

**SPATIAL COORDINATE FRAMES OF THE SALIENCE MAP**

Thesis

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## Abstract

The aim of the present study was to investigate whether spatial attention resides in retinotopic, spatiotopic, and / or object-based organized maps (see e.g., Itti and Koch, 2000 for the concept of attentional salience maps). Measures of target facilitation and distractor inhibition (Maljkovic and Nakayama, 1996) were used as tools to answer this issue. In four different experiments, retinotopic, spatiotopic, or object-based spatial information was given to observers and it was examined whether and how this modulated positional priming (target facilitation & distractor inhibition). In the different spatial conditions (retinotopic, spatiotopic, object-based), the locations of the fixation cross and the search display changed across trials. In addition, spatial uncertainty was modulated by varying the number of possible display locations (i.e., frames) where the singleton color target and the two distractors could appear in a single trial. In the 3-frame case (Experiments 1, 3), attentional shifts could occur along the horizontal meridian; in the 7-frame case (Experiments 2, 4), attentional shifts could occur in both the horizontal and vertical meridians. In all experiments, the dependent variables were reaction time and accuracy. In Experiments 3 and 4 eye movements were controlled to rule out any contamination of positional priming (in the spatiotopic / object-based conditions) by overt shifts of attention. The results were that when spatial uncertainty was low (Experiments 1, 3) target facilitation was represented in spatiotopic, but when spatial uncertainty was high (Experiments 2, 4) in object-based coordinates. In contrast, and independent of the number of possible display frames, distractor inhibition was represented in object-based coordinates. The results suggest (i) the existence of multiple reference systems; that (ii) the reference system within which attentional shifts are represented are modulated by spatial uncertainty (or task demands); and that (iii) in the 'default' 3-frame case (as investigated by Maljkovic & Nakayama, 1996) facilitatory and inhibitory shifts of attention are represented in different (spatiotopic / object-based) reference systems.

*Key words:* Salience map, coordinate frames, priming of pop-out

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## Spatial Coordinate Frames of The Saliency Map

In everyday life, people see thousands of things that enter to their visual field via retina. It is not possible to process every kind of visual information at our gaze. Visual selective attention can help us to detect and process only the necessary visual information while not attending to others. In this way, people can easily and quickly go on with their busy lives. Visual attention can also make people keep track of visual inputs when the objects move or when we execute eye movements thus can process visual information in a fast and accurate manner. Two processes, namely top-down and bottom-up processes are involved in attentional deployment. Top-down processes are expectations and previous knowledge of a person and bottom-up processes are the stimulus driven factors implemented by the task (Müller & Krummenacher; 2006).

Although top-down and bottom-up processes of attention have important role in understanding attentional processes, visual processing is still complicated to understand. The priority of processing of a specific item and the mechanism of this process is of interest. Itti and Koch's (2000) saliency model explains how humans can process a complex visual scene and the priority of directing attention to a specific item. The saliency model has its roots in bottom-up control of attention. Bottom-up control of attention would enable selecting the most "salient" stimuli in the scene (Itti & Koch, 2000). According to the saliency model, visual input is represented in topographic feature maps like color, orientation or motion and the information obtained from these different maps are then combined into a single map, which would represent the saliency of a location attended (Itti & Koch, 2000). A visually salient stimulus would attract attention as it would elicit a strong response/activation and less salient stimuli would not be processed so intensively (or would require conscious effort to pay attention), this is named as "winner takes it all". The most salient stimulus would win the competition and be perceived involuntarily (bottom-up) whereas less salient stimuli would need special effort to be perceived (top-down). There is also neuronal basis of the saliency model that the "winner takes it all" principle also applies. According to Itti and Koch (2000), there is competition between neurons and as stated before, the winning location has the most salient item in it. If somehow, the activation of neurons is inhibited, then the most salient item fails to be attended so the next most salient item will be the focus of attention. The brain areas known to be involved in saliency processing are; pulvinar, superior

colliculus, intraparietal sulcus (Itti & Koch, p. 1490, as cited in Robinson & Petersen, 1992; Gottlieb, Kusunoki, & Goldberg, 1998; Colby & Goldberg, 1999; Rockland, Andresen, Cowie, & Robinson, 1999).

The focus of the present study is to investigate the spatial reference or coordinate frame of the salience map introduced by Itti and Koch (2000). The representation of the feature contrast signals, induced by multiple stimuli, on the salience map is of interest. In the literature there are studies that have dealt with the relationship between salience model and the coordinate frames. For example, Barrett, Bradshaw and Rose (2003) investigated the spatial reference system of (endogenous) attention by using a spatial cueing task (Posner, 1980). In a given trial, there was a cue and target display. Each display consisted of three identical geometrical objects (e.g., square, circle, etc.) presented at three out of eight possible locations. Following the presentation of the cue display (for 1000 milliseconds – ms), a (shape or color) prime was presented marking the target object in the subsequent presented target display. In the target display, observers had to indicate the orientation of the letter “T” (oriented either 90° in clockwise or counter-clockwise direction from the vertical) presented in the target object. The critical manipulation was the location of the target in the target relative to the cue display. There were four different conditions. In the valid condition, the target (in the target display) appeared at the same egocentric and allocentric location relative to the cue display. In the egocentric condition, only the egocentric, but not allocentric spatial information was constant across the target and cue displays. In the allocentric condition, only the allocentric, but not egocentric information was constant across two displays. In the fourth non-valid condition, the target appeared at a new (egocentric and allocentric) location relative to cue display. Barrett et al. (2003) found that participants responded faster and more accurate when the egocentric location of the target remained the same during cue and target displays (valid, egocentric conditions) relative to changes of both egocentric and allocentric displays (non-valid condition). In addition, less response errors occurred in the allocentric relative to the non-valid condition. According to Barrett, Bradshaw and Rose (2003), the importance of the former finding is that the “egocentric shifts of attention towards a target primed by a non-spatial feature entails the selection of primed object in egocentric coordinates” (p. 46). In addition, the finding of accuracy gains (in the allocentric condition) reveals the presence of multiple spatial coordinate frames of attention in an endogenous feature-orienting task.

A study was done by Maljkovic and Nakayama (1996) similar to Barrett et al.'s. In their study, the spatial representation of positional priming, whether it is retinotopic and object-based was investigated. Three stimuli (1 target, 2 distractors) were presented in a horizontal row. The three locations were the relative locations of the stimuli. There were also four different absolute locations where a given horizontal row of stimuli could appear (i.e., top-left, top-right, bottom-left, bottom-right). Across consecutive trials, the target could appear either at a relative-same (providing a measure of object-based priming) or absolute-same location (providing measures of both retinotopic and object-based priming). The results were that repetitions of the target locations led to RT gains in both conditions, which led Maljkovic, and Nakayama (1996) to conclude that facilitatory target is an object-based effect (i.e., that facilitatory shifts of attention are represented on an object-based salience map that 'stores' the relations between items).

