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The details of the article are as follows:

Donovan, T., Crawford, T., & Litchfield, D. (2012). Negative priming for target selection with saccadic eye movements. *Experimental Brain Research*, 222, 483-494.

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Negative priming for target selection with saccadic eye movements

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Abstract

We conducted a series of experiments to determine whether negative priming is used in the process of target selection for a saccadic eye movement. The key questions addressed the circumstances in which the negative priming of an object takes place, and the distinction between spatial and object-based effects. Experiment 1 revealed that after fixating a target (cricket ball) amongst an array of semantically-related distracters, saccadic eye movements in a subsequent display were faster to the target than to distracters or new objects, irrespective of location. The main finding was that of the facilitation of a recent target, and not the inhibition of a recent distracter or location. Experiment 2 replicated this finding by using silhouettes of objects for selection that based on feature shape. Error rates were associated with distracters with high target-shape similarity therefore Experiment 3 presented silhouettes of animals using a distracters with low target-shape similarity. The pattern of results was similar to that of Experiment 2, with clear evidence of target facilitation rather than inhibition of distracters. Experiment 4 and 5 introduced a distractor together with the target into the probe display, to generate competitive selection in the probe condition. In these circumstances clear evidence of spatial inhibition at the location of the previous distractors emerged. We discuss the implications for our understanding of selective attention and consider why it is essential to supplement response time data with the analysis of eye movement behaviour in spatial negative priming paradigms.

Keywords: negative priming, saccadic eye movements, attention, inhibition, visual search, target selection

Negative priming for target selection with saccadic eye movements

When we conduct a visual search of the environment to locate an object, such as a specific pair of shoes in a shoe shop or the face of a friend in a crowd, this requires the precise control of the eyes and presumably the suppression of interference from the irrelevant distractors. But is a distracter actively suppressed for a saccadic eye movement and if so, which of its properties? The negative priming paradigm has been extensively used to explore some of the key cognitive processes that include the active inhibition of an irrelevant distracter (for review, see Tipper, 2001). Negative priming has been demonstrated across a range of paradigms that have included various stimulus domains such as location (Tipper, Weaver, & Houghton, 1994), words (Malley & Strayer, 1995), objects (Tipper & Driver, 1988) and the individual features of multidimensional visual objects (Fanini, Nobre & Chelazzi, 2006). In our previous work a negative priming task was used to provide insight into the role of spatial location priming in the control of saccadic eye movements (Crawford, Hill, & Higham, 2005). Although the processing of the location of an object appears to be obligatory (e.g., Chen & Cave, 2006), attention to location is just one of several ways in which object selection can be based. Müller, von Mühlelen, & Geyer, (2007) have shown a dissociation between target selection (which they argued was based on location information) and distracter inhibition (which they argued was object based). The aim of the current experiments was to establish whether negative priming plays a role in saccade target selection to realistic objects and to distinguish between the processing of distracter location and identity. It is critical for our understanding of the underlying mechanisms, to determine the boundary conditions in relation to the negative spatial priming itself. The negative priming paradigm consists of two displays, the first being termed the ‘prime’

display, which in our experiments consists of a target and two distracters. Participants are required to attend to the target and to ignore the distracters. In the second display, termed the 'probe' display, the target can appear at the previous location of the target, the location of the distracters or at a new location. Response times are typically slowed on trials in which the target appears in the location of a previously ignored distracter. It is in this 'ignored repetition' condition, that response times are increased relative to other conditions (Tipper, 2001).

There have been few negative priming experiments using saccadic eye movements, which is surprising as eye movements and attention are so closely linked (Belopolsky & Theeuwes, 2009). Building on our previous research on inhibition of distracters and location (Crawford et al., 2005), we examine whether such effects emerge with realistic objects. In the present study we measured the saccadic reaction time (SRT), the delay between the appearance of a target in the probe display and the time the eyes start to move towards the target. The frequent use of abstract stimuli should be extended to realistic objects, in order to formulate ecologically valid inferences on the operating principles of human selective attention. Therefore the stimuli used in the present study are depictions of real objects selected within semantic categories (sport/animal) of various cricket items and animals respectively. In the first experiment greyscale images of the cricket items were used; in the second, silhouettes of the cricket items; and in the third experiment silhouettes of animals. These series of experiments allowed us to explore the effects of low-level factors such as shape and the type of object on the spatial priming of objects. In Experiments 4 and 5 we investigate the impact on saccadic priming of a distracter presented together with the target in the probe display.

Experiment 1

Methods

Participants

Twelve participants (11 female, mean age = 19yrs) were naive to the aims of the experiment and had normal or corrected visual acuity (assessed with the Snellen chart). No participant had consumed any alcohol in the 12-h preceding the experiment or taken nicotine in the hour prior to testing. None of the participants had a history of mental health problems and none were currently taking any form of medication. Participants were screened in this manner for all experiments. The study was approved by the Lancaster University departmental ethical research committee.

Apparatus and stimuli

All stimuli were presented on a 19" CRT monitor (60 Hz) and eye movements were recorded with an EyeLink II Tracker (head mounted, 500Hz temporal resolution, 0.5 degrees spatial resolution). The stimuli consisted of 4 greyscale images of items relating to cricket: a ball, a set of wickets, a bat and a hat. Objects were displayed on a white background and had average size of 1.44° x 2.44° and were positioned 5° away from the centre of the screen. There were 360 trials with each trial consisting of a prime and probe. Each trial began with a central fixation point. After 850ms or 1000ms the prime display appeared for 1500ms. In the prime display the target (i.e. ball) was presented together with 2 of 3 possible distracters (bat, hat and wicket) in a regular spatial arrangement (see Figure 1). A fixation point was then displayed for a random period between 850ms and 1000ms followed by the probe display for 1500ms. In the probe display a lone object (ball, bat, hat, or wicket) was presented either at the location of the prime display target, the location of a previous distracter or a new location. This meant that there were

conditions where the previous target from the prime display, a previous distracter or a ‘new’ distracter not used in the prime, was the lone item (see Figure 2 for full description of conditions). We simplified the task by using a single object in the probe display as the negative priming effect is obtained even if a distracter is not presented (e.g. Milliken, Tipper, Houghton & Lupianez, 2000). The 9 trial conditions were randomly presented in 10 blocks of 36 trials each. Within each block there was an equal proportion of each trial type. There were an equal number of target presentations at each of the 4 locations in the prime and probe, and an equal number of presentations of each of the distracters as targets in the probe.

