not necessarily exclude with each other. For example, by using electrophysiological measures (EM), Töllner, Gramann, Müller, Kiss, and Eimer (2008; cf. below) investigated the processing stage of perceptual-, i.e., dimension-, and response-related priming effects in visual pop-out search. They found that repetitions vs. changes of the target's perceptual attributes *only* modulated early, i.e., attention-related, EMs, whereas repetitions vs. changes of the target's response attributes, only modulated late, i.e., response-related, EMs. This suggests that perceptual and response priming are co-phenomena. Related to this claim, Lamy, Yashar and Ruderman (2010) put forward the idea of "dual-stage" account of inter-trial priming, in which both early (i.e., featural) and late priming effects can co-occur, but differ with regard to their temporal characteristics. According to their account, perceptual priming builds up fast, i.e., within 100 – 300 ms following the onset of the current trial. Response priming, on the contrary, becomes manifest later in the trial, beginning only around 400 ms after the onset of the trial. The idea of independent attention and response priming is also at the heart of Olivers and Meeter's (2006; see also Meeter & Olivers, 2006) "ambiguity" hypothesis, which states that inter-trial priming is determined by the degree of ambiguity – or uncertainty – regarding the target's perceptual- or response-defining features. For example, Meeter and Olivers (2006) showed that featural priming (Maljkovic and Nakayama, 1994) is larger with 3-item relative to 12-item displays – an effect which they attributed to reduced target pop-out, and thus increased ambiguity, with 3- relative to 12-item displays. In a sense, ambiguity refers to the efficiency of feature contrast – or saliency – computations. Assuming that these are spatially scaled (see e.g., Nothdurft, 1991, and Krummenacher, Müller, & Heller, 2002) saliency coding is improved with denser inter-item spacing – as in Meeter and Olivers's 12-item condition. Geyer. Zeheitleitner, and Müller (2010) showed that the target's relative saliency also plays a role in other forms of priming – in their case position priming. The core finding was that distractor inhibition, i.e., trial n target presented at trial n-1 distractor relative to neutral (empty) location, was affected by display size: The inhibitory effect was larger with 3-item relative to 4-, 6-, and 8-item displays. Interestingly, the facilitatory effect, i.e., n target presented at n-1 target relative to neutral location, was uninfluenced by the set size manipulation. This led Geyer et al. (2010; see also Geyer, Müller, & Krummenacher, 2007) to surmise that position priming consists of two distinct memory types: Target facilitation and distractor inhibition. These points are discussed in more detail in the Discussion section.

The present work aims at testing one of the core assumptions of accounts of *position priming of visual pop-out search*. Namely the memory underlying position priming enables more efficient visual selection (e.g., Maljkovic and Nakayama, 1994, 1996, 2000; see also McPeek, Maljkovic, & Nakayama, 1999). The specific question(s) addressed is whether position priming aids the selection of the target by focal attention and if so, whether there are differences between the memory underlying target and distractor locations. While the studies reviewed above point out to a role of – at least feature – priming in attention guidance, it is an open question whether also position priming acts on attention representations. To address this question, in the current study event related brain potentials were recorded in addition to the manual RTs.

Electrophysiological correlates of inter-trial priming effects

The electroencephalography (EEG) method is one of the most commonly used techniques in the cognitive neurosciences. On the basis of signal averaging, i.e., event-related potential technique (ERP), it is possible to extract information about the temporal duration of cognitive processes during a particular task – such as visual search. ERPs have a high temporal resolution allowing for the measurement of brain activity in the milliseconds (ms) range. ERP components can differ in their type (sensory- vs. motor-related ERPs), lateralization (lateralized vs. non-lateralized), and deflection (positive vs. negative; for a review, see, e.g., Woodman, 2010). The naming and functional significance of the respective ERP component follows these characteristics. For example, a negative deflection of ERP waveform approx. 200 ms after the stimulus onset at posterior electrodes contralateral to the target is termed as the N2pc component. This component is attributed to the deployment of focal attention (Eimer, 1996; Eimer, Kiss, & Cheung, 2010b; Kiss, van Velzen, & Eimer, 2008; Töllner et al., 2008, 2010, 2011, 2012) and it has been found in feature-singleton (Luck & Hillyard, 1994; Eimer, 1996) and conjunction search (Luck, Fan, & Hillyard, 1993) as well.

Modulations of the N2pc component due to the memory-based guidance of visual search were obtained for different forms of priming, such as feature and dimension priming. These studies aimed at testing an attention account of priming: Repetitions vs. changes of the target's defining attributes were expected to influence N2pc dynamics (i.e., latency, amplitude). For example, Eimer et al. (2010b) investigated whether featural priming (Maljkovic & Nakayama, 1994) modulates N2pc waves. They found that both N2pc latency and amplitude differed between the repeat trials, where target's color was identical across two subsequent trials, and change trials, where the target's color changed across two subsequent trials. Specifically, N2pc latency was reduced and N2pc amplitude was enhanced in repeated relative to change trials. This led Eimer et al. to surmise that featural priming enables more efficient attentional selection. Taylor, Muggleton, Kalla, Walsh, and Eimer (2011; see also Campana, Cowey, Casco, Oudsen, & Walsh, 2007) went on in combining transcranial magnetic stimulation (TMS) with the ERP methodology in order to determine the contribution of right angular gyrus (rANG) and the frontal eye fields (FEF) to featural priming and the ERPs evoked by these structures. Their aim was also to test an attention account of featural priming. Their idea was that feature priming modulates attention selection and that rANG and FEF are important attention control structures. If so, then blocking these structures should hamper featural priming. This is exactly what the authors found: rANG-TMS diminished priming, particularly by up-modulating (facilitating) RT performance in feature change trials. Further, rANG-TMS led to an enhanced (negative) ERP deflection at posterior electrodes (i.e., PO7 of left hemisphere, PO8 of right hemisphere), approximately 210 ms after the stimulus onset. Again, this effect was specific to the feature change trials and was found only for targets in the left visual field (no effects were found for target in the left or right field when TMS was applied to the left or right FEFs, respectively). Taylor et al. (2011) concluded that rANG is an important structure for feature priming. Specifically, the claim was made that rANG-TMS reduces the detrimental effects associated with the target feature changes, that is the interference from previous feature-based priming memory traces on the attentional selection of the current (changed) target item.

Töllner and colleagues (2008, 2010, 2012) were the first who investigated modulations of the N2pc wave due to dimensional priming, in their terms ‘dimension weighting’. The dimensional weighting account, *DWA* Müller et al., 1995; Found & Müller, 1996), assumes that dimension-specific saliency signals (Wolfe, 1994) would have to be amplified at the transition from the pre-attentive to the focal attention stage (i.e., master map of integrated saliency signals) and that these (dimension) weighs are maintained across trials.

As a result, RTs to detect the target are faster when the dimension is repeated compared to a change of the targets defining dimension. In the latter, limited attention weights would have to be shifted from one to the other dimension, which is a time-consuming process. In an attempt to test this *attention account of dimension priming*, Töllner et al. used a visual search task, where the targets defining dimension was variable across trials. In a given display, there were seven distractor stimuli (blue circles) and one target singleton, defined either in the color (red circle) or form (blue square) dimension. In addition, each stimulus contained a grating that was oriented either vertically or horizontally. Observers' task was to discriminate the orientation of the grating in the target stimulus. Thus, their task did allow the authors to investigate the separate effects of repetitions vs. changes of the target's dimensional and response parameters. Töllner et al. (2008, 2010) found that N2pc latencies were shorter and their amplitudes were larger when the target defining dimension was repeated across subsequent trials (e.g., color → color) relative to a change of the target's defining dimension (e.g., form → color). This result was predicted by DWA: Weighted dimensions led to faster transmission of dimension-specific saliency signals onto the master map of integrated priority signals. As a result, attention is allocated more efficiently towards the repeated target (indexed by the N2pc). The results of Töllner are interesting in two other aspects. First, Töllner et al. also found that repetitions relative to changes of the targets response attributes also led to the modulations of the ERP waveform. Specifically, the response-locked lateralized readiness potential (rLRP; cf. below; in short: rLRP indexes response activation) was enhanced in same compared to different response trials. It is worth noting that in Töllner et al., the effects of repetitions vs. changes of the target's dimensional and response attributes were completely independent of each other. That is, the N2pc wave was modulated by dimension-related, but not response-related, repetitions vs. changes of the target attributes. rLRP, on the contrary, was contingent on the repetitions vs. changes of the response-related, but not dimension-related, target attributes. Töllner et al. took this result pattern to mean that independent weighting (memory) systems exist for visual dimensions and actions. Second, another response-related component, the stimulus-locked lateralized readiness potentials (sLRP; cf. below: in short: sLRP indexes response selection), was influenced by both repetitions vs. changes of the target's dimension and response attributes. In particular, sLRP waves peaked earlier for repetitions (and changes) of both the targets dimension and response attributes relative to repetitions of only the targets dimensional or response attributes (i.e., partial repetition cost). Töllner et al. took this to mean that priming effects in visual pop-out search can arise also at a stage where perceptual representations are translated in response representations. Such processes of response selection are relatively fast when all target attributes are either the same as or different from the preceding trial. In contrast, processing disadvantages arise when only some, but not all, target attributes match (or non-match) – in which case, additional processing time is required for response selection. At the heart of this *account of priming of response selection* is the idea that although repetitions vs. changes of the target's dimensional and response attributes are statistically uncoupled, a repetition (change) of the target dimension will lead the visuo-attentional system to expect a repetition (change) of also other target attributes, such as its response-defining features (see, e.g., Kingstone, 1992). In case of a violation of a prediction, such as repeating only dimensional, but not response, attributes, a processing cost will arise and (perceptual) priming will diminish.

Another ERP component deployed in visual search studies is the contralateral delay activity (CDA) which is observed approximately around 400 ms after the stimulus onset. CDA is assumed to reflect information to be withhold in working memory (WM) – such as a definition of the target – or target template – in order to be able to perform the task (Dell'Acqua, Sessa, Jolicœur, & Robitaille, 2006; Jolicœur, Brisson, & Robitaille, 2008;

Mazza, Turatto, Umiltá, 2007; Perron et al., 2009; Wiegand, Finke, Müller, & Töllner, 2013). The CDA component is sometimes referred to as Sustained-Posterior-Contralateral-Negativity (SPCN). The distinction between N2pc and CDA builds up on the findings from Mazza et al. (2007), who let their observers perform a localization and discrimination tasks, while N2pc and CDA components were concurrently assessed. Mazza et al. used search displays that were identical in the two tasks. There were twelve diamond-shaped search stimuli with a missing corner at either the left or right side. The search items were arranged in a circular array. In the localization task, participants had to report the target's location, as being on the left vs. right monitor half. In the discrimination task, they had to report the missing corner of the target. The authors hypothesized that if the N2pc and CDA component reflect different processes of target selection (N2pc) and target identification (CDA), then ERP waveforms should differ between the two tasks. Specifically, since both the localization and discrimination tasks would require target localization, but only the discrimination task target identification, N2pc waves were expected for both tasks and a CDA wave only for the latter task. The results confirmed this prediction.

A third component assessed in visual search is the lateralized readiness potential (LRP), assumed as an index for the planning and the execution of overt responses (e.g., Hackley & Valle-Inclán, 2003; Eimer & Coles, 2003). Two forms of LRPs are usually recorded, reflecting different aspects of motor-related processes: *Stimulus-locked LRPs – sLRP*, marking the time it takes for observers to select an appropriate response and *response-locked LRP – rLRP*, being an indicative of the time it takes for observers to perform the actual response. For example, Wiegand et al. (2013) investigated sLRP and rLRP (in addition to sensory-related ERP components – such as CDA) in order to test where processing differences arise in visual pop-out search between young and old participants (typically, older participants show RT disadvantages relative to younger participants). They found that particularly sLRP waves peaked later in time in the older group suggesting that processing differences arise at a stage where a specific visual input is mapped onto a specific response.

Experiment 3.1

The aim of the present study was to investigate the electrophysiological mechanism(s) underlying positional priming of pop-out – i.e., target facilitation and distractor inhibition (Maljkovic & Nakayama, 1996). In order to do so, a distinction was made between sensory-related and response-related processes. As a suitable index for sensory-related processes, the N2pc component was employed, reflecting the operation of focal, selective attention. Due to the fact that the time window of the N2pc is typically not limited to 200 ms following the stimulus onset – instead, variations of the ERP waveform due to the operation of attention occur in the time range of 175-300 ms (Töllner, Zeheitleitner, Krummenacher, & Müller, 2011); the N2pc component will be named as the “PCN” component (i.e., Posterior-Contralateral-Negativity) hereafter. Another marker of sensory-related processes is the Ppc component (Positivity-posterior-contralateral; Fortier-Gauthier, Moffat, Dell’Acqua, McDonald, & Jolicoeur, 2012; Leblanc, Prime, & Jolicoeur, 2008). Ppc is typically found at lateral occipital electrodes approx. 100 ms after the stimulus onset (140–190 ms). In a very recent investigation, Jannati, Gaspar, and McDonald (2013) reported Ppc waves for target and distractor singletons. They used a variant of pop-out visual search, where two feature singletons were in the display, one being the target and one a distractor (cf. Theeuwes, 1992; Geyer & Müller, 2009). Target and distractor-related Ppc’s were found for lateral targets and central distractors or central targets and lateral distractors, respectively. Since Ppc was elicited by the two types of singletons, this ERP wave likely reflects low-level sensory processes. In some sense, Ppc can be taken as a measure of pure (i.e., “raw”) stimulus saliency with this info being represented at pre-attentive, i.e., dimensionally-organized, stages of visual processing. PCN, on the other hand, is a measure of behavioral saliency reflecting the deployment of attention based on an “amalgamation” of bottom-up and top-down priority signals at the integrated ‘master’ map of locations (e.g., Wolfe, 1994). A third measure of sensory-related processes employed in the present study was the CDA component, taken as an index for (post-selective) processes of target identification (e.g., Wiegand et al., 2013). The two response-related ERP components obtained in the current investigation of position priming were sLRP (being an indicative of response selection) and rLRP (reflecting response activation / execution).

In the literature, a distinction has been made between the processes of target facilitation, i.e., speeding up of RTs to trial n targets presented at trial n-1 target relative to empty (neutral) locations, and distractor inhibition, i.e., slowing of RTs to trial n targets presented at n-1 distractor relative to neutral locations (e.g., Maljkovic & Nakayama, 1996; for more recent evidence see, e.g., Finke et al., 2009). Given this, it is possible that the two effects differ with regard to the stages they influence in the visual processing chain. Maljkovic and Nakayama (1996, 2000) surmised that position priming facilitates attentional selection. One way how this may work is that the saliency computations are expedited and, respectively, slowed at previous target and distractor positions. As a consequence, visual selection is faster for the target at previous target and slower for the targets at previous distractor locations. In a sense, target facilitation and distractor inhibition could be considered as instances of a spatial weighting mechanism (similar as the dimension weighting mechanism), increasing or, respectively, decreasing priority signals at the level of the master map. If this is the case, both target and distractor priming should become manifest in variations of (the latency of) the PCN (acceleration vs. deceleration, respectively). In addition, target location repetitions relative to changes may also give rise to more efficient target identification or response selection processes. For example, the re-presentation of the target at an identical location might give rise to the (implicit) assumption that also the targets response attributes are repeated across trials. As a result, repetitions of both target location and response will elicit a faster sLRP, relative to a repetition of the target's position (but change of its response). Further, it is also possible that positional priming influences the time required for target identification. In this regard, Töllner et al. (2013) have recently shown CDA amplitude to scale with task requirements: CDA amplitudes were higher, the more difficult it was for observers to attentionally analyze the target and select its response-defining feature. In an attempt to explain this, they surmised that CDA (amplitude) is related to the location-specific encoding of visual input into visual short-term memory (VSTM). Thus, in their terms CDA in visual pop-out search mirrors similar cognitive operations as to those involved in classical WM tasks (such as maintaining info in WM; see, e.g., Carlisle, Arita, Pardo, & Woodman, 2011). Applied to the current experiment it is possible that position priming expedites the "read-in" of information in VSTM (VSTM is ultimately involved in processes after the selection of the target's perceptual and response attributes, such as the coupling of a visual representation with a motor representation). If so, targets appearing at previous target locations should be accompanied by lowered CDA amplitudes relative to targets appearing at neutral (baseline) locations.