Another study on the relationship between (exogenous) attention and coordinate frames is by Golomb, Chun and Mazer (2008). The aim of their study was to investigate whether the salience of the spatial attention is represented in retinotopic or spatiotopic maps by combining behavioural and eye movement data. The participants were exposed to a gaze-contingent behavioural task where they were asked to execute eye movements as they were keeping a cued location in their working memory. In their Experiment 1 (saccade task), participants initially had to fixate a white dot that was followed by a cue item (a black square) and participants were asked to memorize the location of the cue item. Then they had to make a saccade towards a new white dot. After some delay (75 – 600 ms), a probe stimulus (a small black line - either oriented 45° to the left or right) was presented. Participants should report the orientation of the line. Importantly, the probe stimulus could appear at the same spatiotopic or same retinotopic location as the cue item or at a different location (i.e., control location). It was found that both spatiotopic and retinotopic locations of the memory cue were significantly facilitated compared to the control cue location. Interestingly, there was a significant attentional benefit in the retinotopic location right after a saccade generation (75 ms delay) although participants were biased to use a spatiotopic strategy (i.e., they had to memorize the cue's location in exact screen coordinates; in addition, the number of trials where probes appeared in the same spatiotopic location as the memory cue was twice as high than the retinotopic location). These findings lead to the conclusion that the retinotopic

coordinate frame has a major role in spatial attention (see also their Experiments 2 and 3).

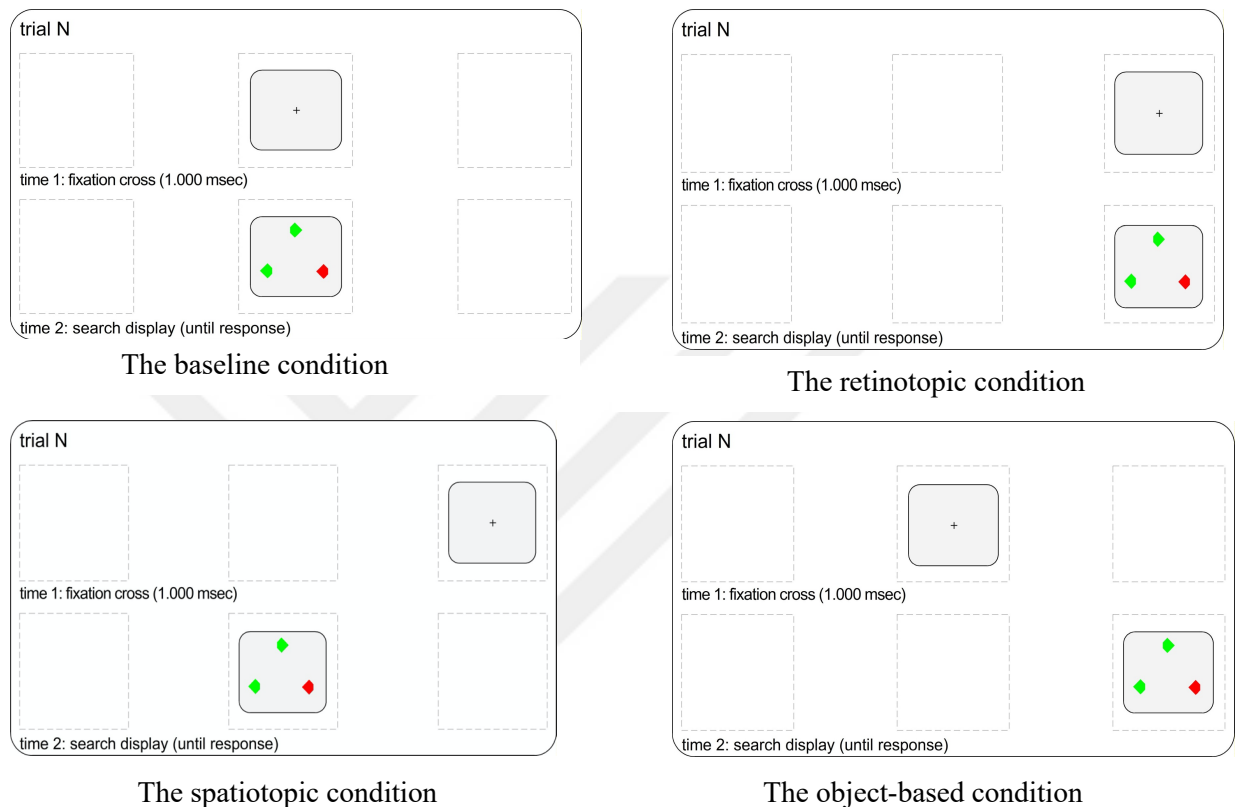
The results obtained by Barrett et al. (2003) and Golomb et al. (2008) suggest that in ‘default mode’ the salience map is organized in retinotopic coordinates. But there are several problems associated with these studies. For example, Barrett et al.’s (2003) investigated shifts of endogenous attention only in egocentric / allocentric conditions, which did not allow them to disentangle spatiotopic and retinotopic representations – particularly in the egocentric condition. Further, Golomb et al.’s (2008) study lacks a manipulation of an object-based coordinate frame and participants had to memorize only one item. In addition, observers should make eye movements towards specific locations which may have boosted retinotopic representations. Therefore, it is an open issue whether (exogenous) shifts of attention are represented in a retinotopic manner; whether there are differences in the spatial reference systems underlying facilitatory and inhibitory shifts of selective attention; and how the salience coding is influenced by the number of possible item locations (display frames). The present study attempts to investigate the spatial coordinate frame(s) underlying the attentional salience map by measuring shifts of selective attention (target facilitation, distractor inhibition) under retinotopic, spatiotopic, and object-based conditions using a positional priming of pop-out paradigm (Maljkovic & Nakayama, 1996).

Priming of pop-out (PoP) has been investigated by Maljkovic and Nakayama in several papers (1994, 1996, 2000). Pop-out occurs when a feature singleton ‘easily’ captures attention among distractors (cf. Wolfe, 1998). For example, if there were multiple stimuli located around a fixation cross and the color and/or the shape of one stimulus differ from the rest of the stimuli, then the different odd stimulus (target) would capture attention and participants would respond. In PoP, target selection is dependent on the features of the target in the previous trial. If the specific feature of the target is repeated within the trials, the target selection process gets faster and it has been stated that PoP is an “attention guiding mechanism facilitating attentional deployment” without any kind of conscious process” (as cited in Chun & Nakayama, 2000, p. 69) (Maljkovic & Nakayama, 1996). In the present study PoP is used as a method to measure the effect of trial  $n-1$  on trial  $n$  performance. According to Chun and Nakayama (2000), the cross-trial effects reflect implicit memory mechanisms that would improve one’s performance in visual search. In positional PoP, facilitatory and

inhibitory effects are obtained (Maljkovic & Nakayama, 1996). That is: targets are detected faster and more accurately when the location of the target is same relative to the location of the target in trial  $n-1$  (i.e., facilitation). In contrast, target detection is slower and less accurate when the trial  $n$  target is presented at a  $n-1$  distractor location (i.e., inhibition). Facilitation and inhibition are calculated according to a baseline where the  $n$  target is presented at a  $n-1$  empty (neutral) location.

In the present study, participants performed a pop-out visual search task identical to the one used by Maljkovic and Nakayama (1996). The target defining feature (color) and the response-defining feature (orientation) were manipulated independently – in addition to the location of the target (target at target, at distractor, or at neutral location). In four different experiments the positional cross-trial priming effects (target facilitation, distractor inhibition) are investigated in four different conditions: the baseline condition, serving as a control condition, the retinotopic condition, the spatiotopic condition and the object-based condition. In the baseline condition, the fixation cross and the three search stimuli are located on the centre of the screen on each trial. That is, and in case of the target appearing at a target location across trials, the search stimuli are presented at the same retinotopic, spatiotopic, and object-based locations (note that the three search stimuli always appeared in terms of an near equilateral triangle – thus also the object coordinates were same across trials). In the retinotopic condition, in trial  $n-1$  the fixation cross and the search display would be located on the left side of the screen and in the next trial (trial  $n$ ) they would be located on the right side of the screen. This would require participants to make a shift from left to right and then from right to left across trials. Thus, in this condition only the retinotopic (and object-based), but not spatiotopic locations were same across trials. In the spatiotopic condition, the fixation cross would be located either on the left or on the right side and the search display would be located always in the centre of the screen. If the fixation cross is located on the left side in trial  $n-1$ , then it would be located on the right side in trial  $n$  (and vice versa). Again, this condition would require participants to shift attention from left to right towards the fixation cross, but the search items would appear in the centre of the screen. Thus, in this condition only the spatiotopic (and object-based), but not retinotopic locations would be same across trials. In the object-based condition, the fixation cross would be always located in the screen centre, but the three search items would change their locations from left to right side and from right to left side across trials. For example, if the display is located

on the left side of the screen in trial n-1, then it would change its location to right side of the screen in trial n. Importantly, in the object-based condition, only the information relating to the object wherein the three search items are presented (the ‘triangle’), but not retinotopic nor spatiotopic information would be repeated across trials. Figure 1 shows the four conditions.