<< Insert Figure 1 about here >>

Procedure

The experiment was conducted at the Department of Psychology at Lancaster University. Participants were seated 60cm from the display and were instructed to fixate the target in the prime display while ignoring the distracters, and to fixate the lone item in the probe display as quickly as possible. They were given 10 practice trials and at the start of each block a 9 point calibration was conducted. Participants were encouraged to have a break between blocks if they were having difficulty maintaining concentration.

<< Insert Figure 2 about here >>

Results and discussion

Trials with saccades faster than 80ms and slower than 500ms were discarded (see Table 1). Trials where the participant made saccades towards distracter items rather than the target in the prime trial were excluded and analysed separately. A two-way repeated measures analysis of variance (ANOVA) was carried out with stimulus type (target, distracter, new object) and location (target location, distracter location, new location) as within-subject factors. There was a significant main effect of stimulus type ($F(2, 22) = 21.18, p < .001, \eta_p^2 = .69$). Bonferroni-corrected comparisons revealed that when the prime target (ball) was the probe target, SRTs ($M = 152$ ms) were significantly faster than for a probe target that was a previous distracter ($M = 159$ ms) or a for a new object ($M = 162$ ms) (both $ps < .001$). However, there was no difference in SRTs when the target was a recent distracter or a new object ($p > .49$). There was no effect of location ($F(2, 22) = 0.23, p = .79, \eta_p^2 = .02$). Thus SRT was not dependent on whether the probe object was presented at a previously occupied location of a target, distracter or a new location. There was however a significant interaction between stimulus type x location ($F(4, 44) = 3.18, p = .022, \eta_p^2 = .22$), this was due to the faster response to new objects in new locations.

Overall incorrect fixations were directed to distracters in 25% of the prime trials. Of these the hat was fixated in 87% of trials where it was present as a distracter. Attention was clearly captured by the hat distracter which has a relatively high similarity in shape to the ball target (see Figure 3 for an example). However, whilst structural similarity of objects can influence visual attention, structural similarity does not necessarily underpin negative priming (Tipper, 1988). These results demonstrated no evidence that the location of a recent distracter provides a source of an inhibition for selective attention with objects from the same semantic category. It seems that attention was allocated primarily on the basis of the object identity. In a typical spatial

negative priming paradigm where the target appears in the location of a distracter, this would constitute an ignored repetition trial, and where the target appears in another location would be a control trial. A study by Amso and Johnson (2005) found spatial negative priming in children and adults based on saccadic latency. However, in the latter study a single distracter was used and there was a clear difference in salience between the target and distracter; whereas the target was a colourful animated image the distracter was always a grey diamond. In the current experiment there was no significant difference in SRT between these displays. Since SRTs to the target were faster in all conditions in comparison to saccades to a previous distracter, it is likely that this facilitation is due to positive priming or a preview benefit.

<< Insert Figure 3 about here >>

Experiment 2

Although the location of a recent distracter is inhibited when using simple stimuli (e.g., Crawford et al., 2005), Experiment 1 did not find this effect with realistic objects. However, the display items contained detailed visual information that would greatly enhance the identification of the objects. It was possible that when object identity is enriched the spatial location of the distracters may not be prioritized for saccadic eye movements, yielding negligible effects on negative priming. In the current experiment we eliminated much of the visual content of the display by using object silhouettes to determine whether this would enhance the processing of the distracter locations. Thus in Experiment 2 we addressed the following question: When shape information becomes the major discriminating feature and the principal basis for object identity will the location of a distracter emerge as a source of inhibition for a saccadic eye movement?

Method

The stimuli used in Experiment 1 were converted into silhouettes with Adobe Photoshop (version 10). Twelve participants (6 female, mean age = 21 yrs) were naive to the aims of the experiment and had normal or corrected visual acuity (assessed with the Snellen chart). For this experiment eye movements were recorded with EyeLink 1000 Tracker (1000 Hz temporal resolution, 0.01° spatial resolution) using a chin support. The procedure and timings of the stimuli were identical to Experiment 1.

Results and Discussion

Trials with saccades faster than 80ms and slower than 500ms were discarded (see Table 1). Trials where the participants made saccades towards a distracter item, rather than the target in the prime display, were excluded and analysed separately. A two-way repeated measures ANOVA showed a significant main effect of stimulus type ($F(2, 22) = 4.34, p = .026, \eta_p^2 = .28$). However, Bonferroni-corrected comparisons indicated that when the probe target was the previous prime target (ball) ($M = 163$ ms) there was only a trend for SRTs to be faster than when the probe target was a previous distracter ($M = 169$ ms) ($p < .072$) or a new object ($M = 171$ ms) ($p < .078$). There was no difference in SRTs depending on whether the probe target was a recent distracter or a new object ($p = .99$). Moreover, there was no effect of location ($F(2,22) = 0.66, p = .52, \eta_p^2 = .06$). SRT was not reliably influenced according to whether the probe stimulus was presented at the previous location of the target, distracter or new location. In addition, there was no significant interaction between stimulus type x location ($F(4,44) = 1.19, p = .32, \eta_p^2 = .06$).

Overall incorrect fixations were directed to a distractors in 19% of the prime trials. Of these the hat was fixated in 81% of trials where it was present as a distracter. The results of Experiment 2 were consistent with Experiment 1. Despite the fact that the object stimuli were presented as silhouettes the reduction in visual detail did not cause attention to be allocated on the basis of location rather than object identity. Instead, reducing visual information in this way reduced the facilitatory effects of eye movements to a previously attended target.