Method

Participants

14 observers (female: 8, mean age: 23, *SD:* 1.74) recruited from the subject panel of the Department Psychology (units of General & Experimental Psychology and Neuro-Cognitive Psychology) participated in the study. All participants had normal or corrected-to-normal visual acuity and all were right-handed. The participants were naïve to the purpose of this study and interested participants were debriefed about the study purposes after the experiment ended. Informed consents were taken from everyone prior to starting the

experiment and anonymity of the responses was guaranteed. Participants were paid at a rate of 8 Euro (10 USD) per hour or received course credits for their participation.

Apparatus & Stimuli

The search display consisted of four stimuli presented on a gray background (22 cd/m²): one target and three distractors (size: 1.51° x 1.51°). The target and the distractors were either red or green with the colors being chosen to be near-equiluminant: red, 33 cd/m²; green, 35 cd/m². All stimuli had a cut-off section (size: 0.25°) either at the top or at the bottom part. The black fixation cross had a size of 0.76 ° x 0.76° and a luminance of 0.3 cd/m². The stimuli were presented on a circular layout with horizontal and vertical axes of 7.57° and 7.57°. Observers' task was to detect and subsequently discriminate the location of the target notch (top versus bottom) by pressing corresponding mouse buttons. Observers with odd (even) participant numbers responded to the top notch with the left (right) and bottom notch with the right (left) mouse button in the first experimental session. These mappings were reversed in the second session. Stimulus presentation and response recording were done by a standard PC equipped with a Microsoft Windows XP Prof operating system. The experimental control software was purpose-written in C++. Stimuli were presented on a 19-inch CRT screen (AOC; Amsterdam, NL). The screen resolution was set to 1024 x 768 pixels with a refresh rate of 85 Hz. Participants responded to the location of the target notch by pressing the right or left button of the computer mouse with the thumb of their right or left hand, respectively. The distance between the participant and the screen was approximately 75 cm. The experimental cabin was dimly lighted.

Procedure

The experiment consisted of two consecutive sessions with each session comprising of 8 blocks of 896 trials, leading to a total number of 1,792 trials. At the beginning of the experiment, observers practiced the experimental task in a total of 32 trials (data not recorded). On a given trial, the fixation cross was presented for 500 ms, which was followed by the stimulus display presented for 200 ms, followed by the manual response. When observers responded too slowly (i.e., trial RT > 1500 ms) or did an erroneous response, they were alerted to this by the presentation of warning messages (“Too slow” / “Error”), for 1000 ms, at the end of the critical trial. The inter-trial interval was slightly jittered, ranging between 950 and 1050 ms (random variable). Figure 1 illustrates a trial sequence. Observers were instructed to maintain gaze at the central fixation cross and to respond as fast and as accurate as possible. At the end of every 4th block, in both sessions, observers took a short break. Mean block RTs and error rates were presented at the end of each block. Each session lasted approx. 50 minutes.

Design

The search display consisted of eight possible stimulus locations arranged on a circular layout. In a given trial, four out of eight locations were occupied by the search items (1 target, 3 distractors). The four items could form either a (virtual) square or a diamond configuration. The target was equally likely to appear at any of the four locations in the square or diamond configuration. Note that, and since in the present investigation the lateralized ERP waves were of interest, for the diamond configuration only RTs and ERPs to targets presented at peripheral locations were taken into analyses. In half of the trials, a red target and green distractors were presented and vice versa in the other half. The cut-off section of each stimulus (top versus bottom notch) was determined randomly on each trial. With regard to the previous trial n-1, the target on the current trial n could appear at three possible locations: at a previous target location (*TT*; 33% of all trials), at a previous distractor location (*TD*; 33% of trials), or a previously empty, i.e., ‘neutral’ location (*TN*; 33% of trials). Further, RT and ERP data were analyzed as a function of repetitions vs. changes of the target’s response-defining feature (the location of the cut-off section).

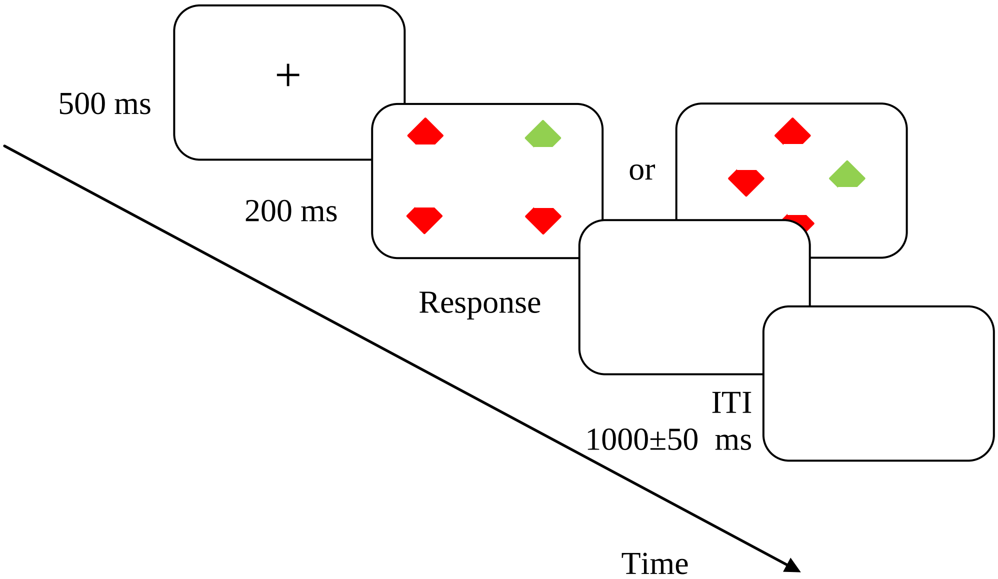


Figure 1. Illustration of a trial sequence. Following the fixation cross, the search display with four items (1 target, 3 distractors) was presented for 200 milliseconds (ms). This event was followed by observers' manual response. The task was to respond to the missing corner (top vs. bottom) of the target stimulus. The intertrial interval (ITI) varied between 950 and 1050 ms.

EEG Recording and Data Analysis

The EEG was recorded from 64 electrodes with a sampling rate of 1 KHz. The electrodes were located on the basis of the international 10/10 system (American Electroencephalographic Society, 1994). EEG signals were amplified by BrainAmp amplifiers (Brain Products, Munich, Germany) using a 0.1 to 250 Hz band-pass filter. Electrophysiological signals were filtered offline with a 1 to 40 Hz band-pass (Butterworth zero phase, 24 dB/Oct). All electrodes were referenced to FCz during recording and re-referenced offline to averaged mastoids. Impedances were kept below 5 kΩ. Independent component analysis (ICA) was conducted to exclude blinks and/or horizontal eye movements. Only trials with correct responses were included in the analysis. Before averaging, the signals exceeding ±60 µV and lower than 0.5 µV within the intervals of 500 ms (indicating dead channels) were selected on an individual channel basis and were removed from the analysis.

For the Ppc, PCN and CDA analyses, the EEG data were epoched offline into 700 ms periods (200 ms pre- and 500 ms post-stimulus onset) for the baseline correction. Statistical analyses were conducted for the Ppc, PCN, and CDA latencies and the mean amplitudes as a function of target position change. The Ppc latencies were determined as the maximum positive deflection within the 60-200 ms time window at the post-stimulus stage. The PCN and CDA latencies were determined as the maximum negative deflection within the 150-350 ms and 350-500 ms time windows at the post-stimulus stage respectively.

For the LRP analyses, both stimulus-locked and response-locked ERPs were extracted. The response-locked LRPs were obtained by epoching the EEGs into 1 s periods (800 ms before and 200 ms after the response onset). The stimulus-locked LRPs were obtained by epoching the EEGs into 800 ms periods after the stimulus onset relative to a 200 ms pre-stimulus baseline. In order to compute the LRPs for each condition, the waveforms at the electrodes C3/C4 ipsilateral to the side of the motor response were subtracted from contralateral ERPs. Jackknife-based scoring method (Miller et al., 1998) was used to determine the onset latencies of the stimulus- and response-locked LRPs. The jackknife method uses the way to define the LRP onset latencies on the basis of the amplitude reaching a certain specified point compared to the baseline. To determine the stimulus- and response-locked LRP onset latencies, 50% and 90% of the maximum amplitude respectively was used in line with the suggestions of Miller et al. (1998).

Results

Behavioural data were analyzed using “R” (R Development Core Team, 2007) and Statistica (Version 5). The first three warming-up trials in each block were excluded from the analysis. Further, the error trials (8%) and the trials following an error trial were also excluded from the analysis. Finally, trials with RT values larger than 1000 ms and smaller than 200 ms were classified as outliers (2.10%) and were not included in the analysis. For the diamond-shaped displays, trials in which the target was located at central positions (top or bottom locations of the diamond configuration) were not included in the analysis. Electrophysiological data were analyzed by using Brain Vision Analyzer (Version 1.05, Brain Products, Munich, Germany).

Behavioural Data

Accuracy Performance: Error rates were analyzed by means of a 3 x 2 repeated measures ANOVA with target position (TT, TN, TD) and target response (same, different) as factors. There was a main effect of target location on accuracy [*F*(2, 26) = 8.86, *p*<.01]: Error rates were lowest for targets presented at the previous target location, intermediate for targets at previous neutral location, and highest for targets at previous distractor locations (7 vs. 8 vs. 9%; all p's <.05; see also Figure 2). In addition, there was a significant interaction [*F*(2,26)=9.39, *p*<.01], suggesting that the pattern of error rates was more pronounced, overall, for the same relative to different response trials (same responses: 5.40 vs. 9.23 vs. 9.21 %; different response trials: 7.79 vs. 7.50 vs. 7.85 % in the TT, TN, and TD, conditions, respectively).

RT Performance: There was a significant main effect of target location on RTs [*F*(2, 26)= 56.72, *p*<.01]. RTs were faster for targets presented at previous target than neutral locations (558 vs. 584 msec; p < .001) and slower for RTs at n-1 distractor than neutral locations 597 vs. 584 msec; p < .001). Figure 2 presents the mean RTs and the error percentages for the three different target location conditions. Furthermore, the main effect of the target response [*F*(1, 13) =8.64, *p*<.01] was due to RTs being faster in the same relative to different response trials: 572 vs. 588; p < .001] and the target position x target response interaction approached [*F*(2, 26)=35.15, *p*<.01] was significant. As illustrated in Figure 3, the interaction was due to the fact that target location facilitation (RT_{TN} minus RT_{TT}) was larger in same relative to different response trials (44 vs. 13 ms; p < .001). In contrast, distractor location inhibition

(RT_{TD} minus RT_{TN}) was uninfluenced by the repetitions vs. changes of the target's response features (13 and 13 ms). In the literature an interaction between repetitions vs. changes of perceptual and response-related target attributes has been attributed to a late, i.e., post-selective locus of the priming effects (e.g., Hillstrom, 2000; Huang et al., 2004; Lamy et al., 2010; Töllner et al., 2008). Given that the target position facilitation interacted with the response repetition, it is likely that this effect influences processes after the attentional selection of the target. In contrast, distractor inhibition was uninfluenced by the repetitions vs. changes of the targets response features, suggesting an early locus of the inhibitory effect. However, on the basis of manual RTs, one can only indirectly infer the underlying processing stages and priming mechanism(s). Thus, will electrophysiological data confirm the hypotheses of *late target location priming* and *early distractor location priming*?

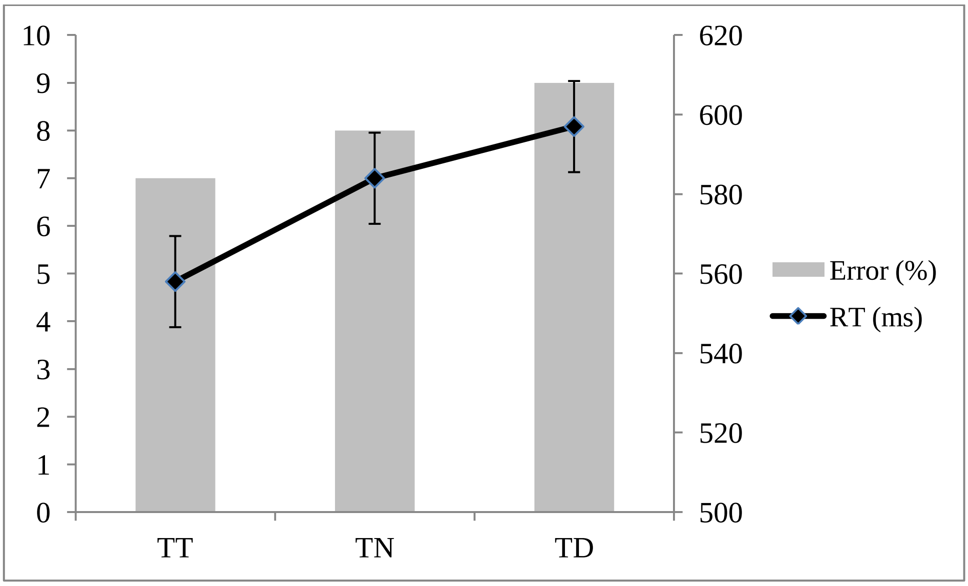


Figure 2. RT and accuracy data: Mean reaction times (in ms; lines) and error rates (in %; bars) as a function of target location: target at previous target location (TT), at previous neutral location (TN), at previous distractor location (TD).

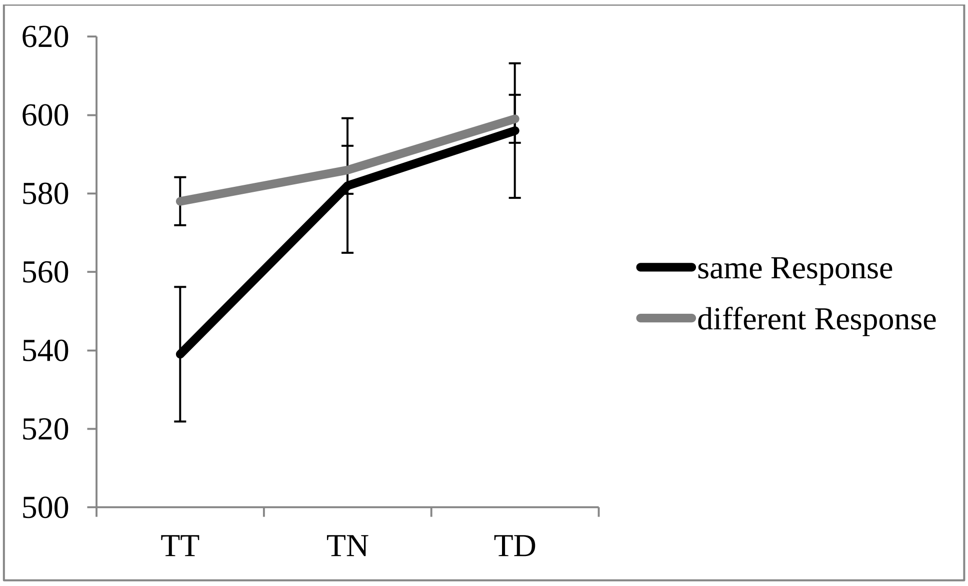


Figure 3. The plot of the interaction between the target position repetition (target at target (TT), target at neutral (TN) and target at distractor (TD)) and the response repetition (same/different).

Electrophysiological Data

Ppc: As illustrated in Figure 4B, there was a positivity – Ppc – occurring approx. 140 ms after the stimulus presentation. In order to check whether this positivity was a reliable effect, the Ppc component of the ERP waveform occurring at electrodes PO7/PO8 was analyzed as a function of the target position. This analysis revealed a significant effect [$F(2,13)=18.50$, $p<.001$]. Post-hoc tests showed that Ppc amplitude was higher for targets at previous target positions (1.28µV) relative to targets at previous neutral and distractor positions (0.68µV and 0.33µV; both p’s < .02).