*Figure 1.* Illustration of the four spatial conditions used in Experiments 1 through 4.

Experiment 1 investigates positional priming of pop-out paradigm (PoP) by presenting the search display in three different display frames located in a horizontal meridian. The three display frames are on the left side, on the centre and the right side of the screen. Eye movements were not controlled, meaning that participants were allowed to make gaze shifts. Experiment 2 investigated positional PoP by presenting the search display in seven different display frames located both in horizontal and vertical meridians. The seven display frames are on top, in the middle and on the bottom for both left and right side of the screen (3x2) and also on the center of the screen. As in Experiment 1, eye movements were not controlled. Experiments 3 and 4 investigated positional PoP with three and seven coordinate frames respectively. The

rational of these two experiments was to control for eye movements and to make sure that priming effects (in the spatiotopic and object-based conditions in Experiments 1 and 2) were not affected by eye movements (that could result in retinotopic positional PoP in these conditions). Eye movement control was achieved by instructing participants to maintain gaze on the fixation cross. In addition, in these experiments eye movements were recorded by an EyeLink II system. In all experiments, positional facilitatory and inhibitory priming effects were investigated as markers for reference frame(s) of salience map. For example, if the reference frame underlying positional facilitation is retinotopic (as suggested by, e.g., the results from Maljkovic & Nakayama, 1996), then one should observe facilitatory positional priming in the baseline and retinotopic, but not spatiotopic and object-based conditions. Further, it is hypothesized that RT and accuracy performance gets worse as the task gets more difficult (with the 'easiest' condition being the baseline condition and 'hardest' condition being the object- / spatiotopic conditions because additional shifts of attention towards the display items would be required in these conditions after the appearance of the fixation cross). Thus, one would expect a "condition main effect" on RTs. Lastly, it is hypothesized that RT (priming) modulations would occur depending on spatial uncertainty. Because the modulation of the number of possible display frames is an essentially new issue, it is expected that at least with three display frames one should observe reliable facilitatory and inhibitory priming at least in the baseline, spatiotopic, and, retinotopic conditions (see, e.g., Bucher, 2008). In the following, three display frames are referred to as the "low spatial uncertainty" and seven display frames as the "high spatial uncertainty" conditions.

## Method

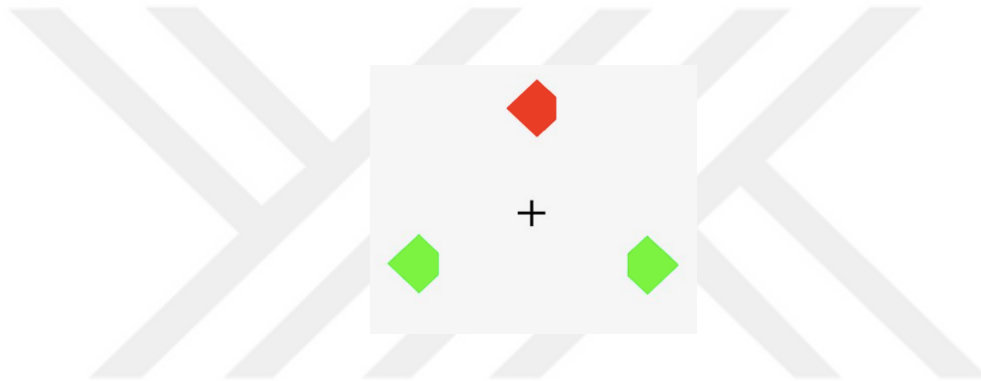
### EXPERIMENT 1

#### *Participants*

Twenty participants (female = 13) participated in the study with the mean age of 26.8 ( $SD = 5.92$ ). Convenient sampling method was used. All participants had normal or corrected to normal visual acuity and except one participant, all participants were right handed. Participants were debriefed about the study on the basis of their wish at the end of the experiment and anonymity of their responses was guaranteed. Participants were paid 8 Euros per hour at the end of the experiment for their participation in the study.

### *Apparatus*

Eye tracking method was used to record participants' eye movements by using Eye Link II version 2.22. The search display consisted of three diamond shaped stimuli presented on a white background ( $30.0 \text{ cd/m}^2$ ): Two distracters and one target (size  $1.37 \times 1.37^\circ$ ). If the distracters were in red, then the target would be in green and vice versa. The colors were near-equiluminant: red,  $7.7 \text{ cd/m}^2$ ; green,  $8.0 \text{ cd/m}^2$ . The screen background was white ( $30.0 \text{ cd/m}^2$ ). All stimuli had a cut-off section (size:  $0.10 \times 0.10^\circ$ ) either on the left or on the right side – as shown in Figure 2. The black fixation cross had a size of  $0.36 \times 0.36$  and luminance of  $0.5 \text{ cd/m}^2$ . The cut-off sections ( $.36 \times .36^\circ$ ) were determined randomly and independently for each target and distractor stimulus.



*Figure 2.* The illustration of the search display used in the present experiment (baseline condition). The target (here in red) appeared together with two distractors (here in green) in visual field around the fixation cross on a white background. Colors of the target and distractor stimuli changed randomly within the trials.

The stimuli were arranged on an ellipse layout with horizontal and vertical axes of  $8.85^\circ$  and  $7.26^\circ$  respectively. With respect to the previous trial  $n-1$ , targets on trial  $n$  appeared at one of three types of position: at the same position as the target on the previous trial, at the position of a distracter on the previous trial, or at a position that had no stimulus on the previous trial (neutral baseline). Stimulus presentations and response recordings were supplied by a computer with Microsoft Windows XP software. LG Plasma TV was used to present the stimuli. Participants responded with keyboard buttons (Y for left sided cut off, N for right sided cut off) placed on the table in front of the participant. The distance between the participant and the screen was approximately 68 cm and participants' head positions were maintained with a

head and chin rest. The experiment cabin was dimly lighted.

### *Procedure*

The experiment consisted of a practice session (4 blocks, 20 trials each) and the experimental session (10 blocks, 96 trials each). Per participant, the baseline condition consisted of 40% of trials, the retinotopic condition, the spatiotopic condition and the object-based condition consisted of 20% of experimental trials. The fixation cross was presented on a white background for 1000 ms and was followed by the presentation of the search display with two distractors and one target until response. The inter-trial interval was 1000 ms.

There were three possible locations for the fixation cross and the search display to occur: On the left side, on the centre and on the right side of the screen. These display frames were separated by a distance of about  $13.1^\circ$ . The task, identical to Maljkovic & Nakayama (1996), was to press the Y (for left sided cut off) or N (for right sided cut off) button on the keyboard as fast and as accurately as possible according to the position of the cut-off target section. Participants' reaction times and error rates were recorded. Error feedback was not provided. Participants were instructed verbally and tested individually. The experiment lasted around 1-1.5 hours per participant.