<< Insert Table 1 about here >>

Experiment 3

Experiment 1 and 2 detected no evidence of distractor inhibition of spatial location or object identity in the saccadic negative priming using realistic objects. The analysis of misdirected saccades in the prime displays, demonstrated a clear example of an interaction based on visual similarity between a target and a distractor (we detected a high proportion of misdirected saccades to the hat distracter, rather than the ball target). In addition to target-distracter interaction based on visual similarity, previous work has shown there is also an interaction amongst visually presented stimuli at the semantic level (see Moores et al. 2003). The current experiment examined whether there might also be a semantic interaction between members of an arguably more familiar semantic category (animals), and to better control the visual similarity between targets and distracters. Given our predisposition to rapidly process animals (Thorpe, Gegenfurtner, Fabre-Thorpe, & Bulthoff, 2001) would this semantic category be more likely to generate inhibition when presented as distractors in the context of a negative priming task? Silhouettes of a cat, deer, owl and mouse were presented in the prime display, where the mouse

served as the target (see Figure 4). In experiments 1 and 2 the hat appeared to be the only competing distracter, with most errors made to the hat even though semantically ball and bat are more closely related. Semantically, cat and mouse are often associated together, but the distracters do not share many common shape features, and therefore any issues of visual similarity should be diminished. This reduction in visual similarity may be a condition for negative spatial priming to emerge for saccadic eye movements to objects.

<< Insert Figure 4 about here >>

Method

The method for this experiment was essentially identical to Experiment 2. Ten participants (7 female, mean age 26) were naive to the aims of the experiment and had normal or corrected visual acuity (assessed with the Snellen chart). For this experiment eye movements were recorded with an EyeLink 1000 Tracker (1000Hz temporal resolution, 0.01° spatial resolution) using a chin support. The animal silhouettes had an average size of 2.13° x 2.06°. The procedure and timings were identical to Experiment 1 and 2.

Results and Discussion

Trials with saccade latencies that were faster than 80ms and slower than 500ms were discarded (see Table 1). Trials where the participants generated a saccade toward one of the distracters rather than the target in the prime display were excluded and analysed separately. A two-way repeated measures ANOVA showed a significant main effect of stimulus type ($F(2, 18) = 4.48, p = .026, \eta_p^2 = .33$). Bonferroni-corrected comparisons indicated that when the probe

object was the previous (prime) target SRTs ($M = 163$ ms) were significantly faster than when the probe target was a previous distracter ($M = 166$ ms) ($p = .042$) and approached significance when compared with a new object ($M = 167$ ms) ($p = .097$). There was no difference in SRTs based on whether the probe target was a recent distracter or a new object ($p = .99$). Moreover, once again there was no effect of location ($F(2, 18) = 1.66$, $p = .22$, $\eta_p^2 = .16$), the specific location of the probe stimulus yielded no reliable differences in reaction times regardless of whether the probe was presented at the location of the previous target, distracter or new object. In addition there was no significant interaction between stimulus type x location ($F(4, 36) = 0.46$, $p = .76$, $\eta_p^2 = .05$).

Overall incorrect fixations directed to the distracters comprised 40% of the prime trials. Of these 28% of the errors were to the deer, 39% to the cat, and 33% to the owl. The fact that there was a higher error rate in Experiment 3 (40%) compared to Experiment 1 (25%), and Experiment 2 (19%) suggests that it was more difficult for participants to make a saccade towards the target and to ignore the distracters on the basis of shape information alone.

The results of this experiment are consistent with the previous experiments. There was clear evidence of facilitation emerging from the probe target with no evidence of inhibition at a distracter location. In order to increase power of the analyses, given that we found no evidence of inhibition in any of the experiments, we conducted a three-way mixed ANOVA across the three experiments with experiment (greyscale, silhouette, animal), as between subject factors and stimulus type (target, distracter, new object) and location (target location, distracter location, new location) as within-subject factors. The mean SRTs across experiments were not significantly different ($F(2, 31) = 0.88$, $p = 0.43$, $\eta_p^2 = .05$). There was a main effect of the stimulus type in the display ($F(2, 62) = 20.19$, $p < .001$, $\eta_p^2 = .39$) with significantly faster SRTs to the target ($M =$

159 ms) compared to the distracter ($M = 165$ ms) and new object ($M = 167$ ms) (both $ps < .001$). However, there was still no effect of location ($F(2, 62) = 0.85, p = .43, \eta_p^2 = .02$) and no interactions (all $ps > .098$, all $\eta_p^2 < 0.07$).

The combined data from the 3 experiments were also analysed separately for those trials in which the target was not correctly located and fixated in the prime display. There was no significant difference in error SRTs across experiments ($F(2, 31) = 0.27, p = 0.76, \eta_p^2 = .02$), but there was a significant effect of stimulus type ($F(2, 62) = 11.46, p < .001, \eta_p^2 = .27$). Saccades towards new objects ($M = 167$ ms) were slower than to previous target objects ($M = 157$ ms) ($p < .001$) or recent distracters ($M = 161$ ms) ($p < .028$). In contrast to the correctly fixated data, there was a marginally significant effect of location ($F(2, 62) = 3.05, p = .054, \eta_p^2 = .09$), but there were no interactions (all $ps > .116$, all $\eta_p^2 < .11$). Bonferroni-corrected comparisons revealed that when participants erroneously generated a saccade to a distracter, saccades to subsequent probe objects at the location of the recent distracter were faster ($M = 159$ ms) than the probe objects at the recent target location ($M = 164$ ms) ($p = .041$) but not a new object location ($M = 162$ ms) ($p = .73$). These results are interesting as these were error trials where the target was not correctly fixated in the prime trial. Correct fixation of the target in the prime trials enhances performance when fixating the target in the probe trials. However, when there is an error in locating the target in the prime trial, the distracter item is foveated and this facilitates saccade eye movements towards probes that subsequently appear at this location. Note that it would not be possible to make this distinction in a negative spatial priming task in which manual reaction times (in the absence of eye-tracking) was used as the sole dependent measure, as the precise location and time course in the allocation of visual attention in the prime trial cannot be readily ascertained.