PCN: Figure 4A shows the ERP waveforms obtained from the electrodes PO7/PO8 contralateral and ipsilateral relative to the current target position across all possible target location transitions (TT, TN, TD). In order to assess any differences in the PCN component due to variations of the targets position and targets response, PCN amplitudes and latencies were subjected to separate analyses. There were main effects of target position on both the

PCN amplitude and latency [amplitude: $F(2,13)=13.45$, $p<.001$; latency: $F(2, 13)=3.91$, $p<.05$]. PCN amplitudes were (numerically) highest for targets appearing at previous distractor positions (-3.24 µV), intermediate for targets at previous neutral positions (-2.99 µV), and lowest for targets at previous target positions (-2.32 µV). Post-hoc test revealed the difference in PCN amplitude between the target and distractor position significant ($p=.02$). PCN latencies were (numerically) lowest for targets at target positions (256 ms), intermediate for targets at neutral locations (261 ms) and slowest for targets at previous distractor locations (275 ms). Post-hoc test revealed the difference between PCN latencies in the target-at-neutral and target-at-target relative to the target-at-distractor location condition significant (both p's < .05). Figure 4B illustrates the PCN wave differences across all target locations. There was no effect involving the factor target response on the PCN amplitude or the latency (in the Figure, PCN waves are collapsed across same and different response trials).

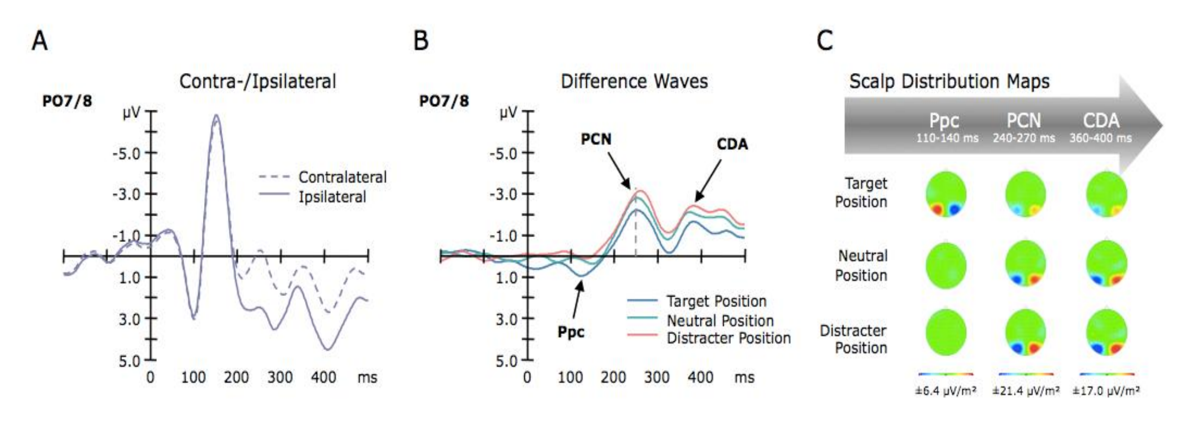


Figure 4. Grand averaged ERP waveforms as a function of target position change. Panel (A) shows the difference waveforms at electrodes PO7/PO8 contralateral (dashed line) and ipsilateral (solid line) to the target position. Panel (B) shows the ERP difference waveforms for the Ppc, PCN and CDA component obtained by subtracting the ipsilateral from the contralateral activity in each target position condition (blue: target at target, green: target at neutral, red: target at distractor position). Panel (C) illustrates the scalp distribution maps for the Ppc, PCN and CDA components as a function of the three target positions conditions.

CDA: CDA amplitudes and latencies were also analyzed separately as a function of target position and target response. There was (only) a significant effect of target position on CDA amplitude [*F*(2,13)=18.57, *p*<.001]. As confirmed by post-hoc tests, CDA amplitudes was higher (i.e., more negative) for targets at previous neutral and distractor positions relative to targets presented at previous target locations (-2.82 µV and -2.63 µV vs. -1.91 µV; both *p*'s < .05; see also Figure 4B).

Stimulus-locked LRP (sLRP): Motor related lateralized ERPs (sLRP and rLRP) were obtained from the electrodes C3/C4. The stimulus locked LRPs were analyzed as a function of the target position and target response (again separate analyses were performed for sLRP amplitude and latency). Target response repetitions vs. changes had a significant effect on the sLRP amplitude [*F*(1,13)=15.53, *p*<.002]; different response trials elicited higher amplitudes (-1.80 µV) than the same response (-1.31 µV) trials. Further, the sLRP onset latencies were modulated by the factor of target position [*F*(2,13)=8.42, *p*<.05]. The sLRP latency was shorter for targets at previous target positions relative to targets at previous neutral and distractor locations (350 vs. 383 and 396 ms; both *p*'s < .05). In addition, there was a significant interaction between target position and target response [*F*(1,13)=5.20, *p*<.05]. This interaction, illustrated in Figure 5, marks the fact that position-related modulations of sLRP latency were more pronounced overall on same relative to different response trials. Specifically, for the same response trials, targets presented at previous target positions led to shorter PCN latencies compared to targets at previous neutral or distractor locations (325 vs. 389 and 410 ms; both *p*'s < .05). For different response trials, on the contrary, modulations of sLRP due to repetitions vs. changes of the targets position were almost absent and non-significant: 376, 377, and 382 ms (data in the TT, TN, and TD transitions). In sum, the repetitions vs. changes of the targets' response features had an effect on the PCN amplitude. Further, repetitions vs. changes of the target's position influenced sLRP timing. However, this effect interacted with observers' manual response: Position-related sLRP effects were observed only on same-response trials.

Response-locked LRP (rLRP): rLRP amplitudes and latencies were analyzed in separate ANOVAs, each with target position and target response as factors. Repetitions vs. changes of the targets' response feature (only) had a significant influence on the amplitude of the rLRP wave [$F(1,13)=17.47$, $p<.001$]; rLRP amplitudes were higher (more negative) on different-response relative to same-response trials (-2.80 µV vs. -2.27 µV; see also Figure 5). The rLRP-onset latency was not significantly modulated as a function of target position change or response change or their interaction.

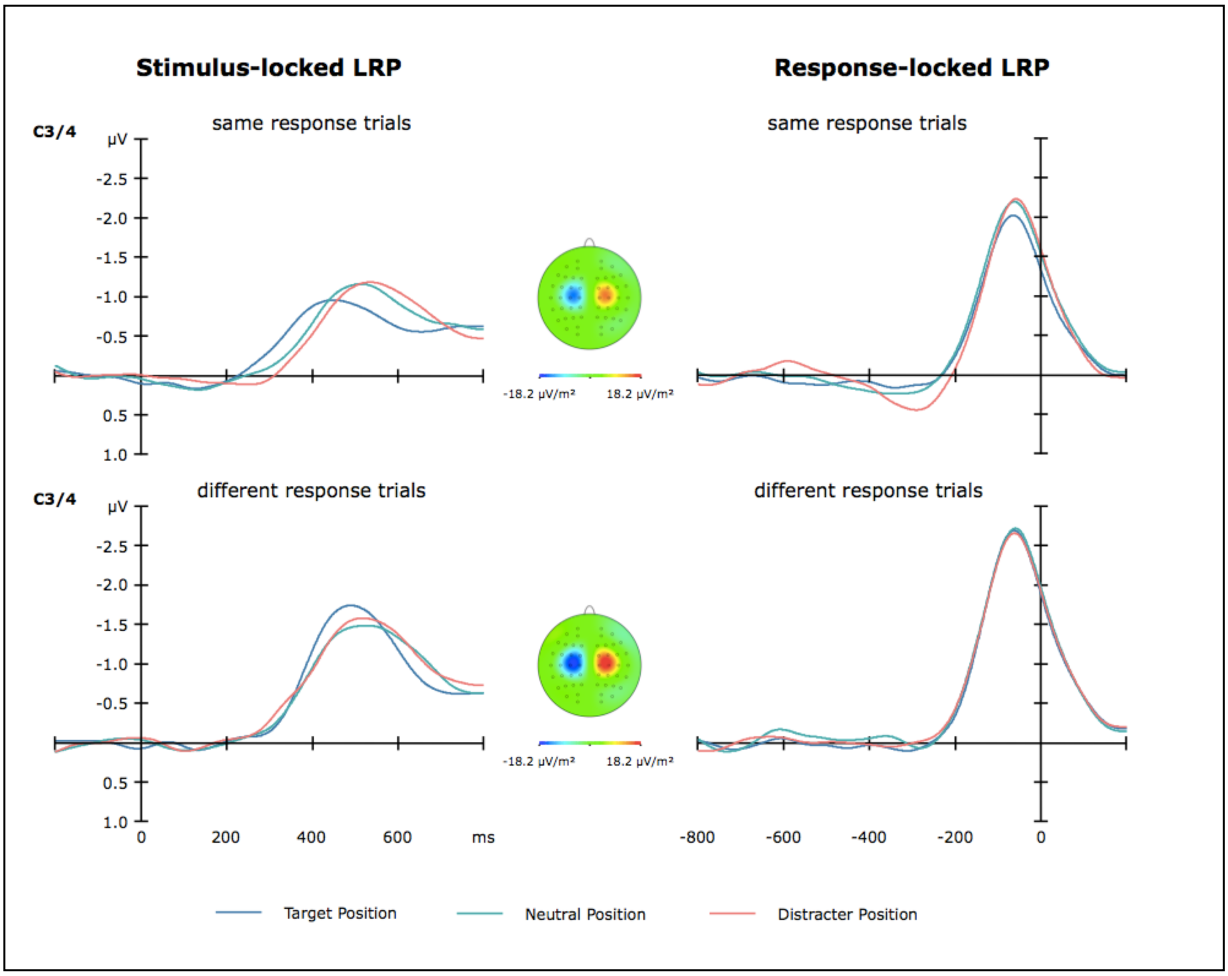


Figure 5. Lateralized readiness potentials obtained from electrodes C3/C4 as a function of target position change (blue line: target at previous target location, green line: at previous neutral location, red line: at previous distractor position) and target response change (same vs. different across two subsequent trials). The left panel shows the stimulus-locked LRPs in the time window of 800 ms following stimulus onset. The right panel shows the response-locked LRPs in the time window of 800 ms prior to response onset.

Discussion

Summary of findings

The aim of this chapter was to investigate the electrophysiological correlates of positional priming effects, namely target facilitation and distractor inhibition. By combining the RT data with the analyses of event-, i.e., sensory- and response-, related ERP components, it was possible to determine the level(s) of perceptual processing where the two effects aid visual pop-out search. A distinction was made between the processes associated with the selection of the target by focal attention and post-selective processes of target identification, response-selection, and response-activation / execution. The sensory ERP components of interest were the Ppc – reflecting enhanced stimulus, i.e., bottom-up, saliency values, PCN – reflecting the selection of the target by focal attention, and the CDA – reflecting processes associated with target identification. The response-related ERP components of interest were the stimulus-locked LRP, indexing response selection, and response-locked LRP, indexing response activation and / or execution. Lateralized ERP components were analyzed as a function of target position (target at target, at neutral, at distractor positions) and target response (same vs. different) across the subsequent trials (n-1→ n).

Manual responses were faster for targets presented at previous target and slower for targets presented at previous distractor locations, relative to n-1 neutral locations, respectively. Thus, there was reliable facilitation of previous target and inhibition of previous distractor locations. Such position repetition effects have been attributed to a visual short-term memory system aiding visual selection, that is, the covert and overt attention shifts (Maljkovic & Nakayama, 1996, 2000; McPeek et al., 1999). Other accounts, on the contrary, have attributed priming effects in visual pop-out search to the speeding-up of processes that occur after selection of the target by focal attention. Regarding the latter accounts, it has been suggested that priming can act on various post-selective processes, including (1) target identification (e.g., Töllner et al., 2013); (2) response selection (Yashar & Lamy, 2011; Töllner, Gramann, Müller, Kiss, and Eimer, 2008); and / or (3) response preparation or production (Töllner et al., 2008, 2012). The present pattern of RT and, importantly ERP, effects can help to decide between these alternatives. There are six important observations:

First, RT advantages for targets presented at previous target locations interacted with the response repetition. Following the interaction logic adopted in prior studies (e.g., in Huang et al., 2004) this result is likely to reflect a ‘late’ locus of position-based target facilitation (repetitions vs. changes of the targets response can, by definition, only influence pop-out search after the target is selected by focal attention). However, on the basis of the RT data, it is impossible to derive conclusions as to the exact stage in visual processing, where repetitions of the target’s position and response attributes influence RT performance. Position-based distractor inhibition, on the contrary, was uninfluenced by repetitions vs. changes of target’s response attributes, suggesting an early locus of the inhibitory priming effect. But again, and as mentioned previously, on the basis of RT data one can make only indirect inferences about the locus of position priming effects.

Second, targets presented at previous distractor locations led to a slowing of the PCN latencies relative to targets presented at previous neutral (and target) locations. This suggests that the inhibitory effect is indeed an early effect decelerating the selection of the target by focal attention (considered below).

Third, targets presented at previous target locations elicited reduced CDA amplitudes relative to targets appearing at neutral (and distractor) locations. This indicates that target position priming influences post-selective processes of extracting and subsequently encoding response-relevant information in VSTM (Töllner et al., 2013; Wiegand et al., 2013). However, there is at least one alternative interpretation of the position-related CDA effect. In particular, it is possible that CDA amplitude differences in the critical conditions “simply” reflect a continuation (‘travel’) of earlier modulations of the ERP waveform towards the later stages. Recall that the amplitude of the (early) Ppc wave was larger (more positive) in target at target location relative to target at neutral (and distractor) location trials. It is thus possible that a more positive deflection of the Ppc at an early time point in the ERP waveform did affect the less negative deflection of the CDA at a later time point. Thus, the traveling of early – Ppc – waves could at least in part explain position-related effects on late – CDA – waves.

Fourth, sLRP latencies were also modulated by position-related effects. However, the beneficial effect of repeated target positions on response selection was limited to same-response trials. As stated in the Introduction Section, the interaction between (repetition vs. changes of) the position and response attributes might be due to (implicit) assumptions about the coupling of the two stimulus entities (e.g., Töllner et al., 2008), such as that the repetition (change) of the target's position leads the visual-attention system to expect also a repetition (change) of the target's response feature. As a consequence, processing disadvantages arise when only one attribute – in this case the target's position, but not its response – is repeated across trials, in which position-related performance gains may be abolished (canceled). Importantly, the results from sLRP analyses support the view that the re-presentation of the target at a former target location expedites post-selective processes of response selection.

Fifth. rLRP parameters (amplitude, latency) did not vary as a function of the target location across two subsequent trials. It is thus unlikely that that position priming influences response activation (execution) processes.

Sixth, targets presented at previous target locations also lead to a more positive deflection of the Ppc component relative to target appearing at previous neutral or distractor locations. Recent ERP investigations of visual search suggest that Ppc reflects "raw" stimulus saliency, that is, the distinctiveness of an item relative to its neighboring items independent of whether this item is a target or distractor (e.g., Jannati et al., 2013). Applied to the present experiment this could mean that position priming enhances stimulus contrast, i.e., pop-out, at the previous target location. However, the question that follows is why such up-modulations of stimulus saliency were not translated in more efficient attention selection, reflected in the timing of the PCN. One idea might be that processing of targets at previous target locations is affected by a secondary memory mechanism, in addition to position target priming, namely inhibition of return (*IOR*; e.g., Posner et al., 1984). IOR marks the fact that attention, once deployed to a specific locations, has a tendency not to return to that location. As such, target position priming and IOR would interact in a competitive manner. For example, IOR might be conceived as a location-specific, inhibitory tagging mechanism (Klein & McInnes, 1999) that filters out enhanced saliency values resulting from position target priming at the transition from the pre-attentive to the attentive (master map) stage. An alternative explanation is that saliency values from pre-attentive, dimensionally-organized stages are feed-forwarded to the attentive stage, but are suppressed at the level of the master map. Under this account, IOR would operate directly at the level of the master map. Whatever thesis is correct, the discrepancy of the effects of target position priming on Ppc amplitude, but the lack thereof in PCN timing, would suggest that an inhibitory mechanism and position target priming can co-occur and that the former mechanism outperforms position priming. Here it is suggested that this inhibitory mechanism is similar to, if not identical with, IOR.