## **EXPERIMENT 2**

### *Participants*

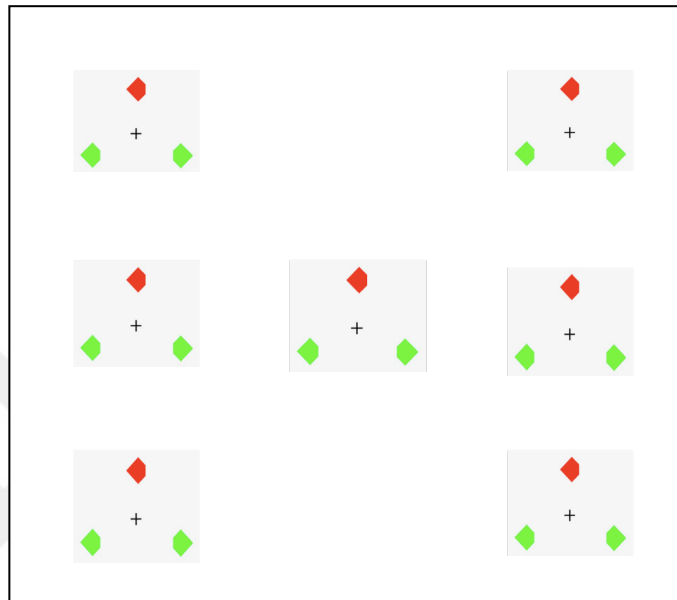
Twenty-one participants (female = 13) participated in the study with the mean age of 26 ( $SD = 6.33$ ). Convenient sampling method was used. All participants had normal or corrected to normal visual acuity and except one participant, all participants were right handed. Participants were debriefed about the study on the basis of their wish at the end of the experiment and anonymity of their responses was guaranteed. Participants were paid 8 Euros per hour at the end of the experiment for their participation in the study.

### *Apparatus*

The apparatus of the Experiment 2 is identical with Experiment 1 with the exception of having seven spatial coordinate frames to present the search display and the fixation cross instead of three spatial coordinate frames. The fixation cross and the search display could occur at seven different locations on the screen. The possible locations are; top, middle, bottom corners on the left hand side and right hand side

located vertically plus the on the center of the screen. The distance between the fixation cross and the search display was  $13.1^\circ$ .

Figure 3 shows the possible locations that the fixation cross and the search display could be presented.



*Figure 3.* The illustration of the possible locations for the fixation cross and the search display to be presented. On each trial, the fixation cross and the search display could be presented in one of the seven possible locations on the screen.

### *Procedure*

The procedure is identical with Experiment 1 except the case of having seven spatial coordinate frames instead of three spatial coordinate frames.

## **EXPERIMENT 3**

### *Participants*

Twelve participants (female = 8) participated in the study with the mean age of 26.5 ( $SD = 7.92$ ). Convenient sampling method was used. All participants had normal or corrected to normal visual acuity and all participants were right handed. Participants were debriefed about the study on the basis of their wish at the end of the

experiment and anonymity of their responses was guaranteed. Participants were paid 8 Euros per hour at the end of the experiment for their participation in the study.

#### *Apparatus*

The apparatus of the Experiment 3 is identical with Experiment 1. The only difference was that participants were instructed not to make any eye movements. In addition, eye movements were recorded by an SR Research EyeLink II using the standard settings (note that head movements were not recorded because of the large plasma monitor). As the task is more difficult to perform without eye movements (as it was obtained from pilot testing), the fixation cross (size  $0.78 \times 0.70^\circ$ ) and the stimuli (size  $2.21 \times 1.98^\circ$ ) were enlarged in this experiment. In addition, the fixation cross remained on the screen until the response to make it easier for the participant to suppress eye movements. Further, the distances between the display frames were reduced to  $10.71^\circ$ .

#### *Procedure*

The procedure is very similar to Experiment 1 with the exception of forbidding eye movements and the presentation of the fixation cross during the presentation of the search display. Participants were instructed to look at the fixation cross and to maintain their gaze on the cross till the next trial.

## **EXPERIMENT 4**

#### *Participants*

Same participants were tested as in Experiment 3.

#### *Apparatus*

The apparatus of the Experiment 4 is identical with Experiment 2 with the exception of using larger fixation crosses (size:  $0.78 \times 0.70^\circ$ ) and search stimuli ( $2.21 \times 1.98$ ). In addition, the fixation cross remained on the screen until the response to make it easier for the participant to inhibit eye movements.

#### *Procedure*

The procedure is identical with Experiment 2 with the exception of forbidding execution of eye movements. There was at least one day break between the third and the fourth experiment to eliminate practice effects that might be caused by memory traces.

## Results

The data analyses were done by using SR Research's "Data Viewer", "R" (R Development Core Team, 2007), and SPSS. In all experiments, the first and last three trials in each block were excluded from the analysis. In addition, RT values smaller or larger than  $\pm 2.5$  standard deviations were treated as extreme values and also excluded from the analysis. Error trials (and trials in which eye movements occurred – for Experiments 3 & 4) were also excluded from analysis.

### EXPERIMENT 1

The percentage of trials excluded due to having extreme RT values was 2.2%.

#### ANOVAs

Separate repeated-measures ANOVAs were computed to test for the effect of target location on accuracy and RT in the four different spatial conditions. It was found that there was a significant main effect of target position on participants' RT values in all conditions. (Baseline:  $F(2, 19)=86.97, p<.05$ , Retinotopic:  $F(2, 19)=24.93, p<.05$ , Spatiotopic:  $F(2, 19)=44.79, p<.05$ , Object-based:  $F(2, 19)=11.27, p<.05$ ). Table 1 represents the mean RT values at different target locations in four different conditions. The main effect of target position on accuracy was found to be significant only in the baseline condition,  $F(2, 19)=8.58, p<.05$ .

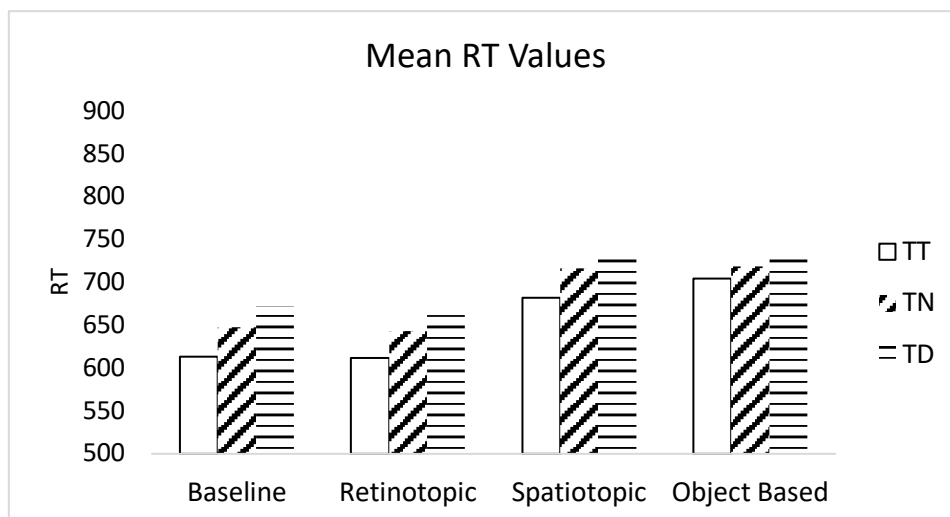


Table 1. The mean of RT values for different target positions.