Experiment 4

The previous reported experiments above were designed to determine the role of negative priming in saccade target selection and to dissociate object and spatial based processing in the saccadic negative priming task. These experiments have reported a facilitation of the target object that was presented in the prime display, but there was no evidence of spatial negative priming for realistic objects. This was surprising given our previous evidence of spatial negative priming for saccadic eye movements to colour LEDs (Crawford et al, 2005). One common feature of the current experiments was the presentation of a single object (target, distracter or new object) in the probe display. This was a reasonable procedure given the extensive previous evidence that negative priming with eye-movement and manual responses is often evident with a single item in the probe display, and that a distracter is not essential for the negative priming effect to emerge (Milliken, Tipper, Houghton & Lupianez, 2000; Crawford et al, 2005; Chao 2009, 2011). Within the context of eye-tracking studies a single item in the probe display enables automatic responses and eliminates any confusion about which target or distracter object is to be selected for the saccade. However, it was possible that the relatively fast response times in Experiments 1-3 reflected a rapid low-level process, that left little scope for negative priming to emerge. Could the rapid speed of target detection in the probe trials, have minimized any effects of negative priming? To address this issue, we introduced an additional selective attention component by adding a distracter to the probe display. The aim was to determine whether competitive selection in the probe display would give rise to negative priming that was absent in the previous experiments.

Method

This experiment used the silhouette objects from Experiment 2. Eleven participants (7 female, mean age = 33 yrs) were tested who were naïve to the aims of the experiment and had normal or corrected visual acuity (assessed with the Snellen chart). Eye movements were recorded with an EyeLink 1000 eye-tracker using a chin support.

Apparatus and stimuli

The stimuli consisted of 4 silhouette images of items relating to cricket that were used in Experiment 2, a ball, a set of wickets, a bat and a hat. There were 288 trials with each trial consisting of a prime and probe. Timings and procedures were identical to Experiment 2 with the exception that the cricket ball was employed as the target across all trials and within all displays. In the probe display the ball was presented either as a lone object (i.e no distracter), or in the presence of previously presented distracter (bat, hat, or wicket). We ensured that the distracter in the probe display only appeared at either the same distracter location, or the alternate distracter location. Thus the distracters was never presented in a new location, or the location of the target in the prime display. The target object was presented either at the location of the prime display target, or the location of a previous distracter. The 4 trial conditions were randomly presented in 8 blocks of 36 trials each. Within each block there was an equal proportion of each trial type. There were an equal number of target presentations at each of the 4 locations in the prime and probe, and an equal number of presentations of each of the distracters in the prime and probe displays.

Procedure

Eye movements were calibrated using a nine-point calibration. Following 8 practice trials participants underwent 8 blocks of 36 trials in which location and distracters were completely counterbalanced. Participants were seated 60cm from the display and were instructed to fixate the target (ball) in the prime display while ignoring the distracters, and again to fixate the target (ball) in the probe display as quickly as possible and ignore any distracters if present. At the start of each block a 9-point calibration was carried out, if necessary. Participants were encouraged to have a break between blocks if they were having difficulty maintaining concentration.

Results and discussion

Trials with saccades faster than 80ms and slower than 500ms were discarded (see Table 2). Trials where the participants incorrectly directed saccades towards a distracter rather than the target in the prime trial were excluded and analysed separately. A two-way repeated measures ANOVA was carried out with distracter (no distracter, one distracter) and target location (target location, distracter location) as within-subject factors. This revealed a main effect of distracter presence ($F(1, 10) = 20.83, p < .001, \eta_p^2 = .68$), with longer SRTs ($M = 174$ ms) when the probe display included a distracter compared to the target in isolation condition ($M = 162$ ms). There was also a main effect of target ($F(1, 10) = 10.45, p = .016, \eta_p^2 = .51$) but no significant interaction ($F(1, 10) = 1.20, p = .736, \eta_p^2 = .01$). When the target object was presented at a location of a previous distracter, SRTs ($M = 174$ ms) were significantly slower in comparison to a target at the previous target location ($M = 162$ ms).

The number of trials in which distracters were erroneously fixated before the target only accounted for 15% of trials (13% from the prime display; 2% from the probe display), and this

low error rates is consistent with Experiment 2. In terms of the most salient distracter, however, the majority of these errors in both displays were due to the hat (62% from the prime, 52% from the probe), with the bat (22% from the prime, 23% from the probe), and wicket (16% from the prime, 24% from the probe) misdirecting much fewer eye movements.

<< Insert Table 2 about here >>

Evidence of spatial negative priming for saccadic eye movement failed to emerge in Experiments 1-3. Negative priming for identity can be eliminated, or even reversed, in the absence of a probe distracter (Tipper & Cranston, 1985). However, little is known about spatial negative priming in the context of saccadic eye movements to realistic objects. Therefore the current experiment examined the spatial effect of a target presented together with a distracter in the probe display. Given the previous demonstration that the location of a recent distracter is inhibited in a saccadic negative priming task (Crawford et al., 2005) we focused on the spatial effects of the distracter, rather than attempting to control both object identity and location. The findings revealed there was an increase in saccadic reaction times of target-distracter trials over target-target trials, despite no general increase in the mean saccade latencies across the other conditions in comparison to the previous experiments.