Distractor priming influences early, target priming late stages of visual processing

Maljkovic & Nakayama (1994, 1996, 2000) examined several attributes of the memory underlying (position) priming, such as its implicit character (i.e., observers were unable to influence the amount of priming—Maljkovic & Nakayama, 1994; Experiment 4; but see, e.g., Müller et al., 2003 for discrepant findings and conclusions), that priming can accumulate across sequences of (repeat) trials (Maljkovic & Nakayama, 1994; Experiment 7), that (position) priming is represented in allocentric, i.e., object-centred, rather than egocentric, i.e., spatiotopic or retinotopic, coordinates (Maljkovic & Nakayama, 1996, Experiment 3; see also Chapter 2 of this thesis), or that it can last up to 90 sec (Maljkovic & Nakayama, 2000; Experiment 3). Further, they put forward the claim that the memory underlying *position priming* aids attention orienting and gaze shifts. However, to the best of our knowledge, this assumption was motivated by theoretical considerations rather than empirical testing. [But note that this is not to argue against an attention account of priming in pop-out search. For example, and as stated in the Introduction Section, Eimer and Kiss (2010a) or Töllner and colleagues (2008, 2012) reported suggestive evidence for the claim that featural and dimensional priming guide attention]. The present ERP investigation of position priming confirmed Maljkovic and Nakayama's claim of the guidance of attention from position priming. However, the evidence was limited to distractor location priming. Target location priming, on the contrary, modulated processes after the selection of the target by focal attention. Candidate processes are target identification and response selection.

Models of visual search assume that target selection operates from an overall-saliency (or master) map of the display, with the relative activation of the master map units determining the allocation of attention (e.g., Koch & Ullman, 1985). The master map units integrate, in parallel, the output of the weighted (Müller, Heller, & Ziegler, 1995) dimension-specific feature contrast signal computations via spatiotopic connections between feature analyzers and the master map. Attention is deployed to the location with the highest saliency value. In this architecture, distractor position priming can be conceived of as a spatial weighting mechanism modulating (reducing) saliency coding at the overall priority map. An alternative idea is to think of distractor location priming to affect saliency coding at pre-attentive, dimensionally-organized saliency maps. This idea is plausible, given that the dimensional context of the target was not modulated in the present experiment. However, earlier data by Krummenacher, Müller and Heller (2002) would suggest that spatial weighting operates at the overall-saliency stage. The core finding of Krummenacher et al. was that of an interaction between dimension-based and space-based repetition effects: Dimension repetition effects were larger for target appearing at, or in close spatial proximity to, the previous target location. Assuming (A) dimension priming to influence saliency coding at the master map (e.g., Töllner et al., 2008); and (B), the interaction of two variables to index a common processing stage (Sternberg, 1969), position distractor priming is likely to influence feature contrast computations at the overall priority map of integrated saliency signals.

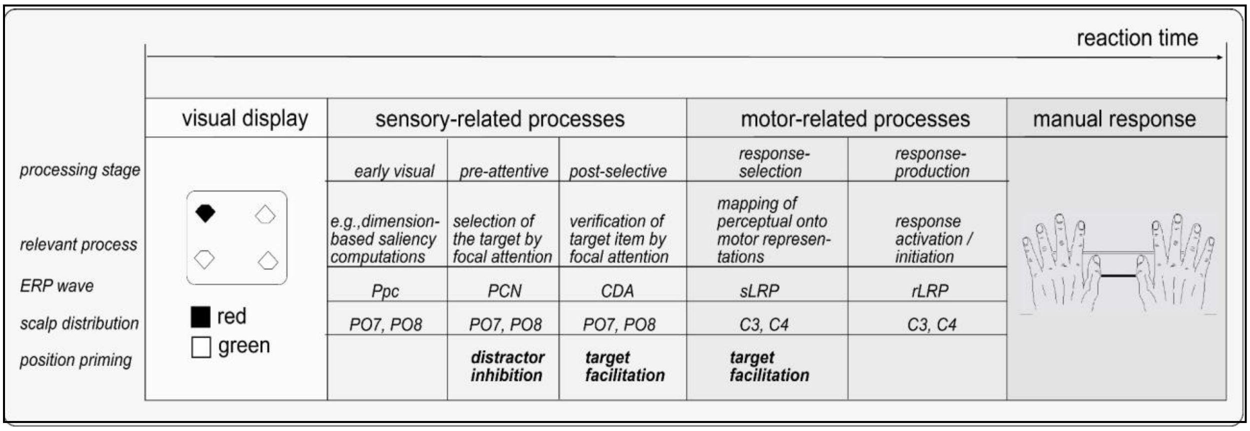
Following the visual selection, the target is analyzed by means of its response defining attributes, a process which becomes prominent in discrimination tasks (Mazza et al., 2007; Töllner et al., 2013) – as in the present study. During this process, visual information is extracted by focal attention and encoded in VSTM. The present experiment shows that target position priming aids this stimulus identification process. An alternative, though not mutually exclusive, view is to conceive of the identification process as a checking process, whose function is to verify whether the selected item is indeed the target (e.g., Huang et al., 2004). In this regard, Rangelov, Müller and Zeheitleitner (2013) recently put forward the idea that checking of selected items comes to the fore particularly with sparse displays, as in the present investigation (of 4-item displays), as target pop-out is relatively small with these displays and the target is not necessarily the first item being selected (see also Becker, 2008). As a result, the visuo-attention system would have to confirm that the selected item is indeed the target stimulus. In relation to the present investigation, it is possible that target position priming facilitates the checking process.

Once the selected item is confirmed as the target item and / or the target's response defining feature is identified, a visual (target) representation is coupled with a motor representation. The results show that the re-representation of the target at an identical location facilitates this response selection process, which was expressed by expedited sLRP timing. But this facilitatory effect was contingent on whether also the target's response attributes were repeated across trials. As stated above, this interaction might result from implicit hypotheses about the coupling of position and response features (as suggested by Töllner et al., 2008 for dimensional and response attributes). An alternative view is to consider response selection as a matching process between the target's response-relevant features across trials:

Response selection is fast, when the target's response features are same across trials (main effect of response repetition on RTs and sLRP timing in the current investigation). However, the interaction between target position and target response raises the idea that the matching also involves other target attributes, such as its position or its color attributes (note that target color was a random variable in the present study). The matching account builds up on the logic that RT benefits in the current trial result from either a full match or a full non-match of target attributes relative to the preceding trial(s), including attention-relevant (color), response-relevant (orientation), and irrelevant target features (target position): The idea being that when all to-be-checked target attributes are either the same as or different from the preceding trial, a decision about the mapping of a given stimulus representation onto a motor representation is relatively fast. In contrast, processes disadvantages arise when only some, but not all, target features match (or non-match) – in which case, additional time is required for target response selection. This idea was tested by an additional analysis on repetitions vs. changes of target color and orientation, which revealed a significant interaction: [$F(1,13)=4.96$, $p<.05$]. Note that the current *episodic matching account of response selection* is similar to earlier proposals of repetition effects in visual pop-out search (e.g., Hillstrom, 2000; Huang et al., 2004). However, it is different from, or more precise in, its assumption about the locus of the matching process in the visual processing chain. Here, it is suggested that the matching processes occur at the response selection stage, rather than the target identification stage, as proposed by, e.g., Huang et al. (2004). Evidence in favor of the current proposal comes from the pattern of ERP effects. Only the measures of response selection (sLRP), but not target verification (CDA) were influenced by combined repetitions of the target's position and response across trials.

In sum, the pattern of ERP results give rise to the assumption that position-related target facilitation and distractor inhibition are independent phenomena. While facilitation of

RTs to targets presented at previous target positions is likely due to more efficient target verification and response selection processes, the slowing of RTs to targets presented at previous distractor locations most likely results from less efficient attentional selection. This account is illustrated in Figure 6.



	visual display	sensory-related processes			motor-related processes		manual response
processing stage		*early visual*	*pre-attentive*	*post-selective*	*response-selection*	*response-production*	
relevant process		*e.g.,dimension-based saliency computations*	*selection of the target by focal attention*	*verification of target item by focal attention*	*mapping of perceptual onto motor representations*	*response activation / initiation*	
ERP wave		*Ppc*	*PCN*	*CDA*	*sLRP*	*rLRP*	
scalp distribution	■ red ☐ green	*PO7, PO8*	*PO7, PO8*	*PO7, PO8*	*C3, C4*	*C3, C4*	
position priming			***distractor inhibition***	***target facilitation***	***target facilitation***		

Figure 6. Decomposition of visual pop-out search into distinct perceptual and motor-related stages and associated ERP waves. The last row "position priming" shows where position priming, i.e., target facilitation and distractor inhibition, influence performance in the visual information processing chain.

Further evidence for the independence of facilitatory and inhibitory position priming comes from recent studies using a variety of neuroscientific methods (in addition to ERPs). For example, Finke et al. (2009) tested (14) patients with left-sided visual neglect and (14) healthy controls who performed the priming of pop-out task (Maljkovic & Nakayama, 1996). Interestingly, while the facilitatory priming effect was present in both groups, the inhibitory priming effect was reduced in the neglect compared to the control group. Further, two patients with lesions close to the right frontal eye field showed almost no inhibitory priming (but reliable facilitation). While these results suggest independence of target facilitation and distractor inhibition, it would also suggest that rFEF is a critical structure in distractor inhibition. Subsequent work by Campana et al. (2007) using transcranial magnetic stimulation (TMS) showed that also lFEF contributes to position distractor priming. The critical observation in Campana et al. was that application of fFEF-TMS in the intertrial interval led to modulations (decrease) of RTs in different-position trials, but not same-position, trials. This result is suggestive of an effect of TMS on distractor, and not target, location processing.

Summary

The results of the current ERP investigation of position priming (Maljkovic & Nakayama, 1996) show that this form of priming is not a unitary mechanism. Instead, position priming manifests at various stages in the visual processing information chain. The most important conclusion drawn from the present experiment is that Maljkovic and Nakayama's (1996) were only partially right in their view of position priming as *position priming of pop-out*. While target position priming expedites processes after focal attention selection, such as target identification plus the mapping of the target's perceptual onto a motor representation, only distractor location priming modulates the efficiency of focal attention shifts.

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Chapter 5:

Reinforcement of inhibitory positional priming by spatial working memory contents

Abstract

This chapter examined whether positional priming of pop-out is modulated by spatial working memory (WM). In Experiments 4.1 and 4.2, observers were presented with a to-be-memorized item (Experiment 4.1: triangle; Experiment 4.2: circle) prior to performing a block of search trials, with triangular stimulus configurations (one target, two distractors) on an underlying elliptical frame. Each search block was followed by a memory test (i.e., memory conditions). In Experiment 4.3, the presentation of the memory item (triangle) was immediately followed by the memory test, and the search block was performed after this test (i.e., no-memory condition). It was found that targets presented at a previous target were detected faster and targets presented at a previous distractor location slower, relative to a previous empty (‘neutral‘) stimulus location, respectively. While facilitatory position priming was uninfluenced by the memory manipulation, inhibitory positional priming was larger in the memory than no-memory condition, but only when the memory stimulus (triangle) matched the (triangle) configuration formed by the three search items. This finding of larger inhibitory priming under memory conditions provides further evidence that positional priming, rather than being purely bottom-up determined, is open to top-down influences.

Keywords: Attention, spatial working memory, positional priming of pop-out search

Introduction

Memory-based guidance of attention

The ability to concentrate, or focus attention, for the purpose of visual selection is an important requirement in almost all everyday tasks (such as driving a car). Studies using the visual search paradigm (e.g., Müller & Krummenacher, 2006) have revealed that visual selection is under the control of externally generated guidance signals (such as stimulus salience; e.g., Koch & Ullman, 1985; *bottom-up control*) and internal guidance signals (such as the activation of a 'target template' in working memory; e.g., Duncan & Humphreys 1989; *top-down control*).

Recently, guidance of focal attention based on working memory (WM) contents has received a great deal of interest (see Soto, Hodsoll, Rotshtein, & Humphreys, 2008, for a review). To examine the role of memory-driven processes in search more directly, the relevant studies combined a WM task with a visual-search task. Typically in this paradigm, observers are initially presented with an item to be kept in memory, which is then followed by the search display. After having given the search task response (e.g., speeded target-present/absent decision), observers are presented with a number (e.g., three) memory probe items and asked to indicate which one corresponded to the to-be-memorized item. Using this procedure, Soto and colleagues (Soto, Heinke, Humphreys, Blanco, 2005; see also Soto, Humphreys, Heinke, 2006) observed that when the color of the memory item coincided with that of the target item, search RTs were faster compared to a baseline condition in which the color of the memory item did not reappear in the search display; further, when the color of the memory item coincided with one of the search distractors, RTs were slower relative to the baseline condition. The target in this task was defined by an orientation difference relative to the distractors, that is, color was completely irrelevant for performing the search. Importantly, such (color-based) 'capture' effects were evident only when observers had to actively maintain in memory, rather than passively view, the ‘memory’ items, arguing against implicit priming of search stimuli by the pre-viewed memory items (see below). Soto et al. (2005) took these findings to indicate that WM contents automatically guide attention based on matching feature (color) information (see also Olivers, Meijer, & Theeuwes, 2006b; Kristjánsson & Nakayama, 2003). Note that Soto et al. (2005) observed memory-driven attentional capture effects even when the color of the memory item and the search target never coincided – i.e., when the memory item could only share its color with one of the distractors (but never the target) – supporting the idea that memory-based attentional capture is an automatic, that is, non-suppressable effect. Other studies also revealed capture effects for the dimensional (rather than featural) identity of the memory item (Pan, Xu, & Soto, 2009). Such effects were also revealed when a memory item was to be verbally, rather than visually, encoded; that is, activating the internal representation of the word “color”, for example, was found to enhance the detection of color-defined, as compared to, e.g., orientation-defined, singleton feature targets (Müller, Krummenacher, & Heller, 2004; see also Müller, Reimann, & Krummenacher, 2003, and Töllner, Zehetleitner, Gramann, Müller, 2010).

Note that WM guidance is different from other forms of memory-based control of attention – such as repetition priming (e.g., Kristjánsson & Campana, 2010; Geyer, Shi, & Müller, 2010). Importantly, priming effects in visual search are typically attributed to implicit (i.e., ‘passive’) memory traces of previous target attributes. That is: priming is thought to be (mainly) bottom-up or stimulus-driven (e.g., Maljkovic & Nakayama, 1994; Pinto, Olivers, Theeuwes, 2005). In contrast, WM capture effects are considered as explicit (i.e., ‘active’) effects (Soto et al., 2005; see also Wolfe, Butcher, Lee, & Hyle, 2003). Consistent with this distinction, Soto, Humphreys, and Rotshtein (2007) showed that (passive) priming and (active) WM effects are dissociable in terms their underlying neural structures and dynamics.

Spatial working memory driven attentional capture

The present chapter examined whether spatial WM influences positional priming (Maljkovic & Nakayama, 1996; Geyer, Müller, & Krummenacher, 2007) and, if so, under which (memory) conditions such influences would become manifest. Positional priming refers to the observation that RTs are faster when the current target appears at a previous target location (i.e., target location facilitation) and slower when it appears at a previous distractor location (i.e., distractor location inhibition), relative to a previous empty ('neutral') location.

In Maljkovic and Nakayama's (1996) original experiments on positional priming, observers responded to the 'orientation' (i.e., the side, left vs. right, of the cut-off section) of a color singleton target (diamond): either a single red object amongst two green distractors or a green object amongst 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. 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. –The existence and functioning of these and other priming mechanisms (such as dimension-based priming; e.g., Müller, Heller, & Ziegler, 1995; Found & Müller, 1996; Töllner, Gramann, Müller, Kiss, & Eimer, 2008) have received a great deal of interest in the meantime (e.g., see Meeter & Olivers, 2006, and Olivers & Meeter, 2006a, for an attempt to synthesize the various approaches into a unitary account). Nevertheless, it remains unclear whether and how *positional* priming (Maljkovic & Nakayama 1996) relates to other forms of search guidance – in particular, top-down guidance signals provided by information that has to be actively held in WM while performing the ‘Maljkovic-and-Nakayama’ task.