#### t-Tests

T-tests were computed to see if the relative RT values (target facilitation, distractor inhibition) were different between the different conditions with regard to facilitation and inhibition processes. Table 6 represents the mean number of facilitation and inhibition values for each condition.

#### *Facilitatory Priming*

Differences in the amount of target facilitation between the baseline vs. retinotopic and between the baseline vs. object-based conditions were non-significant. Facilitation between the baseline condition and the spatiotopic condition was marginally significant  $t(1, 19) = -1.92, p=0.07$ . Facilitatory priming values were significantly different from zero in the retinotopic and object-based conditions. These results imply that when participants are presented with three spatial frames, the crucial manipulation fails to generate facilitatory priming. Nevertheless, the significant differences of all conditions from zero imply that the manipulation is not completely unsuccessful.

#### *Inhibitory Priming*

Distractor inhibition compared between baseline vs. retinotopic, baseline vs. spatiotopic, and baseline vs. object-based conditions is all non-significant. Inhibitory priming values are significantly different from zero in all conditions. Having no differences in inhibitory priming performance in the four conditions leads to the fact that the inhibitory shifts of spatial attention are represented in the object-based frame. These results imply that, when the search display is presented in three spatial frames the crucial manipulation fails to generate inhibitory priming, as there is no statistical difference in inhibitory priming performance across four conditions. Based on the RT values, it can be concluded that target detection performance is not significantly slower / faster in a specific condition compared to the baseline condition. As all other conditions (retinotopic and spatiotopic) are present in the object-based condition, inhibitory priming is represented in the object-based frame in this experiment.

## **EXPERIMENT 2**

The percentage of trials excluded due to having extreme RT values is 2.0%

#### *ANOVAs*

Separate repeated-measure ANOVAs (in the four spatial conditions) revealed main effect of target position on participants' RT values in all conditions. (Baseline:  $F(2, 20)= 96.43, p<.05$ , Retinotopic:  $F(2,20)=36.73, p<.05$ , Spatiotopic:

$F(2,20)=35.79, p<.05$ , Object-based:  $F(2,20)=20.14, p<.05$ ). Table 2 represents the mean RT values at different target locations in four different conditions. There was a main effect of target location on accuracy in the baseline ( $t(2,20)=3.32, p<.05$ ), and spatiotopic ( $t(2,20)=3.34, p<.05$ ), conditions. The effect was non-significant in the retinotopic and object-based conditions.

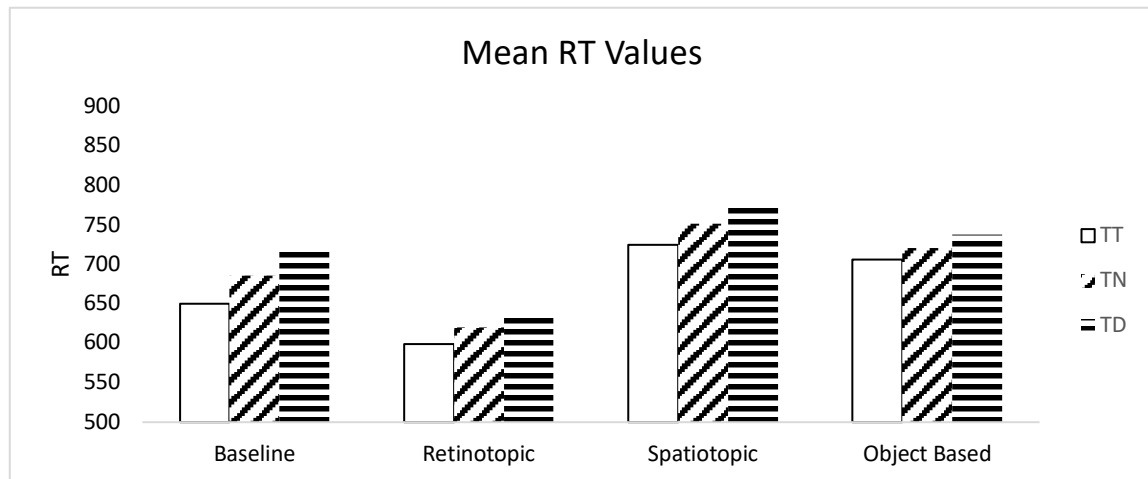


Table 2. The mean of RT values for different target positions.

#### *t-Tests*

T-tests were computed to see if the relative RT values are significantly different from each other across different conditions with regard to facilitation and inhibition processes. Table 6 represents the mean number of facilitation and inhibition values for each condition.

#### *Facilitatory Priming*

Differences in target facilitation between the baseline vs. retinotopic and the baseline vs. object-based conditions was significant,  $t(1, 20) = 2.35, p<.05$  and  $t(1, 20) = 4.25, p<.05$  respectively. Facilitation between baseline condition vs. spatiotopic condition is non-significant. Facilitatory priming values are significantly different from zero in all conditions. These results imply that the spatiotopic frame has no role in facilitatory priming when the search display is presented in seven frames.

#### *Inhibitory Priming*

Distractor inhibition compared between the baseline vs. retinotopic and baseline vs. object-based conditions is significant,  $t(1, 20) = 3.92, p < .05$  and  $t(1, 20) = 2.97, p < .05$  respectively. Inhibition between baseline condition vs. spatiotopic condition is marginally significant,  $t(1, 20) = 1.88, p = .074$ . Inhibitory priming values are significantly different from zero in the retinotopic and object-based conditions. The inhibitory priming values follow the trend of the results of the facilitatory priming; the spatiotopic frame has a small role in the representation of inhibitory priming compared to other conditions.

### EXPERIMENT 3

The percentage of trials excluded due to having extreme RT values is 2.8%. The percentage of fixations for all participants in all conditions is % 0.

#### ANOVAs

Separate repeated-measures ANOVAs revealed that there was a significant main effect of target position on participants' RT values in all conditions (Baseline:  $F(2, 11) = 65.04, p < .05$ , Retinotopic:  $F(2, 11) = 5.43, p < .05$ , Spatiotopic:  $F(2, 11) = 12.61, p < .05$ , Object-based:  $F(2, 11) = 3.52, p < .05$ ). Table 3 represents the mean RT values at different target locations in four different conditions. The main effect of target position on accuracy was found to be significant only in the baseline condition,  $F(2, 11) = 6.75, p < .05$ .

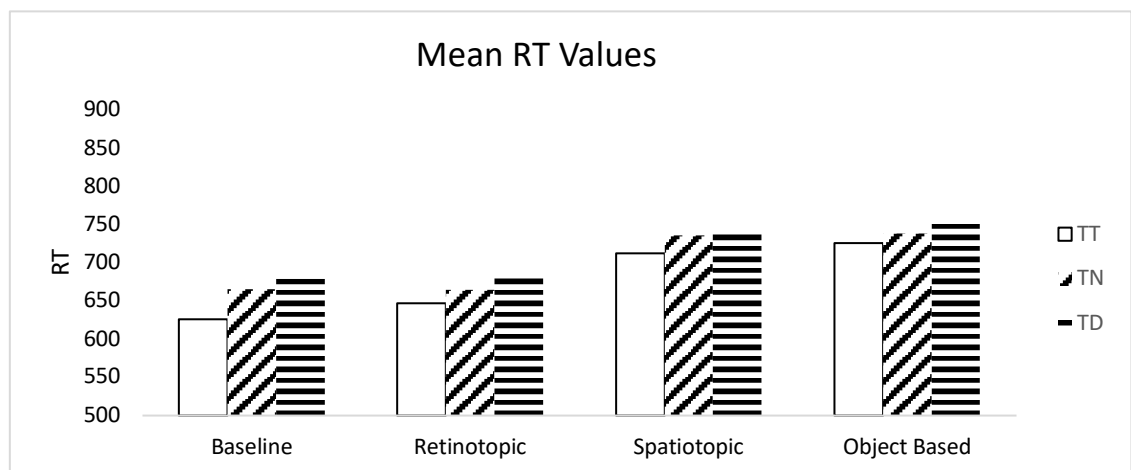


Table 3. The mean of RT values for different target positions.