Experiment 5

In Experiments 1-3, negative priming of objects showed no evidence of inhibition of spatial location or object identity. Experiment 4, incorporated a competitive selection component (i.e.

target + distractor) to the probe display, and revealed an increase in saccadic reaction times in Target to Distracter Location trials over Target to Target Location trials. Overall saccade latencies were not substantially increased in comparison to previous experiments showing that the absence of negative priming cannot be attributed to a floor effect of the reaction times. However, the source of the differential effects remained unclear. There are 2 possible sources: the difference in response time could be due to a facilitation of the target location or inhibition at the location of the distractors. In the current experiment we locate this source by including a third condition, in which the target in the probe display could appear at a new location. This provides a critical baseline condition baseline condition, to clarify the spatial effect on saccadic eye movements.

Method

This experiment was identical to Experiment 4, with the addition of a further 2 conditions: Target to New Location with a distractor, Target to New Location with no distractor in the probe display. This prime display was unchanged from Experiment 4. Thus the complete experiment consisted of a set of Target to Target, Target to Distracter and Target to New Location Trials. Eleven participants (7 female, mean age = 32 yrs) were naive to the aims of the experiment and had normal or corrected visual acuity (assessed with the Snellen chart). Eye movements were recorded with an EyeLink 1000 eye-tracker using a chin support.

Apparatus and stimuli

The stimuli consisted of 4 silhouette images of items relating to cricket that were used in Experiment 4. There were 432 trials with each trial consisting of a prime and probe. Timings and

procedures were identical to Experiment 4. The 6 trial conditions were randomly presented in 12 blocks of 36 trials each. Within each block there was an equal proportion of each trial type.

There were an equal number of target presentations at each of the 4 locations in the prime and probe, and an equal number of presentations of each of the distracters in the prime and probe displays.

Procedure

Eye movements were calibrated. Following 8 practice trials participants underwent 12 blocks of 36 trials in which location and distracters were completely counterbalanced. Participants were seated 60cm from the display and were instructed to fixate the target (ball) in the prime display while ignoring the distracters, and again to fixate the target (ball) in the probe display as quickly as possible and ignore any distracters if present.

Results and discussion

Trials with saccades faster than 80ms and slower than 500ms were discarded (see Table 2). Trials where the participants made saccades towards distracter items rather than the target in the prime trial were excluded and analysed separately. A two-way repeated measures ANOVA was carried out with distracter (no distracter, one distracter) and target location (target location, distracter location, new location) as within-subject factors and showed a main effect of distracter ($F(1, 10) = 49.08, p < .001, \eta_p^2 = .83$), with longer SRTs ($M = 177$ ms) when the probe display included a distracter than when the target was presented in isolation ($M = 163$ ms). There was also a main effect of target location ($F(1, 10) = 17.67, p < .001, \eta_p^2 = .64$) and the interaction

approached significance ($F(1, 10) = 2.96, p = .075, \eta_p^2 = .23$). Bonferroni-corrected comparisons indicated that when the prime target object was presented at a previous distracter location the SRTs ($M = 179$ ms) were significantly slower in comparison to the target object presented at the previous target location ($M = 162$ ms) or a new location, ($M = 169$ ms) (both $ps < .001$).

Critically, there was no difference in SRTs based on whether the probe target was appeared in the previous target location or a new location ($p = .140$). Therefore these effects are consistent with an effect of distracter inhibition, rather than target facilitation.

Once again the number of trials in which distracters were erroneously fixated before the target only accounted for 17% of trials (15% from the prime display; 2% from the probe display), which is consistent with Experiments 2 and 4. The majority of these errors in both displays were due to the hat (71% from the prime, 63% from the probe), with the bat (17% from the prime, 23% from the probe), and wicket (13% from the prime, 14% from the probe) misdirecting much fewer eye movements.

In this experiment we explored the impact of a probe distracter on target selection for saccadic eye movements using a spatial negative priming paradigm. Experiment 4 and 5 revealed spatially contingent effects of the probe, that strongly resembled negative priming. The reaction times for the equivalent condition in Experiment 2 are shown for the Silhouette cricket items in Table 1 for the two conditions ‘Target in target location’ ($M = 160.67$ ms) and ‘target in distracter location’ ($M = 161.32$ ms). Our previous analyses showed that there was essentially no difference in these RTs. In contrast there was a clear significant difference in the equivalent conditions in the current Experiments 4 and 5. What might account for the difference in equivalent conditions in Experiments 2 and 4? It is unlikely that the current findings can be explained by the overall

speed of the saccadic reaction times, if anything the saccades were generally of shorter latency in the Experiment 4. We return to this issue below.

General Discussion

Previous oculomotor research using simple stimuli, revealed interference of a distracter as measured by an increase in SRTs (Theeuwes, Kramer, Hahn, Irwin & Zelinsky, 1999) and a measure of the curvature of trajectory of a saccade away from a distracter (McSorley, Cruickshank & Inman, 2009). A previous eye tracking study by Crawford et al. (2005) using an array of coloured LEDs as stimuli, clearly demonstrated a significant increase in SRTs when a target was presented at the location of a recent distracter. However, with displays of realistic objects in Experiments 1-3 there was no evidence that inhibition emerged from the spatial coordinates of a distracter. When the cricket objects were presented as silhouettes in Experiment 2 the pattern of results were similar to that of the greyscale images in Experiment 1. Aside from other visual features such as colour, brightness and texture, the recognition of an object can be obtained by extracting shape information (Brodie, Wallace & Sharrat, 1991). Nevertheless, even when shape was the primary feature available for object recognition, and visual similarity was reduced (Experiment 3), location did not emerge as a source of inhibition in Experiments 1-3. Instead, these results demonstrated enhanced performance in terms of SRTs to the prime target object irrespective of its location in a subsequent display. This enhanced target detection may be a form of object priming, as a consequence of accurate fixation of the target in the prime display. The relatively high percentage of saccades to the visually salient hat distracter suggests that object-shape rather than object location may be more relevant in this paradigm.