Indirect evidence for such a relation is provided by findings that inhibitory positional priming is modulated by spatial configural cues inherent in the search display (e.g., Geyer et al., 2007; Geyer, Zehetleitner, Müller, 2010). In more detail, Geyer et al. (2007) examined positional priming under conditions of ‘regular-triangle’ and ‘irregular-triangle’ stimulus arrangements. In the regular-triangle condition, the singleton target and the two distractors were presented in an equilateral triangle configuration (as in Maljkovic & Nakayama, 1996). By contrast, in the irregular-triangle condition, the distances between the three search items were variable, which means that they formed a (variable) non-equilateral triangle configuration. The important finding was that while distractor inhibition, arising from preceding trials *n-5* through *n-1*, was reliable in both conditions, it was twice as large in the regular- as in the irregular-triangle condition. By contrast, target facilitation was statistically uninfluenced by variations of the overall stimulus arrangement. Geyer et al. (2007) took these results to mean that distractor inhibition, in contrast to target facilitation, is modulated by the overall ‘goodness’ (in term of Gestalt psychology) of the arrangement of the search items.

In another experiment, Geyer et al. (2007, Experiment 1) observed that with regular 3-item displays, inhibitory, but not facilitatory, positional priming was two to three times larger with practiced than with unpractised performance (where practiced performance refers to positional priming in the last 1,000 experimental trials and unpractised performance to the first 1,000 trials, out of a total of 3,000 trials). To account for practice effects, Geyer et al. (2007) hypothesized that as a result of practice on the task (i.e., perceptual learning), observers improved in their ability to exploit the equilateral triangle stimulus arrangement, and its regular rotation around the central fixation marker across trials, to guide their search. More precisely, through practice observers build up a spatial mental triangle reference frame (a ‘high-level’ – i.e., identity-independent – memory representation) with the target location as anchor point and then place inhibitory tags at distractor locations based on this reference frame. [This could also explain the finding, referred to above, of larger positional priming with regular than with irregular displays: with irregular displays, observers would have been less able to ‘exploit’ configural cues and subsequently inhibit distractor location on the basis of a (regular) spatial frame.] Critically, this ‘relational-encoding account’ of inhibitory positional priming assumes that distractor inhibition is, to a large extent, configuration-based. In support of this, Geyer et al. (2010; Experiment 3) recently showed that positional inhibition (on trial *N*) can arise even from an empty, (but in relation to the target position) ‘regular’ location on trial *N-1* (i.e., a trial with a rare 2-item display, consisting of the target and one distractor only) where a distractor would have been merely expected (because the vast majority of trials *N-1* consists of regular 3-item displays, with one target and two distractors).

In sum, the results of Geyer et al. (2007, 2010) suggest that inhibitory, but not facilitatory, priming in pop-out search is modulated by the near-equilateral triangle stimulus configuration and observers using this configuration to guide their search (i.e., placing inhibitory tags at distractor locations on the basis of a triangular mental frame). One reason for this discrepancy could be that inhibitory and facilitatory priming are represented by two spatially different memory mechanisms: first, a location-based facilitatory memory system for the target location and second; an object-based inhibitory memory system for the distractor locations (see also Experiment 1 of Geyer et al., 2010 for distinct memory systems underlying target facilitation and distractor inhibition; and Chapter 2 of this thesis for evidence on spatiotopic target facilitation and configuration-based distractor inhibition).

Experiments 4.1, 4.2, and 4.3

Method

In the present set of experiments, the idea of configuration-based encoding of distractor locations was tested further by having observers perform both a search and a WM task. In the search task, observers were required to detect a color singleton and subsequently discriminate its orientation. The three search stimuli (one target, two distractors) were always formed an equilateral-triangle arrangement. In the WM task, observers were first presented with a to-be-memorized item (a triangle) and later had to indicate which of three (triangle) probe items corresponded to the memory item. Positional priming effects in this ‘triangle-memory’ condition were compared to two baseline conditions: a ‘circle-memory’ condition, in which the memory and probe items were (elliptical variations of) circles instead of triangles; and a ‘no-memory’ condition, in which observers performed the (triangle) WM task prior to the search task (see Figure 1). As outlined above, the results of Geyer et al. (2007, 2010) suggest that inhibitory positional priming depends, to a large extent, on observers acquiring a ‘triangular’ mental reference frame that they overlay on the search display, with the target location as anchor point. Given this, it is possible that the triangle-memory condition (i.e., actively keeping a triangular shape in WM) enhances the acquisition and application of such a mental frame that can be used to place inhibitory tags on the distractor locations. If so, one would expect inhibitory positional priming to develop more rapidly, so that significant and substantial inhibitory priming would already be seen within some 500 trials of task performance – rather than requiring 2,000-3,000 trials of practice, as has been demonstrated by Geyer et al. (2007). By contrast, keeping a circle in WM while performing the search task would not be expected to facilitate (the development of) inhibitory positional priming; instead, in fact, it may interfere with acquiring the triangular mental reference frame due to observers being required to maintain the ‘wrong’ type of configuration in WM or due to posing an additional, secondary-task load. And little facilitation would also be expected in the no-memory condition, in which the triangle memory task is completed prior to the search task (though the might be some ‘carry-over’ from the memory to the search task).

Participants

69 observers (mean age: 25.1 years; 51 female; all reporting normal or corrected-to-normal color vision) took part in the experiment. They were recruited from the participant panel of the Department of Psychology (Units of General & Experimental Psychology and Neuro-Cognitive Psychology) and they received either course credit points or payment (8 € / 10 USD per hour). All subjects were naïve as to the purpose of the study.

Apparatus & Stimuli

The experiment was conducted in a dimly lighted laboratory. Data were collected on up to eight standard computers simultaneously; each equipped with the same hardware and operating system (2.8 GHz Pentium IV running under Windows XP Prof, SP2). Stimuli were presented on 19-inch CRT monitors, at a frame rate of 85 Hz and a screen resolution of 1024 x 480 pixels. The experimental control software was purpose-written in C++. Observers viewed the monitors from a distance of approximately 60 cm.

Figure 1 provides illustrations of the experimental setup. Each block of (64) search trials started with an instructional cue presented in black (luminance: 0.5 cd/m², letter height: 0.8°) on white background (30.0 cd/m²) for 2,500 ms at the center of the displays. The instructional cue “Erinnern” (German word for ‘remember’) was to alert observers to the subsequently presented (gray) memory item (18.8 cd/m²): either a triangle (height: 6.1°, width: 5.0°) or circle (diameter: 5.0°), displayed for 250 ms at the center of the monitor. The short presentation time was meant to prevent observers from using the jagged edges of the (diagonal triangular) memory items, that were an unavoidable by-effect of the low screen resolution, for their memory performance. Further, in each block of trials, subtle variants were created for each memory stimulus by randomly displacing the coordinates of the shape's apices by between 0° and 0.8° (triangle) and by between 0 and 1.0° (circle). Pilot testing had shown that when using these values, recognition performance was comparable between triangle and circle memory shapes [correct memory performance: 77.5 and 75.6%, respectively; *t*(18)=.41, *p*=.69].

Procedure

The presentation of the memory items was followed by a blank display interval of 4,000 ms to provide observers with sufficient time to process ('memorize') the memory item. In the triangle- and circle-memory conditions (Experiments 4.1 and 4.2, respectively) this blank interval was followed by the presentation of 64 search trials, on which observers performed the 'Maljkovic-and-Nakayama' task' (see below for details). Following the last search trial in the block, there was another blank interval of 4,000 ms. Then, three probe memory items were presented (either all triangles or all circles), all being subtle variants of the initial memory item. They were gray and of the same size as the memory items, and displayed in a horizontal row in the central region of the monitor (with an inter-item distance of 3.9°). The probe items were labeled underneath by the gray numbers 1, 2, and 3 (18.8 cd/m²; number height: 0.8°). Observers were instructed to indicate the to-be-remembered item by pressing entering 1, 2, or 3 on the number keypad. Then the next block started. In the no-memory condition (Experiment 4.3), the memory item (triangle) was followed by the three probe items (triangles) after a blank display of 4,000 ms. And, after observers had responded in the memory task, there was another blank interval of 4,000 ms followed by the block of search trials.

Design

The search items 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 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 white (30.0 cd/m²). The size of the diamonds was 0.9° x 0.9° of visual angle, with a cut-off section of 0.2° either to the left or the right side. The search elements were arranged on a near-circular ellipse, with horizontal and vertical axes of 17.0° 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 black fixation point, 0.5° x 0.5° in size (0.5 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. With three search items, the separation between adjacent stimuli was eight locations with seven intervening locations.

Each condition (Experiments 4.1, 4.2, 4.3) consisted of 512 experimental trials, divided into 8 blocks of 64 trials. Note that Experiments 4.1, 4.2, and 4.3 were performed by separate groups of 23 observers each, thus equalizing the potential for perceptual learning (i.e., acquisition of a triangular mental reference frame) among the three groups.

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, the stimuli formed an apparent regular (near-equilateral), upward-pointing triangle. 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) by pressing the “Y” and “N” keys of the computer keyboard, respectively, using the index finger of the corresponding hand. If the missing corner section was left, they had to press the “Y” key and if it was right, the “N” key on a German keyboard). Regarding sequences of target positions, on a given trial *N*, the target could appear at either an *n-1* empty location (‘neutral’ baseline), at a location previously occupied by a target, or by a distractor. Observers’ 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. Experiments 4.1, 4.2 and 4.3 consisted of a single session of about 40 minutes each. At the beginning of the sessions, observers performed four blocks of 16 trials each to practice the experimental task (data not recorded).

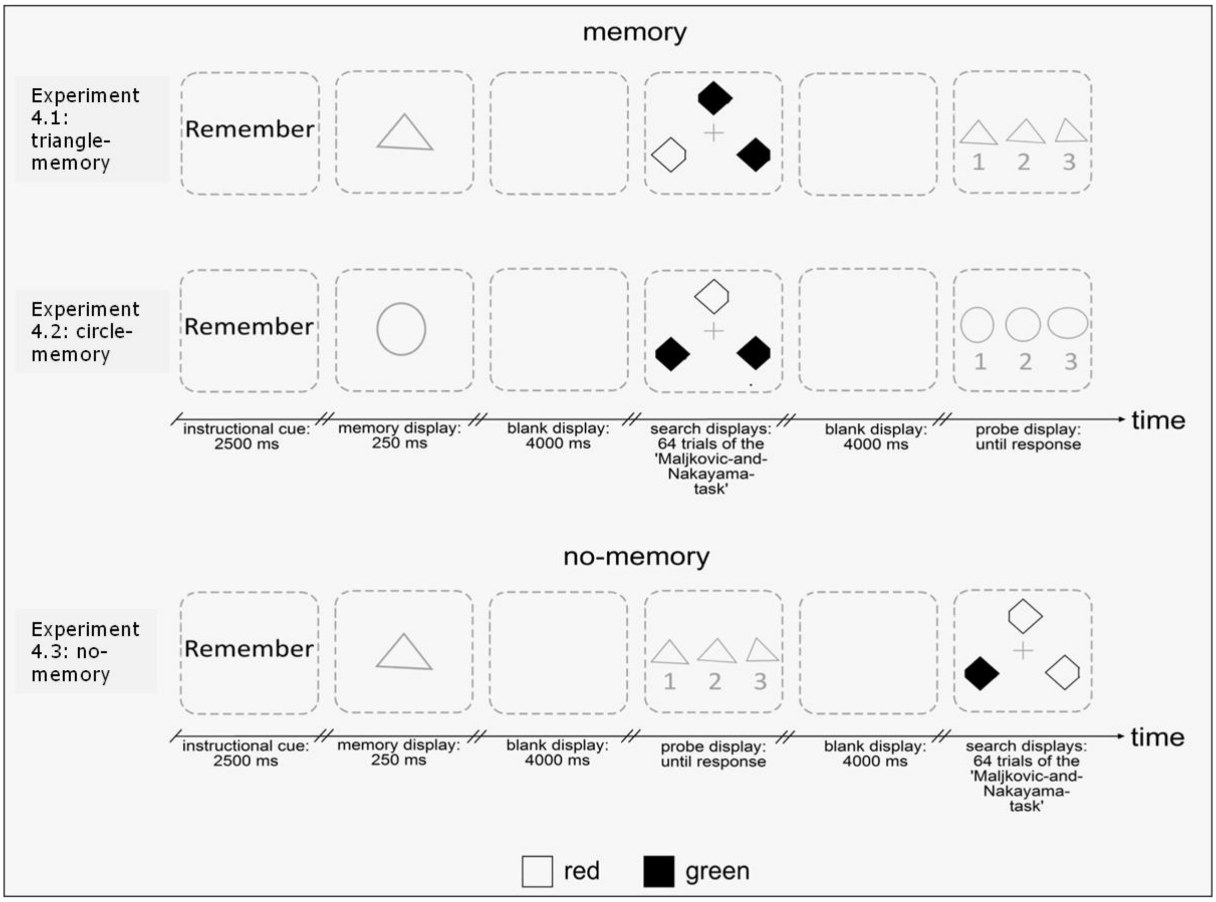

Figure 1. Illustration of the method used in the present Experiments 4.1, 4.2, and 4.3.

Results

Data were analyzed using R (R Development Core Team, 2007). First, RTs following incorrect responses in the memory task were discarded from analysis (overall, 20.7% of trials). Second, for each experimental condition (Experiments 4.1, 4.2, 4.3), RTs outside the range of ±2.5 standard deviations from the mean were discarded as outliers (overall, 2.36% of trials). Third, response error trials were also excluded from the RT analysis (3.3% of all trials; see below). 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.

Memory performance

A between-subject ANOVA of observers' memory performance scores revealed a significant effect of experiment [4.1, 4.2, 4.3; *F*(3,66)=5.88, *p*<.01, MSE=168.40]. Further post-hoc (Tukey LSD) tests showed this effect to be due to lower memory accuracy in both the triangle- and circle-memory conditions relative to the no-memory condition (79% and 73% vs. 86% of correct responses in Experiments 4.1, 4.2, and 4.3, respectively; both *p*'s<.05), as would have been expected. More importantly, performance accuracy was comparable between Experiments 4.1 and 4.2 (79 vs. 73%, *p*=.09), indicating that any difference in the magnitude of inhibitory positional priming between the triangle- and circle-memory conditions (see below) is unlikely to be due to a difference in the difficulty of retaining a particular shape – triangle vs. circle – in WM while performing the search task.

Search task response accuracy

A mixed-design repeated-measures ANOVA of the error rates (see Table 1) with the factors experiment (4.1, 4.2, 4.3; between-subject factor) and target location (at neutral position, at target position, at distractor position; within-subject factor) revealed (only) the main effect of target location to be significant [*F*(2,132) = 18.97, *p*<.01, MSE= 6.44]. Post-hoc (Tukey LSD) tests showed that error rates were lowest for targets appearing at previous target positions, intermediate for previous neutral positions, and highest for previous distractor locations (1.9 vs. 3.4 vs. 4.6%, respectively).

Trial *n* target location relative to trial *n-1*			
	TT	TN	TD
Exp. 4.1: triangle memory condition	699 (1.9)	724 (3.4)	746 (6.0)
Exp. 4.2: circle memory condition	723 (1.8)	743 (3.3)	751 (3.7)
Exp. 4.3: no memory condition	707 (2.1)	738 (3.5)	746 (4.0)

Table 1. Mean RTs (in ms) and, in brackets, error rates (in %) as a function of the target location on trial N relative to its location on trial N-1 (target at target (TT), target at neutral (TN), or at distractor location (TD)) in Experiment 4.1 (memory item: triangle → search task → memory test), Experiments 4.2 (memory item: circle → search task → memory test), and 4.3 (memory item: triangle → memory test → search task).