#### t-Tests

T-tests were computed to see if the relative RT values are significantly different from each other across different conditions with regard to facilitation and

inhibition processes. Table 6 represents the mean number of facilitation and inhibition values for each condition.

#### *Facilitatory Priming*

Target facilitation compared between the baseline condition and the retinotopic condition is marginally significant,  $t(2, 11)=1.94, p=.078$ ; between baseline condition and spatiotopic condition is non-significant and between the baseline condition and the object-based condition is marginally significant  $t(2, 11) = 1.97, p=.075$ . Facilitatory priming values are significantly different from zero only in the spatiotopic condition (and baseline condition). These results imply that when the participants are presented with seven frames and their eye movements are controlled, facilitatory priming fails to be represented in the spatiotopic condition.

#### *Inhibitory Priming*

Distractor inhibition compared between the baseline condition vs. retinotopic condition, baseline condition vs. spatiotopic condition and the baseline condition vs. object-based condition are all non-significant. Inhibitory priming values are significantly different from zero in the baseline and object-based conditions. These results imply that when participants are presented with three frames and their eye movements are controlled, the crucial manipulation fails to generate facilitatory priming. Nevertheless, the significant differences of some conditions from zero imply that the manipulation is not completely unsuccessful.

### **EXPERIMENT 4**

The percentage of trials excluded due to having extreme RT values is 2.5%. The rate of number of fixations for all participants in all conditions is % 0.

#### *ANOVAs*

Separate repeated-measures ANOVAs were computed to test the effect of target location in error rates and RT values for different conditions. It was found that there was a significant main effect of target position on participants' RT values in all conditions except the spatiotopic condition (Baseline:  $F(2, 11)=38.75, p<.05$ , Retinotopic:  $F(2, 11)=23.84, p<.05$ , Object-based:  $F(2, 11)=5.66, p<.05$ ). Table 4 represents the mean RT values at different target locations in four different conditions. The main effect of target position on accuracy was found to be significant only in the baseline ( $F(2, 11)=6.75, p<.05$ ) and spatiotopic ( $F(2, 11)=3.71, p<.05$ ) conditions.

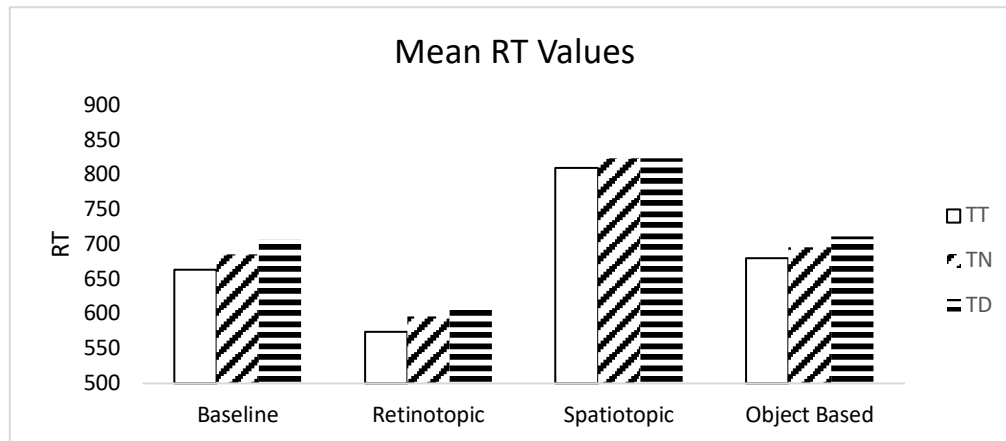


Table 4. The mean of RT values for different target positions.

### *t-Tests*

T-tests were computed to see if the relative RT values are significantly different from each other across different conditions with regard to facilitation and inhibition processes. Table 6 represents the mean number of facilitation and inhibition values for each condition.

### *Facilitatory Priming*

Target facilitation compared between the baseline condition and all other three conditions were all non-significant. Facilitatory priming values are significantly different from zero only in the retinotopic condition (and baseline) condition. These results imply that when the participants are presented with seven frames and their eye movements are controlled, the crucial manipulation of spatial frames fails to generate facilitatory priming.

### *Inhibitory Priming*

Distractor inhibition compared between the baseline condition and the retinotopic condition is marginally significant,  $t(2, 11) = 1.49, p=0.16$ ; between baseline condition and spatiotopic condition is marginally significant  $t(2, 11) = 1.92, p=.08$ ; between the baseline condition and the object-based condition is non-significant. Inhibitory priming values are significantly different from zero in the baseline and retinotopic conditions and marginally significant in the object-based condition. These results imply that when the participants are presented with seven frames and their eye movements are controlled, the crucial manipulation of spatial frames partially fails to generate inhibitory priming. Retinotopic and spatiotopic

frames have a minor role in the representation of inhibitory priming in this experiment.

	<b>EXP. 1</b>			<b>EXP. 2</b>			<b>EXP. 3</b>			<b>EXP. 4</b>		
	TT	TN	TD	TT	TN	TD	TT	TN	TD	TT	TN	TD
Baseline	1.8	2.8	4.2	2.1	2.6	3.7	2.4	3.1	4.9	2	3.4	4.9
Retinotopic	2.3	3.2	2.9	2.5	2.8	2	3.2	3.5	4.6	2.6	2.8	1.7
Spatiotopic	2.6	3.7	3.7	3.8	5	6.4	1.9	4.3	3.4	3.6	4.6	7.1
Object-based	2.9	3.6	4.5	3.2	2.8	3.4	4.7	5.9	5.7	3.4	2.8	1.9

*Table 5.* The mean values of error rates for Experiments 1 – 4 at different target locations (target at previous target (TT) / neutral (TN) / distractor (TD) positions).

Table 6 summarizes the mean values for facilitatory and inhibitory priming processes for all experiments and conditions.

	Facilitatory Priming				Inhibitory Priming			
	Baseline	Retinotopic	Spatiotopic	Obj Based	Baseline	Retinotopic	Spatiotopic	Obj Based
3 frames	26	32	37	17	25	13	17	14
7 frames	36	21	27	15	33	16	26	17
3 frames Eye mov. control	40	18	23	12	13	16	8	18
7 frames Eye mov. control	22	23	13	15	21	13	1	16

*Table 6.* Mean values for facilitatory and inhibitory priming processes in milliseconds for experiments with 3 or 7 spatial coordinate frames & with / without eye movement control.

Table 7 shows the  $p$  values of the facilitatory and inhibitory priming values for all experiments and conditions.

	Facilitatory Priming				Inhibitory Priming			
	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 1	Exp. 2	Exp. 3	Exp. 4
Baseline vs. Retinotopic	$p > .05$	$p < .05$	$p = .078$	$p > .05$	$p > .05$	$p < .05$	$p > .05$	$p > .05$
Baseline vs. Spatiotopic	$p = .070$	$p > .05$	$p > .05$	$p > .05$	$p > .05$	$p = .074$	$p > .05$	$p = .080$
Baseline vs. Object-based	$p > .05$	$p < .05$	$p = .075$	$p > .05$	$p > .05$	$p < .05$	$p > .05$	$p > .05$

Table 7.  $p$  values for the comparisons of facilitatory and inhibitory priming processes between different conditions for all experiments.