In the present experiments the instructions were simple and explicit. In the prime display the target (i.e ball/mouse) should be fixated and the distracters should be ignored. Yet, there were frequent instances of misdirected saccades towards a distracters, indicative of a conflict between the top-down goal of the target search, for the cricket ball, and the bottom up saliency of the visual distracters. Although with real objects top-down control is prioritized, in some circumstances, salient distracters can override top down control and capture attention (Chen & Zelinsky, 2006), particularly if their onset is sudden (Krueger, et al., 2007). In Experiments 1 and 2 the hat was the most salient distracter, as it shared a similar shape to the target, in this case the ball. The effect of target-distracter similarity on attentional capture has also been reported in other studies. For example, Mulckhuyse, Van der Stigchel & Theeuwes (2009) used saccade trajectory deviations to determine the time course of oculomotor competition between bottom-up and top down selection processes. They found that saccadic deviations were modulated by the similarity of target distracter similarity. When the target and distracter are dissimilar suppression of the distracter and selection is more rapid and successful, as revealed by earlier deviations of the saccade away from the distracter. When distracter and target share common features selection is more difficult and the saccade deviation from the distracter is relatively late. The target-distracter similarity effects are consistent with the high proportion of misdirected saccades to the hat in Experiments 1 and 2.

Although there was overall, a higher percentage of errors compared to the previous 2 experiments, the effect of distracter saliency was not clear in Experiment 3, where no single distracter shared distinct overlapping features with the target. The increase in the proportion of misdirected saccades in Experiment 3, presumably reflected the greater difficulty in the distracter target discrimination of the animal shapes. In all the experiments the incorrect saccades were

rapidly corrected to refixate the target. Occasionally saccades were generated towards intermediate locations between the target and distracter in a similar way to the centre of gravity effect (Findlay, Brogan & Wenban-Smith, 1993), though these were rare observations.

We return to the issue raised at the end of the previous section. Experiments 4 and 5 revealed that saccadic negative priming with displays of realistic objects recovers when a distracter is allowed to appear in the probe display together with the target. There is evidence from previous work that a distracter presence on probe trials can have a critical effect on negative priming. Guy et al., (2004) have argued that spatial negative priming is subject to what has been termed ‘selection-state dependency’. In essence, this proposes that the presentation of a target and distracter in the prime display is associated with active inhibition at the location of the distracter. When the target is presented at the previous location of a distracter, the target will be temporarily associated with the distracter (since it shares the same location ‘tag’). Additional time will be required for the target activity to rise to activation threshold thus causing slowing in reaction times. However, the slowing is critically dependent on the resolution of competitive activity between the target and the distracter. In the absence of the distracter on the probe trial, there is no competition to resolve, and therefore no slowing of reaction times (i.e. negative priming) (Houghton and Tipper, 1994). However, research subsequent to the Houghton and Tipper (1994) model has produced a more mixed picture with regards to whether or not a probe distracter is required for negative priming. Guy et al., (2004 p5) observed that the predictability of the distracter presence may be critical to the generation of negative priming. When the probe distracter is predictably absent on every trial (as in our Experiment 2), spatial negative priming may be eliminated (Buckolz et al, 2002; Tipper et al 1990 Experiment 5). In contrast, when the presence of the probe distracter is unpredictable, present on some trials and absent on others, (as

in Experiment 4 and 5), spatial negative priming is observed (Buckolz et al, 2002; Christie and Klein, 2001; Neill et al. 1994). Thus, under these conditions it appears that the selection-state may be critical for spatial negative priming. Experiment 4 & 5 demonstrated that the negative spatial priming recovered with inclusion of a distractor. The findings have important general implications for our understanding of saccade target selection in various contexts. Experiment 5 demonstrated that the difference in saccadic responses to the target in the probe display were due to inhibition (or interference) at the location of distracter, as opposed to facilitation at the target location. Clearly under certain displays saccade target selection incorporates the dual process of target detection and distractor suppression.

There are also important implications for the role of spatial negative priming in target selection for saccadic eye movements to realistic vs abstract items. With realistic stimuli it appears that the internal representation of a saccade target is primarily based on the properties of the target itself, including the identity. A saccadic eye movement is generated more quickly when the target in the prime display is presented as the target again in the probe display, regardless of its location. However, when a competing distracter is likely to appear together with the probe target, inhibition at the location of the distracter may also contribute to target selection for a saccade which we can detect with the spatial negative priming task.

Many studies of negative spatial priming have not taken into account whether or not the target, or a distracter was fixated in the prime display. Our analyses revealed that this factor can have a critical effect on target and distracter priming. We separated out probe trials where the target was correctly fixated from the trials on which the distracter was fixated. The findings revealed that the trials on which the prime target was correctly fixated yielded faster saccades to probe targets irrespective of location. In contrast the trials on which a prime distracter was

fixated resulted in faster saccades when the prime target was presented at the location of the distracter. In one sense these observations are complementary, if we assume that the fixated item in the prime display becomes the effective target for that trial. None-the-less the interpretation of studies will be clouded if the analyses fail to register the ‘item’ that is actually fixated in the prime display. Therefore it is important to ascertain whether or not the target or distracter is fixated in the prime display as these have different outcomes on the response to the probe display. Eye tracking allows the distinction to be made between those trials where attention has been ‘caught’ by distracter items before fixating the target, and those trials where eye movements to distracters are effectively suppressed, and making this distinction has implications for the processing of information in the subsequent probe trial. The use of eye tracking in the negative priming paradigm can help to resolve an important issue highlighted by Christie and Klein (2008) who argue that an alternative explanation for negative priming from distracters could be attributed to inhibition-of-return, as the distracter may have been attended to in the prime display. In the current experiments any prime trial where the target is not fixated and/or a distracter is fixated is discarded ensuring overt attention is only allocated to the target. Thus, we can distinguish the trials on which overt attention returns to the previous location from those trials in which attention is switched to a new location.