RT performance

RTs to the target on trial N (see Table 1) were also examined by a mixed-design experiment x target position ANOVA, which revealed the main effect of target location to be significant: [*F*(2,132) = 31.24, *p*<.01, MSE = 833.33]. No further effects were significant [main effect of experiment: *F*(2,66)=.20, *p*=.81, MSE=20.837,05; interaction experiment x target position: *F*(4,132)=.81, *p*=.52, MSE=833,33]. As confirmed by post-hoc tests, the effect of target location occurred because the RTs to the singleton target on trial *n* were fastest when the target appeared at a trial *n-1* target position, intermediate when it appeared at a trial *n-1* neutral position, and slowest when it appeared at a trial *n-1* distractor position (710 vs. 735 vs. 748 ms, respectively). That is, there was RT facilitation when the current target was presented at a previous target location (25 ms-effect) and inhibition when it was presented at a previous distractor location (13 ms-effect), relative to the neutral-location baseline (Maljkovic & Nakayama, 1996). Of particular interest were the positional priming effects in the three different memory conditions (see Figure 2). Although the target location x experiment interaction was non-significant, a separate (between-subject) ANOVA of the inhibitory effect (RT target at distractor location minus RT target at neutral location) revealed the effect of experiment to be significant: [*F*(2,66)=3.79, *p*<.05, MSE=489.82]. Importantly, post-hoc [Tukey LSD] tests showed inhibitory positional priming to be significantly larger in the triangle- than in the circle-memory condition [4.1 vs. 4.2: 21- vs. 8-ms effects; *p* <.05) and triangle- than no-memory condition [4.1 vs. 4.3: 21- vs. 8-ms effects; *p*<.05). And, inhibitory priming was comparable between the circle- and no-memory conditions [4.2 vs. 4.3: 8- and 8-ms effects; *p*=.97]. By contrast, a (between-subject) ANOVA of the facilitatory effect (RT target at neutral location minus RT target at target location) revealed the effect of experiment to be non-significant: [*F*<1]; that is, in contrast to distractor location inhibition, target location facilitation was not reliably influenced by the memory manipulation (25-, 32-, and 20-ms effects for Experiments 4.1, 4.2, and 4.3 respectively).

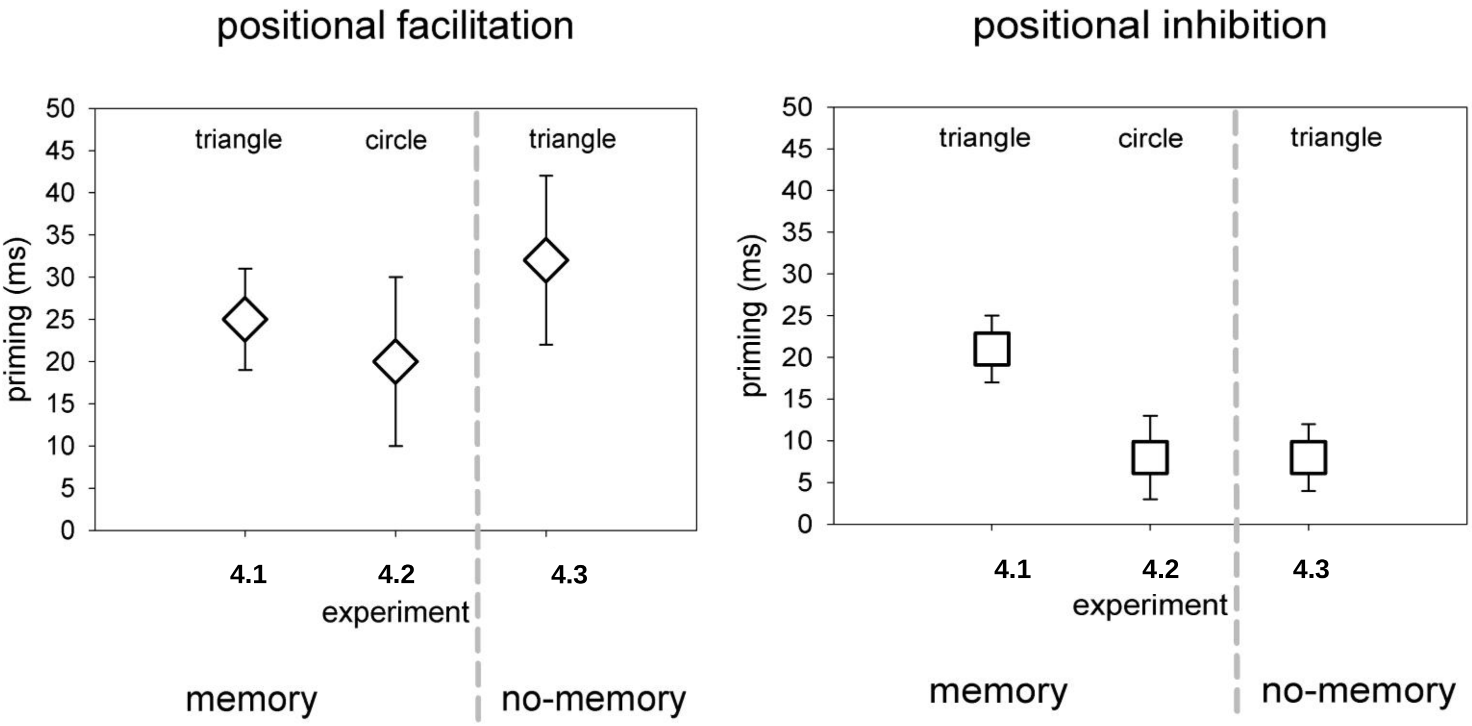

Figure 2. Positional priming and associated standard errors (in ms). Presentation of the target on trial *n* at the location of the target on trial *n-1* produced RT facilitation, independently of the memory condition (right panel). In contrast, presentation of the target on trial *n* at the location of a distractor on trial *n-1* produced inhibition (left panel), but this effect was larger in Experiment 4.1 (memory item: triangle → search task → memory test) than in Experiments 4.2 (memory item: circle → search task → memory test) and 4.3 (memory item: triangle → memory test → search task).

One additional analysis was conducted in order to rule out potential confounds. In more detail, it is possible that positional priming in Experiment 4.1 was larger because the WM triangle stimulus may have made observers notice a triangle in the search display which then could have led to an effect of automatic priming of the triangle display configuration and increased positional inhibitory priming. On this ‘configuration-priming’ hypothesis, it is the triangle configuration of the search items that automatically yields to larger priming, rather than the triangle stimulus that is actively held in WM while performing the search task. To test this, we conducted a control experiment, in which 13 new observers (7 female; mean age: 30.5 years) performed only the search, but no additional WM, task. Importantly, at the beginning of the control experiment (comprising of 4 separate sessions of 512 trials each), observers were told that the search items would appear in terms of a near-equilateral triangle configuration. According to the ‘configuration-priming’ hypothesis, inhibitory priming in the control experiment, even in the first session, should be comparable to priming in the triangle-memory-condition (Experiment 4.1). However, and contrary to the expectation, inhibitory priming in the first session of control experiment (see Figure 3) was reliably smaller than in Experiment 4.1 [9- vs. 23-ms effects; $F(1,34)=6.16$, $p<.05$, MSE = 8.93; F value corrected for different sample sizes – see e.g., Bortz, 1989)]. This suggests that the ‘active’ maintenance of the WM triangle stimulus (Experiment 4.1), rather than the ‘passive’ priming of the display configuration (control experiment), enhances positional inhibitory priming under WM conditions. Of note, in the control experiment, inhibitory priming of distractor locations increased as a function of practice on the task (see Figure 3 and also Table 2). This was confirmed by a separate within-subject ANOVA which revealed a practice main effect [$F(3,36)=6.00$, $p<.01$, MSE=254.52]. Post-hoc (LSD) tests showed that inhibitory priming was smallest in session 1 (9-ms effect), intermediate in sessions 2 and 3 (15- and 22-ms effects), and largest in session 4 (34 ms effects) of the control experiment. Interestingly, inhibitory priming in Experiment 4.1 was as large as the effect arising from relatively practiced trials in the in the control experiment [Experiment 4.1 vs. session 3 of control experiment: 23- vs. 22-ms effects; $F(1,34)=.78$, $p=.83$, MSE=3.43; F value corrected for different sample sizes]. This suggests that active maintenance of the WM triangle stimulus can reinforce (expedite) the acquisition of a spatial mental frame for the inhibition of distractor locations.

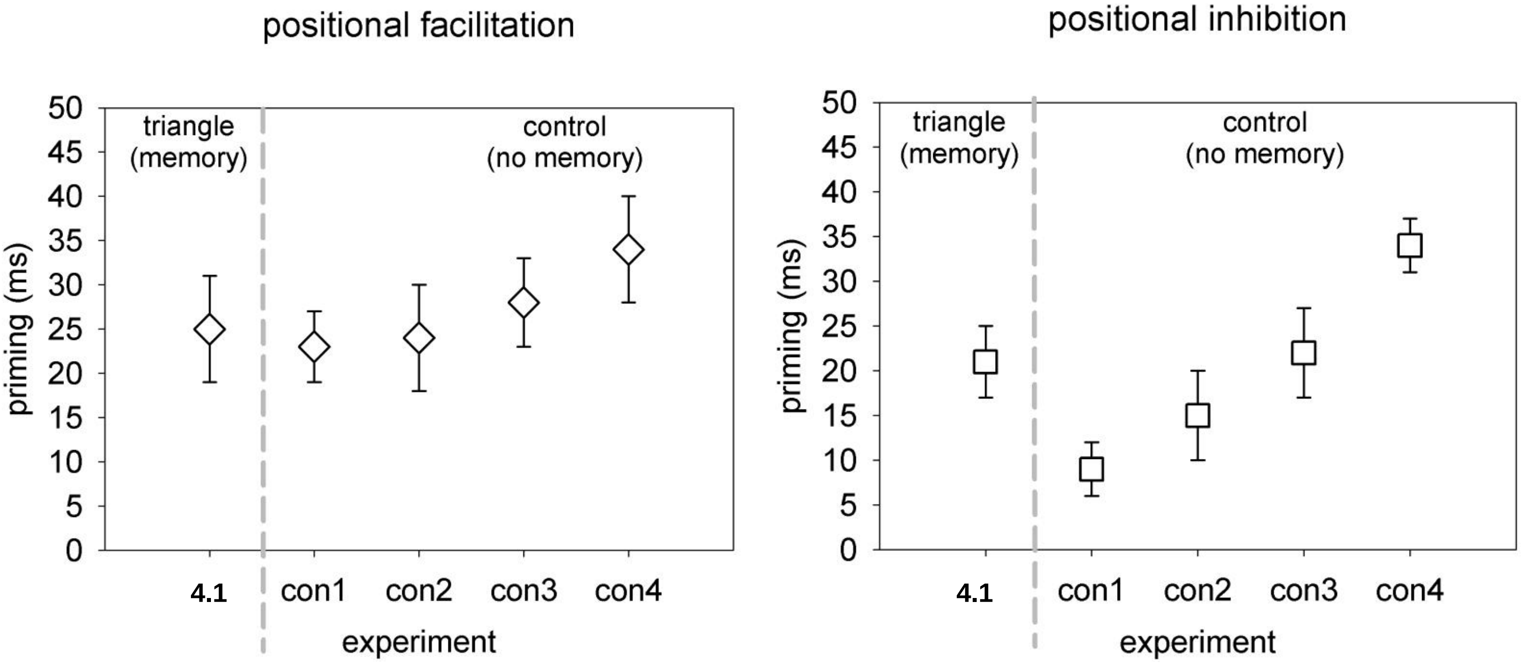

Figure 3. Mean positional priming and associated standard errors (in ms) in the triangle-memory condition ("4.1"; left panel of each figure) and each session of the control experiment ("con1", "con2", "con3", "con4"; right panel of each figure). The left side shows facilitatory positional priming (RT target at blank location minus RT target at target location); the right side inhibitory positional priming (RT target at distractor location minus RT target at blank location). Each data point represents the positional priming performance arising from 512 experimental trials.

Trial *n* target location relative to trial *n-1*			
	TT	TN	TD
Control exp.: First session (trials 1-512)	673 (2.8)	696 (4.3)	705 (4.2)
Control exp.: Second session (trials 512-1,024)	657 (0,5)	681 (4.1)	697 (4.4)
Control exp.: Third session (trials 1,025-1,536)	633 (0.9)	662 (4.3)	684 (4.7)
Control exp.: Fourth session (trials 1,537-2,048)	624 (2.8)	653 (4.5)	692 (4.1)

Table 2. Mean RTs (in ms) and, in brackets, error rates (in %) as a function of the target location on trial *n* relative to its location on trial *n-1* (target at target (TT), target at neutral (TN), or at distractor location (TD)) in the 'control' experiment, in which observers performed only the pop-out search task, without an additional WM task. The 'control' experiment comprised of four separate sessions with 512 trials each (leading to a total of 2.048 trials). At the beginning of each session, observers were alerted to the near-equilateral triangle configuration of the three search items.

Discussion

Content-specific WM effects

The experiments in this chapter examined the guidance of pop-out search by spatial WM contents, using a positional-priming paradigm (Maljkovic & Nakayama, 1996). Previous studies (Geyer et al., 2007, 2010) had shown that inhibitory positional priming is modulated by the overall regular (i.e., equilateral-triangle) arrangement of the search items: with practice, observers learn to place inhibitory tags on the distractor locations based on a regular (equilateral-triangular) spatial reference frame anchored at the target location (relational-encoding hypothesis). This frame is an object-based mental structure that is overlaid on a given display (because it is object-based, it permits regular rotational transformations across trials on which the global triangle 'orientation' on the underlying ellipse changes), thereby determining the to-be-inhibited locations. [Note that besides this object-based component, there is also evidence of a relatively smaller component, which is location-based – see below.] The present WM manipulation (i.e., triangle-memory condition) was intended to facilitate the acquisition of this relational-encoding routine for the inhibition of distractor locations.

The results were that RTs were expedited when the singleton-feature target was presented at a location previously occupied by a target and slowed when the target was presented at a previous distractor location (both relative to a trial *n-1* neutral-location baseline). Importantly, while facilitatory priming was comparable between Experiments 4.1, 4.2, and 4.3, inhibitory priming was larger in Experiment 4.1 (triangle-memory condition) relative to the Experiments 4.2 (circle-memory condition) and 4.3 (no-memory condition) (with numerically equivalent effects in the two latter conditions). This finding is important because it suggests that spatial WM modulates (the acquisition of) an attentional guidance routine that regulates the deployment of visual attention across trials (here: positional inhibition). In addition, the above pattern provides further evidence that the guidance of attention as based on spatial WM is entirely content-specific (see also Olivers et al., 2006b; Experiment 5): First, inhibitory priming was larger when there was a match between the shape of the memory stimulus and the configuration formed by the three search items (Experiment 4.1 vs. Experiment 4.2: 21- vs. 8-ms effects). And, second, inhibitory priming was equivalent in the ‘circle-memory’ Experiment 4.2 and the ‘no-memory’ Experiment 4.3 (8- vs. 8-ms effects), which also suggests that there was as such no cost associated with keeping the ‘wrong’ type of configuration in spatial WM.

Top-down modulable positional priming

The finding of increased inhibitory priming in Experiment 4.1 also suggests that positional priming is top-down modulable – at least to some extent (see below). This conclusion receives support from other studies (on dimensional priming; see, e.g., Müller et al., 2004), showing that intertrial priming varies as a function of WM demands. For example, in the study of Müller et al. (2004), observers were required to explicitly encode the target-defining dimension (or feature) across blocks of trials. Under this condition, the intertrial priming effects resulting from the repetition of the target dimension were enhanced, relative to conditions in which observers were never required to encode the target’s perceptual dimension (49 vs. 36 ms-effects; Müller et al., 2004; Experiment 2). Importantly, dimension priming was reliable even in the latter condition, which led Müller et al. (2004) to surmise that (dimensional) intertrial priming is mainly stimulus-, or bottom-up, driven (see, e.g., Pinto, Olivers, & Theeuwes, 2006, for a similar, though ‘exclusive’ argument in favour of stimulus-driven priming).