### Discussion

The general scope of the present study was to investigate the salience representations of facilitatory and inhibitory spatial attention by using positional priming of pop-out. In addition, another interest was to examine the role of spatial uncertainty in the determination of salience representations. It was hypothesized that as the spatial uncertainty gets higher, manipulated by the number of display frames, the salience representation would be modulated. The results of Experiments 1 – 4 are discussed in the light of these hypotheses.

### EXPERIMENT 1

Experiment 1 consisted of three spatial coordinate frames and eye movements were not controlled. Attentional shifts occurred only in the horizontal meridian, leading to a low spatial uncertainty condition. As expected, the main effect of target location on RT values was significant. Meaning that when the target was presented at

previous target location, participants responded faster compared to neutral condition and they were significantly slower when the target was presented at previous distractor location. This finding of positional priming is a replication of the findings of Maljkovic and Nakayama (1996). There was a significant effect of target location on accuracy just in the baseline condition. The failure to get this significance in other conditions can be explained by the difficulty of the task in the other conditions, as performing the task in the baseline condition is the easiest. The mean values of error rates mirror the priming effects in most of the conditions as the participants made least amount of errors when the target was located in the previous target location and highest amount of errors when the target was located in the previous distractor location compared with neutral condition.

Comparisons of facilitatory priming between the baseline condition vs. retinotopic and object-based conditions were non-significant. Marginal significance was obtained for the facilitation comparison between baseline vs. spatiotopic conditions. This marginal significance makes sense since the facilitatory priming is explained by the spatiotopic condition since it is larger than the baseline facilitation (37 ms vs. 26 ms.). Inhibitory priming comparison between the conditions baseline vs. retinotopic/spatiotopic/object-based is all non-significant. This means that the spatial coordinate frame underlying positional inhibition is at least object-based.

## **EXPERIMENT 2**

Experiment 2 consisted of seven spatial coordinate frames and eye movements were not controlled. Participants' shifts occurred both in the horizontal and vertical meridians, leading to higher spatial uncertainty compared to Experiment 1. As expected, the main effect of target location on RT values was significant. Meaning that when the target was presented at previous target location, participants responded faster compared to neutral condition and they were significantly slower when the target was presented at previous distractor location. This finding of positional priming is a replication of the findings of Maljkovic and Nakayama (1996). There was a significant effect of target location on accuracy in the baseline and spatiotopic conditions. The mean values of error rates mirror the priming effects in most of the conditions as the participants made least amount of errors when the target was located in the previous target location and highest amount of errors when the target was located in the previous distractor location compared with neutral condition.

Comparisons of facilitatory priming yielded significant differences between baseline vs. retinotopic and object-based conditions. Facilitatory priming is explained by the spatiotopic condition since it has the largest value for target facilitation (27 ms). In addition, facilitatory priming in the spatiotopic condition is as large as it is in the baseline condition, suggesting spatiotopic coordinate frame has a major role in facilitatory priming. Smaller facilitation effect in the object-based condition (15 ms.) compared to the baseline condition (36 ms.) can consolidate the fact that facilitatory priming is represented in spatiotopic coordinate frame. Comparisons of inhibitory priming between the baseline vs. retinotopic and object-based conditions were both significant and marginally significant in the comparison between the baseline vs. spatiotopic conditions. This means that the spatial coordinate frame manipulation was successful in creating inhibitory priming. The priming values between the baseline and spatiotopic conditions are comparable (33 vs. 26 ms) and this can lead to the conclusion that the spatiotopic coordinate frame, as in the facilitatory priming condition, explains inhibitory priming.

### **EXPERIMENT 3**

Experiment 3 consisted of three spatial coordinate frames and eye movements were controlled. Participants' shifts occurred only in the horizontal meridian, leading to a low spatial uncertainty condition. Participants' eye movements were controlled and this control makes the task harder. As expected, the main effect of target location on RT values was significant. Meaning that when the target was presented at previous target location, participants responded faster compared to neutral condition and they were significantly slower when the target was presented at previous distractor location. This finding of positional priming is a replication of the findings of Maljkovic and Nakayama (1996). There was a significant effect of target position on accuracy only in the baseline condition. The mean values of error rates mirror the priming effects in most of the conditions as the participants made least amount of errors when the target was located in the previous target location and highest amount of errors when the target was located in the previous distractor location compared with neutral condition.

Comparisons of facilitatory priming were marginally significant between the baseline vs. retinotopic and object-based conditions, non-significant between the baseline vs. spatiotopic condition. Thus, it can be concluded that when participants

should maintain gaze at the fixation cross, facilitatory priming is represented in spatiotopic coordinates. In contrast, inhibitory priming value was increased in the object-based condition (18 ms.) and the retinotopic condition (16 ms.), and was reduced in the spatiotopic condition (8 ms.) relative to the baseline condition (13 ms.). These results suggest that inhibitory priming is represented in the object-based spatial coordinate frame when the eye movements are controlled.

#### **EXPERIMENT 4**

Experiment 4 consisted of seven spatial coordinate frames and eye movements were controlled. Participants' shifts occurred both in the horizontal and vertical meridians, leading to higher spatial uncertainty compared to Experiment 3. As expected, the main effect of target location on RT values was significant in three conditions except the spatiotopic condition. Meaning that when the target was presented at previous target location, participants responded faster compared to neutral condition and they were significantly slower when the target was presented at previous distractor location. This finding of positional priming is a replication of the findings of Maljkovic and Nakayama (1996). There was a significant effect of target position on accuracy only in the baseline and spatiotopic conditions. The mean values of error rates mirror the priming effects in most of the conditions as the participants made least amount of errors when the target was located in the previous target location and highest amount of errors when the target was located in the previous distractor location compared with neutral condition.

Comparisons of facilitatory priming between the baseline vs. retinotopic/spatiotopic/object-based conditions were all non-significant. This means that under conditions of spatial uncertainty the spatial coordinate frame of positional facilitation is object-based. In a similar vein, inhibitory priming was comparable between the baseline condition (21 ms) and the object-based condition (16 ms). This effect was reduced in the retinotopic (13 ms.) and spatiotopic (1 ms.) conditions. This can lead to the conclusion that object-based spatial coordinate frame has a major role in inhibitory priming and spatiotopic has no role in inhibitory priming.

#### **GENERAL DISCUSSION**

Experiment 1 consisted of three spatial coordinate frames and participants' shifts occurred in the horizontal meridian. Participants were allowed to make eye

movements around the stimuli. The results of Experiment 1 can be compared with Experiment 3 as they both had three spatial coordinate frames. The difference between them is control of the eye movements. Participants were not allowed to make any eye movements in Experiment 3. Facilitatory priming is represented in the object-based reference frame in Experiment 1, but in the spatiotopic coordinate frame in Experiment 3. In contrast, inhibitory priming is represented in the object-based coordinate frame in both Experiments 1 and 3. The same kind of comparison can be made between Experiments 2 and 4. These two experiments consisted of seven spatial display frames and participants' shifts occurred both in the horizontal and vertical meridians. The difference between Experiments 2 and 4 is control of the eye movements. In Experiment 2 facilitatory priming was represented in the spatiotopic coordinate frame, but in the object-based in Experiment 4. Inhibitory priming is represented in the spatiotopic coordinate frame in Experiment 2, but in the object-based coordinate frame in Experiment 4.