This study revealed the influences of both top-down and bottom-up influences on attentional selection. Saccades that were correctly directed to the target in the prime display, reveals the role of top-down control since the ‘target’ was specified in advanced and remained constant throughout all trials. Bottom-up attentional salience capture was revealed by misdirected saccades to a distracter, in particular distracters whose features strongly overlapped with the target. Interestingly, misdirected saccades were not proportionally distributed amongst the

distracters. Thus, even these misdirected saccades revealed the influence of top-down attentional control.

Acknowledgements:

The authors would like to express their gratitude to the reviewer for suggestions regarding Experiments 4 & 5, to Steve Higham for help in experimental programming and data collection, Josh Slater for help in data collection, Becky Crawford, Ben Allen for help with data analyses.

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Figure 1. The sequence and timings of the eye movement displays in Experiments 1-3. The ball is the target.

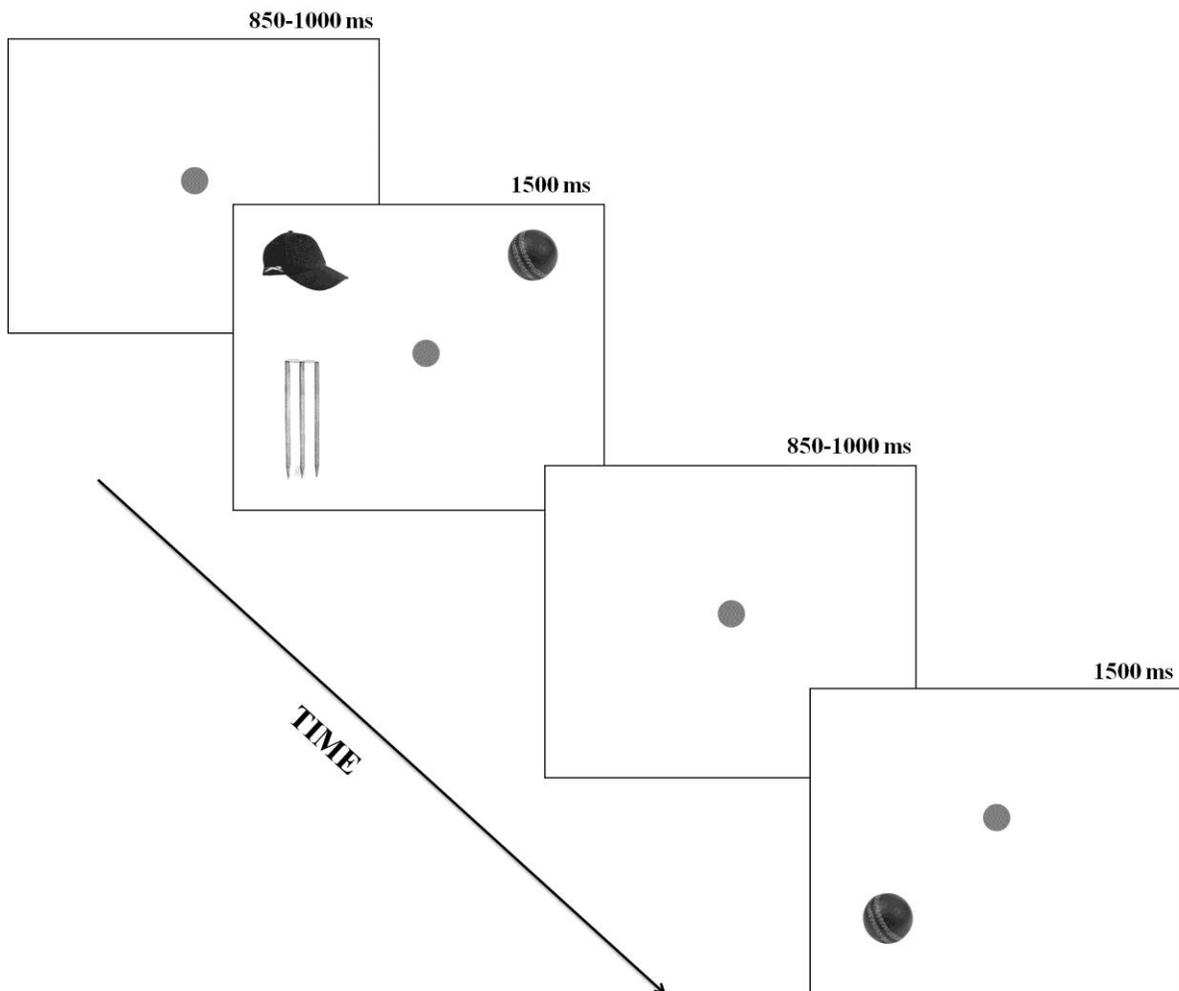


Figure 2. The Prime/Probe displays for each type of condition.