Note that although in the present study, positional inhibitory priming was larger in the triangle-memory condition (Experiment 4.1), there was still reliable inhibitory priming in the baseline conditions (circle-memory, no-memory). That is: even when observers were not required to retain shape (triangle) information, the inhibition of distractor locations was significant. In line with the results of Müller, Krummenacher, Heller (2004), this pattern of findings suggest that positional priming, in 'default' mode, is stimulus-driven (see also Maljkovic & Nakayama, 1994), but can be top-down modulated by WM signals. Given that inhibitory positional priming was two to three times as large in triangle-memory condition than baseline conditions (21 vs. 8- and 8-ms-effects), it appears that only about 1/3 of the effect can be attributed to bottom-up factors (such as the encoding and subsequent inhibition of the distractor locations based on their exact X- and Y-location coordinates), while some 2/3 are mediated by top-down factors, such as the encoding and subsequent inhibition of distractor locations based on a regular, triangular mental reference frame (see also Geyer et al., 2010).

Mechanisms of spatial working memory based guidance

A functional magnetic resonance imaging (fMRI) study provided evidence for distinct neural networks involved in WM-based attentional guidance (Soto et al., 2007; see also Soto et al., 2008). Specifically, Soto et al. (2007) found that WM influences are supported by two distinct brain networks: first, a 'fronto-thalamic network', comprising of, e.g., the dorsolateral prefrontal cortex, assumed to be involved in maintaining to-be-remembered and search target stimuli in working memory (so as to subsequently facilitate shifts of attention towards the target stimulus in the search array); and, second, a 'fronto-posterior' network, comprising of, e.g., the superior frontal gyrus (and the frontal eye fields – FEF), which is assumed to mediate WM guidance via increasing activation in early visual areas (such as those involved in color coding; e.g., V4) when the object (attribute) maintained held in WM is re-presented in the search display, whether as target or distractor (see also Desimone & Duncan, 1995, for a theoretical framework of the interaction between WM and attentional biasing of visual processing). Although Soto et al. (2007) investigated WM effects within single experimental trials (rather than across experimental trials – as in the present study); it is possible that spatial WM modulates inhibitory positional priming via similar ‘fronto-posterior’ structures as suggested by Soto et al. (2007).

In line with this proposal are the findings of a recent study, by Finke, Bucher, Kerkhoff, Keller, von Rosen, Geyer, Müller, and Bublak (2009), on positional priming with 14 patients with left-sided, visual hemi-neglect (these patients are typically unable to detect or respond to stimuli in the left hemi-field due to temporo-parietal damage in the right brain hemisphere). Using a task adopted from Maljkovic and Nakayama (1996), Finke et al. (2009) found that their neglect patients showed intact reliable inhibition of distractor locations, as well as intact facilitation of target locations. However, inhibition of distractor locations was strongly reduced relative to age- and education-matched, healthy control observers. Interestingly, when restricting the analysis to (two) patients whose fronto-parietal attention network was compromised by lesions that encroached the superior frontal sulcus in the region of the right FEF and neighbouring areas, they found no evidence for inhibitory priming of distractor locations at all. These findings suggest that the right FEF is a critical structure in mediating the inhibition of distractor locations (see also Kristjánsson, Vuilleumier, Schartz, Macaluso, & Driver, 2007, for further evidence regarding the role of the FEFs in positional priming as revealed by means of fMRI).

WM- versus LTM-based guidance

Recall that participants in the critical Experiment 4.1 had to maintain the (same) shape in memory for 64 trials, that is, for a much longer time compared to that typically used in studies of WM-based guidance of visual selection. Given this, it is possible that observers maintained the to-be-remembered shape information in LTM, rather than WM. Obviously, this argument rests on the assumption that the storage mechanisms underlying WM are fundamentally distinct from those underlying LTM (Baddeley, 2003). However, there are other conceptions according to which WM and LTM involve essentially the same representations, with WM being the ‘activated’ and ‘focally attended’ part of LTM (see Cowan’s, 1999, 2008 ‘embedded-processed model’ of working memory). On this account, LTM can express its influence only via ‘activated’ memory representations – that is, ultimately through WM. Applied to the present study, it is possible that observers eventually came to encode the shape stimulus in LTM. However, in order to bring about the observed modulation of inhibitory positional priming (and to retrieve the shape information at the end of the search block), the LTM representation would have had to be maintained in a sufficiently activated state to influence the ongoing search process, even though it may not have been consistently within the focus of attention (i.e., properly represented ‘in WM’). In other words, the effect of the to-be-remembered shape information on positional priming may either derive from the maintenance of this information in WM or be driven by the activated state of the shape representation in LTM. The latter would have made it easily retrievable into WM (giving rise to a WM-based effect) or it may have given rise to a direct interaction of the memory-task-relevant LTM representation with the encoding of positional information in the search task. We maintain that both types of effect would be theoretically interesting, and further work would be required to distinguish between them.

Summary

In summary, the present chapter shows that inhibitory positional priming in a pop-out search task, rather than being purely bottom-up determined, is influenced by search-task-irrelevant, though configurally related, contents actively maintained in WM. This effect is content-specific that is, observed only when the stimulus held in WM matches the global configuration formed by the search items. Given that the mental routine, or spatial reference frame, that mediates inhibitory positional priming takes several hundreds of trials to be developed, it is likely that actively maintaining a corresponding configuration in WM speeds up this acquisition (perceptual-learning) process (so that a few hundred trials suffice to yield a substantial effect). At the brain level, WM guidance might influence inhibitory positional priming via a critical structure in the fronto-parietal attention network, the right FEF.

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Chapter 6:

General Discussion

General Discussion

Aim

The aim of this thesis was to investigate the contents – or code – of position priming memory (absolute locations vs. configurations) and how position priming memory is reflected in the brain by using electrophysiological measures. In order to investigate these issues, positional priming of pop-out paradigm was used as a tool as one can draw conclusions with regard to how both target and distractor locations are represented in priming memory. Given the fact that reliable facilitatory and inhibitory priming effects are obtained from a typical positional priming of pop-out task, all studies reported in this thesis used a variant of the positional priming of pop-out task (Maljkovic & Nakayama, 1996). In a typical positional priming of pop-out task, observers perform a feature-singleton (i.e., ‘pop-out’) search task, with the displays consisting of three diamond shaped stimuli (1 target, 2 distractors). The target is defined by its color relative to the distractors (red target, green distractors and vice versa). Each stimulus has a cut-off section either at the left or right side. Participants’ task is to respond to the cut-off side of the target. The RTs were analyzed as a function of target’s location in the previous trial(s). There were three different inter-trial transitions: Target at previous target location (TT), target at previous distractor location (TD), and target at previously empty (i.e., neutral) location (TN). The latter served as a baseline condition against which RTs were compared in the TT and TD conditions. It was found that the RTs were fastest for trial n targets presented at n-1 target locations, intermediate for trial n targets presented at n-1 neutral locations, and slowest for trial n targets presented at n-1 distractor locations. These effects were named as target facilitation and distractor inhibition respectively.

Key findings

The first study (Chapter 2) was designed to investigate the representations(s) underlying target facilitation and distractor inhibition. The search items were presented at different locations, arranged at the horizontal display axis, at the vertical axis or both along the horizontal and vertical axes. In these experiments the number of the display regions to present the fixation cross and the search display varied. Three display regions were used in the horizontal-only and vertical-only axes experiments (1.1 and 1.2 respectively) and seven display regions were used when both horizontal and vertical shifts occurred (Experiment 1.3). This manipulation also enabled to create uncertainty with regard to the presentation of the search display: Three display regions were much more predictable compared to the seven display region condition with regard to the actual placement of the target and distractors across trials. By these manipulations it was possible to disentangle retinotopic, spatiotopic, and object-centered representations separately for facilitatory and inhibitory priming effects and how uncertainty in the placement of the search items influences the ‘use’ of one over the other reference frame. Previous findings suggest that position priming is supported by both spatiotopic (Maljkovic & Nakayama, 1996; Ball, Smith, Ellison, and Schenk, 2009; Jonikaitis & Theeuwes, 2013 and object-centered (Geyer, Zeheitleitner, and Müller, 2010; Tower-Richardi, Leber, and Golomb, 2012) representations. The main question of this chapter was to check whether there are differences in the relative contributions of one over the other reference frame to position priming. It was found that target locations were coded in positional short-term memory with reference to both spatiotopic and object-centred representations (Experiments 1.1, 1.2 vs. 1.3). In contrast, distractor locations were maintained in an object-centred reference frame (Experiments 1.1, 1.2, and 1.3). This finding suggests that the uncertainty induced by the experiment manipulation (3 vs. 7 display regions in Experiments 1.1, 1.2, and 1.3 respectively) is the underlying cause of the transition from spatiotopic to object-centered representation.

On the basis of these findings (specifically object-centred target facilitation), in addition to previous findings on object-centered inhibitory priming (Geyer et al., 2010), the next study (Chapter 3) was intended to further explore the contributions of configural attributes, specifically: What kind of object attributes are buffered in the position priming memory. The potential involvement of spatial configurations versus the spatial categories was tested by presenting the search displays in different visuospatial contexts across trials. By this, it was possible to assess positional priming effects, in addition to the repetitions vs. changes of the configural information. In order to do so, an object category was formed by a set of unique geometrical elements which 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, was defined by a particular element in a given item category (e.g., “¯|_” in the Z-category or “–|” in the T-category; see Garner and Clement (1963)). The search items were arranged as Z- or, respectively, T-configurations and varied across trials. In addition, the configuration of the search items was surrounded by a white Z- or T-shaped frame, reinforcing the inter-element grouping. These conditions made it possible to assess positional priming of target and distractor locations on consecutive trials of repetitions vs. changes of the configurations and the categories. Three inter-trial transitions were introduced: configuration-repetition, configuration-change, and category-change. Facilitatory and inhibitory priming effects were found to be evident and substantial in the baseline – configuration repetition – condition, but diminished in the configuration change and category change conditions. Importantly, the effects of repetitions vs. changes of configural attributes were dependent on the priming type: Target facilitation was influenced by repetitions vs. changes of the items’ exact configuration, and logically, category (i.e., RT facilitation resulting from the re-presentation of the target at the very same absolute location was reduced relative to the baseline when the target was presented in a e.g., “¯|_”-like followed by a “_|¯”-like configuration). In contrast, distractor inhibition was reduced relative to the baseline when the category of the items changed across trials, e.g., a “¯|¯”-like followed by a “_|¯”-like configuration. This pattern of findings support the hypothesis that the items arranged in certain visuospatial layouts are not perceived – and subsequently buffered in positional VSTM – as individual items, but rather as elements of an encompassing configuration and that stored configural attributes differ between target facilitation and distractor inhibition. This study also focused on investigating at which stage the positional priming of pop-out contributes to performance gains in the information processing chain. Namely, the so called pre-attentive and post-selective accounts would attribute the priming effects in visual pop-out search that speed-up the processes that occur prior to or, respectively, after the selection of the target by focal attention. The results indicated that facilitatory, but not inhibitory, priming was dependent on the repetitions versus changes of the response. This may indicate that target facilitation aids late processes, occurring after the selection of the target by focal attention. Consequently, Chapter 4 of this thesis elaborated this proposal using the EEG methodology. The analyzed sensory components were the Ppc, PCN, and CDA, reflecting the operation of focal selective prior to (Ppc, PCN) or after (CDA) the selection of the target by focal attention. Additionally, lateralized readiness potentials (both stimulus- and response-locked) were analyzed in order to be able to investigate the contribution of positional priming to response selection. The sensory-driven ERP components were modulated by the factor of target position. Processing of targets occurring at previous distractor, relative to previous neutral and target, locations modulated the elicitation of the Ppc and PCN waves, indicating that distractor positions were suppressed at early stages of visual processing. Processing of targets occurring at previous target, relative to previous neutral and distractor locations, by contrast, modulated the elicitation of the CDA wave, indicating that post-selective target identification processes were facilitated if the target occurred at the same position as on the previous trial. The stimulus-locked LRPs also revealed a significant contribution of the factor target position. The sLRP component was elicited earlier for targets presented at previous target locations. In addition, sLRPs peaked earlier in same-response trials. This suggests that sLRPs were modulated by both spatial (target position) and non-spatial (response) features. From these behavioural and electrophysiological findings it can be concluded that the distractor location priming manifests at early/pre-attentive stages while target location priming becomes functional at the late/post-selective stages in the information processing chain.

Finally, Chapter 5 provided a more direct test for the thesis that position priming memory and WM share representations (introduced in Chapter 2 of this thesis). Observers were presented with a to-be-memorized item (Experiment 4.1: triangle, Experiment 4.2: circle) at the beginning of each block and had to recall the to-be-remembered item among the three test items at the end of a block. In Experiment 4.3, the memory test was conducted prior to the start of a block. This experiment, without a memory condition, served as a control condition. It was found that inhibitory priming effects were larger in the memory condition (Experiment 4.1) than the no memory condition (Experiment 4.3). Moreover, the effects were comparable in Experiment 4.2 (circle memory) and Experiment 4.3 (no memory baseline), suggesting that increased distractor inhibition in Experiment 4.1 (triangle memory) is due to an overlap in the contents of WM and priming memory (triangle), and not because the secondary WM and search task share executive WM capacity.

Independent facilitatory and inhibitory priming mechanisms

As stated above, one ‘big’ conclusion of the present thesis is that the facilitatory priming and inhibitory priming effects are independent memory phenomena. There are four pieces of evidence that support this argument: First, manipulations of the placement of the search items across trials lead to variations in the reference frame governing target position priming (spatiotopic and object-centred reference frame), but not distractor position priming (object-centred reference frame). The second distinction between target position and distractor position priming is based on manipulations of configural attributes across trials. Facilitatory priming was found to be dependent on repetitions vs. changes of item configurations, as the target position repetition effect was reduced when the configuration of the target changed from one trial to the next. Inhibitory priming, on the contrary, was found to be dependent on repetitions vs. changes of (broader) visuospatial categories. Again, the selective influence of repetitions vs. changes of item configurations (positional target facilitation) and categories (positional distractor inhibition) gives rise to the idea that the two effects are independent phenomena. Another important conclusion that can be drawn from this line of experiments is that the positional priming operates on configural rather than location-specific (absolute) representations. Third, the independence of target and distractor location priming was also indicated by modulations of different ERP components, associated with the two types of priming, respectively. Distractor location priming was reflected in modulations (suppression) of the Ppc and PCN components, whereas target location priming elicited modulations (improvements) in the CDA and sLRP components. The differential conclusion that can be drawn from this data set is that priming can influence various processing stages in visual pop-out search. Another way to say this is that both early and late views of priming are appropriate accounts. The fourth key observation that may give rise to the idea of distinct target and distractor location priming comes from experiments manipulating the WM contents, in addition to assessing position priming performance. The experiments presented in Chapter 5 of the thesis found that WM contents overlapping with the (triangle) configuration of the search items boost (increase) distractor, but not target, position priming. Another conclusion that can be drawn from this result is that position priming memory and working memory share representations.

To sum up, the present thesis provides evidence for the claim that facilitatory and inhibitory position priming effects are independent from each other. In a way, the findings on configuration-centred position priming would give rise to the idea that positional priming involves much more cognition than previously thought and is subject to ‘Gestalt’ factors, expectations etc. – issues that are open to future investigations.

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Deutsche Zusammenfassung

Visuelle Suche und auch Mechanismen selektiver Aufmerksamkeit werden in wesentlichem Ausmaß von Komponenten des räumlichen Gedächtnisses beeinflusst. So kann z.B. die Wiederholung von Merkmalen der Zielreize von einem Versuchsdurchgang zum nächsten die Reaktionszeit im aktuellen Durchgang positiv beeinflussen, d.h. verringern. Dieser Effekt ist als auch als „Priming of Pop-out“ bezeichnet. Insbesondere führt die Wiederholung vs. Veränderung der Position des Zielreizes über Versuchsdurchgänge hinweg zu Effekten der Targeterleichterung (d.h.., das aktuelle Target erscheint am Ort des vorangegangen Targets) und Distraktorhemmung (das aktuelle Target erscheint am Ort eines vorangegangene Distraktors). Die vorliegende Arbeit untersucht, wie Effekte der Targeterleichterung und Distraktorhemmung im visuell-räumlichen Gedächtnis repräsentiert sind, also ob es sich um retinotope, spatiotope, oder objektzentrierte (allozentrische) Repräsentationen handelt und wie die Effekte (Erleichterung, Hemmung) im Gehirn, also elektrophysiologischen Variablen, niederschlagen.