The role of spatial uncertainty in determination of spatial frames was one of the scopes of the present study. It was hypothesized that as the spatial uncertainty gets higher, manipulated by the number of spatial coordinate frames, the salience representation would be modulated. This hypothesis was confirmed in Experiments 3 and 4 – at least for positional facilitation: the salience representation underlying this effect changed from spatiotopic (Experiment 3) to object-based (Experiment 4). This change can be attributed to the differences in the number of frames across the experiments (3 vs. 7) or to the shifts of attention across only the horizontal or both horizontal and vertical meridians (3 vs. 7). A study by Rizzolatti, Riggio, Dascola and Umiltà (1987) could explain the differences in facilitation obtained across different experiments. They investigated the relationship between spatial attention and horizontal and vertical meridians. The aim was to analyze RT costs and gains in different conditions. The possible stimulus locations were vertical or horizontal meridians in and outside of fovea. If the stimuli were presented in the horizontal meridian, attention would be able to cross the vertical meridian and when the stimuli are presented in the vertical meridian, attention would be crossing the meridian dividing the visual field into two halves (Rizzolatti et. al., 1987). In the experiment, participants were presented with a fixation box and four stimulus boxes (located vertically and horizontally in left / right or upper / lower hemifields respectively) with digits around them were placed around the fixation box. The digit that appeared in the

fixation box (in an attended or non-attended hemifields in vertical and horizontal meridians) indicated that i) the stimulus would be shown with a high probability in a specific corresponding stimulus box or ii) all four boxes had the equal probability to contain the stimulus. Task was to fixate and maintain on the fixation box as participants were directing their attention to the (i) cued box or (ii) all boxes. In % 80 of the trials, participants fixated to one box and in % 20 of trials they fixated to all boxes. In the % 80 condition, in % 70 of the trials, the stimulus would appear in the cued box and in % 30 of trials, the stimulus would appear in one of the non-cued boxes. In the valid trials, the stimulus would be presented in the cued location, in the invalid trials, the stimulus would be presented in a non-cued location and in the neutral trials, all the locations would be cued. There was a significant main effect of trial type on RT. RT values were highest in the invalid trials and lowest in the valid trials (Rizzolatti et. al., 1987). The authors (1987) calculated the benefit of orienting attention correctly by subtracting the RT values of valid trials from neutral trials. It was found that the RT gains were present in 7 out of 8 participants; furthermore RT gains were present in conditions of both vertical and horizontal meridians. The results of Rizzolatti et. al. (1987) indicate that RT gain (facilitation) occurs when participants shift attention across different frames.

In contrast to the facilitatory priming, the representation underlying positional inhibition was constant across the two experiments (Experiments 3 and 4). This confirms earlier findings of object-based inhibition (e.g., Geyer, Zehetleitner & Müller, 2010) as well as object-based facilitation (Maljkovic & Nakayama, 2010) – the latter when uncertainty is high (as it was the case in Maljkovic & Nakayama's Experiment 3). The underlying reason why participants switch from a spatiotopic to an object-based encoding route could be due to the number of display frames. It can be speculated that when the number of display frames is higher (as in Experiments 2 and 4), it might be easier to detect target's location on the basis of an triangular object frame as it would reduce the total number of to be detected target locations from 3 locations x 7 frames to 1 object x 7 frames.

The source of salience processing in the brain has been the topic of many studies. Primary visual cortex (V1) pulvinar, superior colliculus, intraparietal sulcus (Itti & Koch, p. 1490, as cited in Robinson & Petersen, 1992; Gottlieb, Kusunoki, & Goldberg, 1998; Colby & Goldberg, 1999; Rockland, Andresen, Cowie, & Robinson, 1999) are known to be responsible for visual processing but there are studies showing

that area V1 is not the only source of salience processing. Finke, Bucher, Kerckhoff, Keller, von Rosen, Geyer, Müller and Bublak (2009) did a priming study on patients with left sided visual hemi-neglect. Aim was to see if positional inhibition would occur in neglect patients. The Maljkovic and Nakayama (1996) task was used and two groups were tested: Neglect group and control group. It was found that inhibitory priming was preserved in the neglect group and facilitatory priming was present in both groups (Finke et al., 2009). This study, in addition to Geyer, Müller and Krummenacher (2007), demonstrates that facilitatory and inhibitory processes are dissociable as they have different processing mechanisms. Patients showing no inhibitory priming had lesions in frontal areas of brain, specifically in frontal eye field (FEF). In addition to Finke et. al. (2009), the findings of the present study also yields dissociation between facilitation and inhibition. Positional facilitation was represented in the spatiotopic reference frame in Experiment 3 and in object-based reference frame in Experiment 4 and positional inhibition was represented in the object-based reference frame in Experiments 3 and 4. So, the dissociation between facilitation and inhibition also accounts for the dissociation between the reference frames underlying positional facilitation and inhibition.

The role of right FEF in inhibitory priming has been shown by Kristjansson, Vuilleumier, Schwartz, Macaluso and Driver (2007). So lesion in FEF area might be a reason for preserved inhibitory priming in neglect patients. Bucher (2008) investigated spatial remapping mechanisms and their impairments in patients with right parietal lesions by using positional priming of pop-out as a tool. Bucher's (2008) study demonstrates the role of parietal regions in facilitatory priming. In three groups (parietal lesion, non-parietal lesion, control) Maljkovic and Nakayama (1996) task was used. It was found that facilitatory priming was enhanced in the parietal lesion group. Inhibitory priming was comparable across different groups. The studies of Finke et al (2009) and Bucher (2008) demonstrate that V1 is not the only brain area responsible for salience processing but frontal and parietal areas do also play a crucial role.

In the future studies, the number of spatial coordinate frames could be increased and changes in priming values can be examined. Another idea would be to change the locations of the search displays. For example, by using seven spatial coordinate frames, like in Experiments 2 and 4, the search displays can be presented on a diagonal meridian. The possible locations to present the search display would be

on the upper left corner, on the centre, on the lower right corner. The results of this experiment would then be compared with the results of experiments having shifts in horizontal and/or vertical meridians (where there would be only 3 display frames). The interesting question would be whether spatial uncertainty is the effect of a larger number of display frames (3 vs. 7) or shifts of the search display across the horizontal and vertical meridian (relative to shifts of the search display across only the horizontal meridian). Lastly, in a different experiment one can present the search display in a way that the shifts would occur just in the vertical meridian but only in one visual field. Meaning that, contrary to the retinotopic condition in Experiments 1-4, the search displays would be always presented on the same side of the screen across trials. In addition to all these different manipulations, RT values with regard to priming performance can be examined from trials  $n-1$  till  $n-10$  and thus changes in priming effects can be observed across trials as Maljkovic and Nakayama (1994) showed that the priming effects can be observed till five to eight trials. These different experiments would enable us to speculate on the nature of facilitatory and inhibitory priming, and if they are affected by different kinds of shifts (horizontal / vertical / diagonal) or by different kinds of spatial coordinate frames (retinotopic / spatiotopic / object-based).

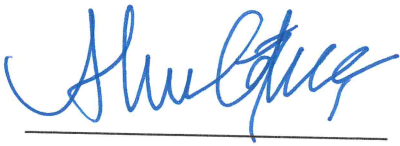
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## Declaration of Autonomy

I hereby confirm that I did this work by myself and that I have used no other sources/references than those mentioned in the reference list.

A handwritten signature in blue ink, appearing to read 'Ahu Gökçe', is written above a horizontal line.

Ahu Gökçe