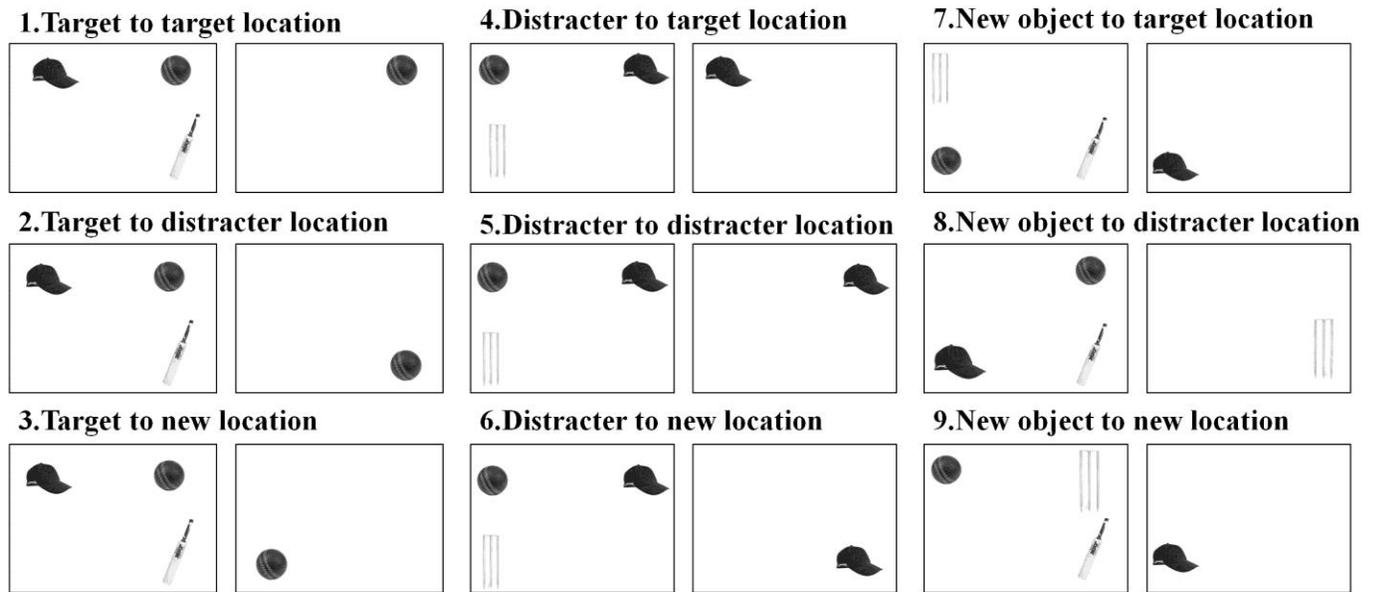


Figure 3. Example of the Hat distracter competing for the first saccadic eye movement to target (Ball)

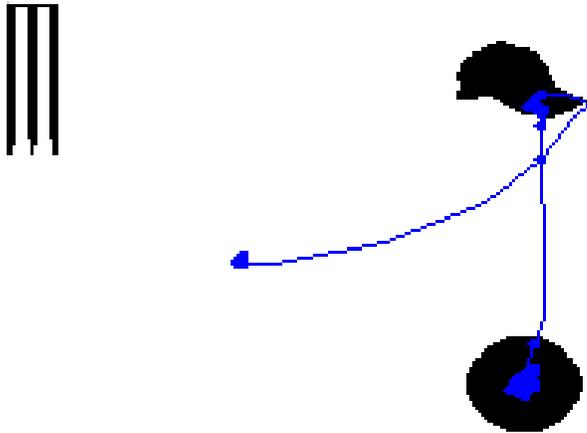


Figure 4 Animal stimuli used in Experiment 3 (Mouse target)

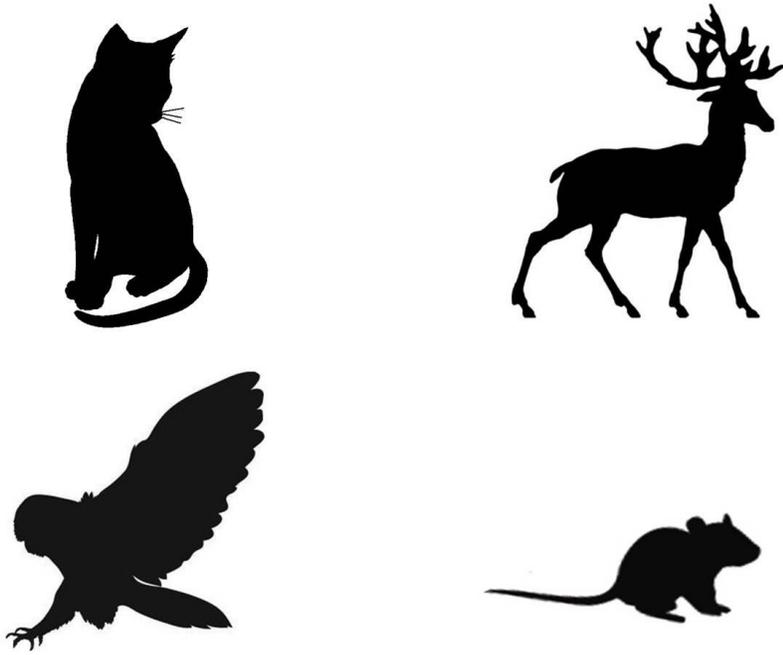


Table 1.

Mean (and standard deviation) saccadic reaction times towards the probe object based on stimuli type and location across Experiments 1-3

Probe Condition	Experiment 1		Experiment 2		Experiment 3	
	Greyscale Cricket		Silhouette Cricket		Silhouette Animals	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Target in target location	154.56	22.26	160.67	23.65	160.81	24.61
Target in distracter location	150.28	21.77	161.32	17.81	164.28	24.08
Target in new location	152.66	18.26	169.29	18.73	164.49	19.27
Distracter in target location	155.60	15.80	170.43	22.22	161.93	20.61
Distracter in distracter location	158.78	22.80	168.57	14.42	169.02	25.88
Distracter in new location	163.90	25.46	168.40	16.49	169.13	23.41
New object in target location	164.61	23.66	172.50	22.26	166.88	28.85
New object in distracter location	162.54	20.86	170.73	17.96	169.89	22.97
New object in new location	157.92	16.97	170.80	21.17	167.22	24.02

Table 2.

Mean (and standard deviation) saccadic reaction times towards the probe object based on target location and the presence of a distracter in the probe display in Experiments 4 and 5

Probe Condition	Experiment 4		Experiment 5	
	Silhouette Cricket		Silhouette Cricket	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>No Distracter in Probe Display</i>				
Target in target location	155.73	20.75	156.53	29.09
Target in distracter location	167.88	18.01	170.10	30.75
Target in new location	-	-	162.47	26.90
<i>One Distracter in Probe Display</i>				
Target in target location	167.75	24.69	166.80	31.32
Target in distracter location	180.93	24.44	187.66	30.92
Target in new location	-	-	175.98	26.96