Kapitel 2 behandelt die Gedächtnisrepräsentationen, die dem örtlichen Priming in der visuellen Pop-out Suche zugrunde liegen (Maljkovic & Nakayama, 1996). Drei Suchelemente (1 Zielreiz und 2 Distraktoren) wurden an unterschiedlichen Positionen präsentiert – ausgerichtet an der horizontalen Bildschirmachse (Experiment 1.1), entlang der vertikalen Bildschirmachse (Experiment 1.2), oder entlang beider Achsen zugleich (Experiment 1.3). In diesen Experimenten (1.1 bis 1.3) variierte die Anzahl der Bildschirmbereiche, an denen das Fixationskreuz und das Suchdisplay angezeigt werden konnte. In Experiment 1.1 und 1.2 wurden Bildschirmbereiche verwendet, die horizontale (Experiment 1.1) oder vertikale (Experiment 1.2) Verschiebungen erfordern. In Experiment 1.3 wurden 7 Bildschirmbereiche verwendet, welche sowohl horizontale als auch vertikale Verschiebungen ermöglichen. Die Präsentation des Suchdisplays war in den Experimenten 1.1 und 1.2 vorhersagbar. Dies war nicht der Fall in Experiment 1.3. Mit Hilfe dieser experimentellen Manipulationen konnten retinotope, spatiotope und objektzentrierte Primingrepräsentationen getrennt voneinander untersucht werden. Zusätzlich konnte der Einfluss der Unsicherheit im Hinblick auf die zukünftige Displayregion der Suchreize (3 vs. 7 Regionen) erfasst werden. Bisherige Studien legen nahe, dass örtliches Priming sowohl durch betrachterzentrierte (Maljkovic & Nakayama, 1996; Ball et al, 2009; Jonikaitis & Theeuwes, 2013) sowie auch objektzentrierte (Geyer et al., 2010; Tower-Richardi et al. 2012) Repräsentationen unterstützt wird. Dieses Kapitel befasst sich hauptsächlich mit der Frage, ob es Unterschiede in der relativen Beteiligung des einen im Vergleich zum anderen Referenzrahmen für örtliche Primingeffekte in der visuellen Pop-out Suche gibt. Es konnte gezeigt werden, dass die Position der Zielreize im lagebezogenen Kurzzeitgedächtnis mit Bezug zu sowohl betrachterzentrierten als auch objektzentrierten Repräsentationen kodiert werden (Experimente 1.1, 1.2 vs. 1.3). Im Gegensatz dazu wurden die Distraktorpositionen in einem objektzentrierten Referenzrahmen aufrechterhalten (Experiments 1.1, 1.2, und 1.3). Dies legt nahe, dass die Unsicherheit, welche durch die experimentelle Manipulation (3 vs. 7 Bildschirmbereiche in den Experimenten 1.1, 1.2, und 1.3) induziert wurde, dem Übergang von betrachterzentrierten zu objektzentrierten Repräsentationen forciert.

In Anbetracht der Tatsache, dass inhibitorisches und erleichterndes Raumpriming (Kapitel 2; s.a. Geyer et al., 2010), durch allozentrische Repräsentationen vermittelt ist, widmet sich Kapitel 3 der Frage, welche Objektattribute bzw. konfigurale Attribute im lagebezogenen Priminggedächtnis gespeichert werden. Hierbei wird in Kapitel 3 zwischen räumlichen Konfigurationen und Objektkategorien unterschieden, welche sich aus einem Satz einzigartiger geometrischer Elemente mit gemeinsamen Merkmalen zusammensetzen, die perzeptuell klar von Elementen anderer Kategorien abgrenzbar sind. Zur Untersuchung dieser

Fragestellung wurden der Singleton-Zielreiz und die Distraktoren über die Versuchsdurchgänge hinweg in verschiedenen, visuell-räumlichen Kontexten präsentiert.

Einzelne auf dem Bildschirm dargestellte Items sind perzeptuell in (objektähnlichen) Gruppierungen organisiert (Wertheimer, 1950). Eine Beispielkategorie stellt die „Z“-Kategorie dar, welche aus den vier Z-förmigen Elementen “¯|_”, “_|¯”, “╵–╷”, und “╷–╵” besteht. Ein weiteres Beispiel für eine Objektkategorie ist die „T“-Kategorie, bestehend aus den folgenden vier T-förmigen Elementen: “¯|¯”, “_|_”, “|–”, und “–|”. Im Gegensatz dazu stellt eine Konfiguration ein bestimmtes Element in einer gegebenen Itemkategorie dar (z.B., “¯|_” in der Z-Kategorie oder “–|” in der T-Kategorie; siehe Garner und Clement, 1963). Die Konfiguration der Items in der Suchaufgabe konnte von Durchgang zu Durchgang variieren, entweder als Z- oder T-Konfiguration. Zudem wurde die Gruppierung zwischen Items durch eine weiße Z- oder T-förmige Umrandung der Suchreize verstärkt. Dadurch konnten örtliche Wiederholungseffekte (Target am Ort eine vorangegangen Targets, Target am Ort eines vorangegangene Distraktors) getrennt von Wiederholungen bzw. dem Wechsel der jeweiligen Konfiguration der Suchreize registriert werden. . Hierbei waren folgende drei Übergänge zwischen den Versuchsdurchgängen möglich: (1) Wiederholung der Konfiguration, z.B. „¯|_“- gefolgt von „¯|_“-Konfiguration; (2) Wechsel der Konfiguration, z.B. „_|¯“- gefolgt von „¯|_“-Konfiguration und (3) Wechsel der Kategorie, z.B. „¯|¯“- gefolgt von „¯|_“-Konfiguration. Als „Baseline“ diente Bedingung 1. Hier wurden maximale Primingeffekte erwartet. Es fanden sich reliable Erleichterungs- und Hemmungseffekte in der Baseline-Bedingung. Die örtlichen Effekte waren in den Bedingungen Konfigurationswechsel und Kategoriewechsel reduziert. Konkret waren erleichternde Effekte im Zusammenhang mit der Wiederholung des Targetorts reduziert in den Bedingungen Konfigurations- und Kategoriewechsel. Die hemmenden Effekte im Zusammenhang der Präsentation eines Targets am vorangegangenen Distraktorort waren „nur“ reduziert in der Bedingung

Kategoriewechsel. Dieses Befundmuster stützt die Annahme, dass die Suchelemente in bestimmten visuell-räumlichen Anordnungen nicht als individuelle Items sondern vielmehr als Elemente einer umfassenden Konfiguration wahrgenommen werden. Dabei unterscheiden sich die memorisierten Attribute für den Targetort-Erleichterungseffekt (=konkrete Suchkonfiguration) und Distraktorort-Hemmungseffekte (=übergeordnete Kategorie).

Kapitel 3 untersuchte auch die Frage, auf welcher Prozessstufe in der visuellen Informationsverarbeitung das örtliche Priming zum Tragen kommt. So würden sog. ‚präattentive' und ‚postselektive' Modelle von – zumindest Merkmalspriming, die örtlichen Gedächtniseffekte entweder auf die Beschleunigung von Prozessen vor bzw. nach der Selektion des Zielreizes durch fokale Aufmerksamkeit attribuieren. Im Hinblick auf diese beiden Interpretationsansätze wurde nahegelegt, dass Priming sich auf eine Vielzahl (postselektiver) Prozesse auswirken kann. Hierzu gehören: (1) die Verifizierung des Zielreizes (Annahme, dass der aktuelle Zielreiz mit bisherigen gespeicherten Exemplaren – also einer Art „template" in einem Kontroll- oder Verifizierungsprozess abgeglichen wird; z.B. Huang et al., 2004), (2) die Selektion der Antwort (z.B. Yashar & Lamy, 2011; Töllner et al., 2008) und / oder (3) Vorbereitung oder Produktion der Antwort (Töllner et al., 2008, 2012). Obwohl die vorliegende Arbeit nicht abschließend zwischen diesen drei dargelegten Prozessen unterscheiden kann, deuten die im Rahmen dieser Untersuchung erzielten Befunde darauf hin, dass die Verifizierung des Zielreizes (Huang et al., 2004) aller Voraussicht nach durch örtliche Wiederholungseffekte in der visuellen Pop-out Suche beschleunigt wird. Angenommen wurde hierbei, dass örtliches Priming im Verifikationsprozess des Zielreizes hilfreich ist, dieser also und auch visuell-räumliche Stimulusattribute einbezieht, neben aufmerksamkeitsrelevanten und handlungsbezogenen Attributen des Targets. Zur Überprüfung dieser Fragestellung wurden die örtlichen Primingeffekte reanalisiert und zwar hinsichtlich der Wiederholung bzw. dem Wechsel der jeweiligen manuellen Reaktion. –

Üblicherweise werden Interaktionen zwischen der Wiederholung / dem Wechsel der Targeteigenschaften (gleiche vs. verschiedene Farbe, Größe, Ort, etc.) und der Wiederholung / dem Wechsel der Reaktionseigenschaften (gleiche vs. verschiedenen Reaktion) als Ausdruck eines späten Lokus der (örtlichen) Primingeffekte gewertet: eine Wiederholung / ein Wechsel der manuellen Reaktion kann de facto nur nach der attentionalen Selektion des Zielreizes die örtlichen Primingeffekte beeinflussen. Die entsprechenden Analysen zeigen, dass der Targetort-Erleichterungseffekt, nicht aber Distraktorort-Unterdrückungseffekt, von der Wiederholung bzw. dem Wechsel der manuellen Reaktion abhängig ist. Dies deutet darauf hin, dass örtliche Primingeffekte, genauer: der Targetort-Erleichterungseffekt, die visuelle Suche erst spät beeinflussen.

Die Frage nach dem (genauen) Lokus der Primingseffekte wird in Kapitel 4 untersucht. Hierzu werden elektrophysiologische Korrelate des örtlichen Pop-out Primings erfasst. Folgende EKP Komponenten sind von Interesse: Ppc („positivity posterior contralateral“), PCN („posterior contralateral negativity“), CDA („contralateral delay activity“) und die stimulus- und antwortgebundenen lateralisierten Bereitschaftspotentiale: sLRP sowie rLRP. Um Lateralisierungseffekte zu testen, wurde erneute eine Variante von Maljkovic und Nakayama‘s (1996) „Priming-of-Pop-Out“-Paradigma, mit vier (anstelle von drei) Stimuli mit kreisförmiger Anordnung verwendet. Der Positionswechsel des Zielreizes (Zielreiz am vorangegangen Targetort, am vorangegangen Distraktorort – die beiden Effekte wurden jeweils gegen eine Baseline getestet in der das Target im aktuellen Durchgang am Ort eines vormals nichtbesetzten oder neutralen Ort präsentiert wurde) erzeugte einen signifikanten Haupteffekt in allen untersuchten Komponenten (Amplituden und Latenzunterschiede, mit Ausnahme der rLRP). Die sensorisch bedingten, ereigniskorrelierten Potentiale, hier: PCN, belegten, dass die Distraktorposition auf einer frühen Stufe der Informationsverarbeitung unterdrückt werden, d.h. Distraktorpriming die Selektion des

Zielreizes durch fokale Aufmerksamkeit moduliert (verzögert) hat. Im Gegensatz dazu beeinflusst das Targetort-Priming spätere Stufen der Verarbeitung in der visuellen Suche, was durch Modulationen (Beschleunigung) der CDA und sLRP für Targets am vorangegangenen Targetort, relativ zu neutralen Orten (und Distraktororten), gestützt wird.

Kapitel 5 diente der Untersuchung der Frage, ob Inhalte des räumlichen Arbeitsgedächtnisses die erleichternden und hemmenden Primingeffekte beeinflussen, also ob beide Formen des visuellen Gedächtnissen über gemeinsame Repräsentationen vermittelt sind: an dieser Stelle soll darauf hingewiesen werden, dass Info im Arbeitsgedächtnis explizit ist und das Behalten von Info Ressourcen erfordert. Im Gegensatz dazu manifestiert sind Priming nahezu automatisch und die Info im Priminggedächtnis ist implizit (vgl. dazu Kapitel 1 der Arbeit). Es ist also sehr wohl möglich, dass den beiden Gedächtnistypen unterschiedliche Repräsentationen zugrunde liegen. Den Versuchspersonen wurde ein zu erinnerndes Item (Experiment 4.1: Dreieck, Experiment 4.2: Kreis) am Anfang eines jeden Experimentalblocks präsentiert und die Instruktion gegeben, das zu erinnernde Item unter den drei Testitems am Ende jedes Blocks abzurufen. In Experiment 4.3 erfolgte der Gedächtnistest vor Beginn eines jeden Blocks. Experiment 4.3 diente als Kontrollbedingung, da hier kein Gedächtnisabruf gegeben war. Hier ließ sich nachweisen, dass inhibitorische Primingeffekte in der Gedächtnisbedingung (Experiment 4.1) größer waren als in der Bedingung ohne Gedächtnisabruf (Experiment 4.3). Darüber hinaus waren die Effekte in Experiment 4.2 (Gedächtnis für Kreise) und Experiment 4.3 (keine Gedächtnisabruf) vergleichbar. Das deutet darauf hin, dass eine gesteigerte Hemmung der Distraktororte in Experiment 4.1 (Gedächtnis für Dreiecke) Folge einer Überlagerung der Arbeitsgedächtnisinhalte sowie des Priminggedächtnisses ist und nicht Resultat einer gemeinsamen Nutzung der Arbeitsgedächtniskapazität durch die Sekundäraufgabe und die Suchaufgabe (was in Experiment 4.3 geprüft wurde).

Die in den verschiedenen Kapiteln dieser Arbeit dargelegten Befunde befürworten eine Dissoziation zwischen erleichternden und hemmenden Priming im Zusammenhang der Orte der Suchreize. Eine solche Sichtweise wird durch diese Befunde gestützt: (1) Örtliches Priming-of-Pop-Out ist durch multiple räumliche Referenzrahmen vermittelt. Hier steht eine betrachterzentrierte Erleichterung der Targetorte einer objektzentrierten Hemmung der Distraktororte gegenüber. Targetort-Priming kann aber auch durch objektzentrierte Repräsentationen vermittelt sein, insbesondere dann, wenn die Orte (Displayausschnitte) wo die zukünftigen Reize erscheinen variable, d.h. nicht prädizierbar, sind. (2) Targetorte und Distraktororte werden nicht losgelöst von der sie einbettenden Konfiguration der Suchreize im Priminggedächtnis gehalten. Dabei unterscheiden sich die dem Erleichterung- und Hemmungseffekt zugrunde liegenden konfiguralen Attribute (Konfigurationen vs. Kategorien). (3) Örtliche Erleichterung und Hemmung beeinflusst unterschiedliche Stufen der Informationsverarbeitung in der visuellen Suche. Während die wiederholte Darbietung des Targets am vormaligen Targetort Prozesse der perzeptuellen Analyse und Antwortauswahl beschleunigt, verzögert die Darbietung des Targets am vormaligen Distraktorort die Auswahl des Zielreizes durch fokale Aufmerksamkeit. (4) Konkurrierende Arbeitsgedächtnisinhalte haben einen förderlichen Einfluss auf die örtliche Distraktorhemmung, nicht aber Targeterleichterung.

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<u>Skills and Language:</u>

Software
Statistical Package for Social Sciences (SPSS)
Statistica
R
Experiment Builder
PsychoPy (beginner)
Brain Vision Analyzer (beginner)

Hardware
SR Research Eye Link I & II
EEG recording with active system

Language
Turkish (native)
English (advanced)
German (B2)