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Attentional repulsion effect despite a colour-based control set

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A salient distractor can have a twofold effect on concurrent visual processes; it can both reduce the processing efficiency of the relevant target (e.g., increasing response time) and distort the spatial representation of the display (e.g., misperception of a target location). Previous work has shown that knowledge of the key feature of visual targets can eliminate the effect of salient distractors on processing efficiency. For instance, knowing that the target of interest is red (i.e., having an attentional control set for red) can eliminate the cost of green distractors on the speed of response to the target. The present study shows that the second mark of irrelevant salient distractors, i.e., distortions in spatial representation, is resistant to such top-down control. Using the attentional repulsion effect, we examined the influence of salient distractors on target localization. Observers had a colour-based control set and the distractors either matched or mismatched with the control set. In the first two experiments, we found systematic mislocalization of targets away from the peripheral distractors (i.e., an attentional repulsion effect). Critically, the effect was caused by distractors that both matched and mismatched the control set. A third experiment, using the same stimuli, found that processing efficiency was perfectly resistant to distractors that did not match the control set, consistent with previous work. Together, the present findings suggest that although top-down control can eliminate the cost of a salient distractor on processing efficiency, it does so without eliminating the distractor's influence on the spatial representation of the display.

Keywords: Attentional repulsion effect; Space representation; Visual attention.

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The capacity for appropriate prioritization of visual information is critical to our successful interaction with the world. This prioritization results from an interplay between top-down (goal driven) and bottom-up (stimulus driven) attentional processes. On the one hand, there is considerable top-down control over attentional selection, and a substantive line of research initiated by Folk, Remington, and colleagues (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994) has shown that people can adopt goal-based attentional control sets (ACS) to limit what types of events are prioritized. On the other hand, salient events in the visual field, such as the sudden appearance of new objects, tend to reflexively capture attention (Theeuwes, 1991, 1992; Yantis & Johnson, 1990; Yantis & Jonides, 1984). The interplay between top-down control and bottom-up attentional capture has been a central topic in understanding human visual cognition, and is the focus of the present study.

Although top-down attentional mechanisms facilitate selection of behaviourally relevant information, the extent to which they prevent processing of irrelevant distractors has been a matter of debate (see, e.g., Folk & Remington, 2010; Theeuwes, 2010). In general, attentional control sets have been shown to be effective in limiting bottom-up attentional capture by peripheral events, especially when the display characteristics, such as stimulus set size and the time interval between the presentation of targets and distractors, are expected by the observers (Lamy, 2005; Yeh & Liao, 2008). In the canonical ACS paradigm (Folk et al., 1992), observers search for a target with a specific feature (e.g., red), but before the target appears there is a sudden onset of an object (the cue) that either matches (e.g., red) or mismatches (e.g., white) the target feature. The typical finding is that the matching cue produces a significant cueing effect (i.e., faster responses for targets at cued locations relative to the uncued locations), whereas the mismatch cue produces no such effect. The difference in response times between cued and uncued trials with mismatch cues is often near zero, suggesting that the ACS acts as a very effective filter of goal-irrelevant information (Folk et al., 1992, 1994; Gibson & Amelio, 2000; Gibson & Kelsey, 1998). This “ideal” ACS has been seen across many experiments, ranging from the original ACS study (Folk et al., 1992) to experiments using ACSs that switch over trials (Lien, Ruthruff, & Johnston, 2010), and even to experiments with multiple, simultaneous ACSs (Adamo, Pun, Pratt, & Ferber, 2010). Not all peripheral events, as one might expect, are effectively filtered, with one such example being onset of new motion (Al-Aidroos, Guo, & Pratt, 2010). It has also been argued that the effectiveness of ACSs partly relies on the observer’s knowledge of the display characteristics (Yeh & Liao, 2008) and the cue–target stimulus–onset asynchrony (SOA; Lamy, 2005). Whereas some researchers have argued that ACSs are simply ineffective with short cue–target SOAs (e.g., Theeuwes, Atchley, & Kramer, 2000), others have argued that the knowledge of a fixed, and even short, cue–target SOA can facilitate effectiveness of ACSs (Lamy, 2005). Importantly, ACSs have been tested against the gold standard of attentional capture, consisting of the combination of an object suddenly appearing with a corresponding change in luminance at that location, and have appeared to be extremely effective in preventing reflexive orienting of attention and allow only goal-relevant information to drive the allocation of attention (see Al-Aidroos, Harrison, & Pratt, 2010).

It should be noted, however, that in the canonical ACS paradigm, the attentional cost of an irrelevant distractor is often measured in terms of the reduced processing efficiency for task-relevant targets. In particular, the aforementioned studies which show an ideal (or close to ideal) ACS inferred the effect of the control setting through the lack of difference in response times between cued and uncued trials when the cues did not share a critical feature with the targets. Besides using reaction time (RT) as the dependent measure, other measures of processing efficiency have also supported the effectiveness of ACSs. For example, using a variant of a rapid serial visual presentation (RSVP) paradigm, Folk, Leber, and Egeth (2002) have shown that distractors that matched the ACS can produce deficits in accuracy of target perception, whereas mismatching distractors do not. Although such studies do not measure RT directly, they still rely on variations in processing efficiency for briefly presented targets after attentional resources are captured by, or controlled against, visual distractors. Overall, when examining the traces of attentional capture on processing efficiency, ACSs appear to be very effective in controlling capture by irrelevant distractors.

Despite the common use of processing efficiency as a measure of attentional capture, it should be noted that outcome of attentional orienting is twofold; besides affecting the efficiency with which visual items are processed, attention can systematically distort spatial representation of the visual display (e.g., Liverence & Scholl, 2011; Ono & Watanabe, 2011; Suzuki & Cavanagh, 1997). The general idea that spatial perception is sensitive to visual attention has been demonstrated in various ways. For example, attentional orienting has consequences for the distribution of spatial resolution in the display (e.g., Tsal & Bareket, 1999; Yeshurun & Carrasco, 1998). Tasks requiring high spatial resolution, such as fine-scaled target localization (Tsal & Bareket, 1999), texture segregation (Yeshurun & Carrasco, 1998), or gap judgement (Shalev & Tsal, 2002; Treisman, Kahneman, & Burkell, 1983) are performed more accurately at an attended location relative to the unattended locations. These findings are consistent with the hypothesis introduced by Tsal and Shalev (1996) that the attended location (compared to the unattended portions of the visual display) is represented by a larger number of receptive fields that have shrunk in size. Consistent with this hypothesis, single-cell recordings from region

MT of monkeys have shown that receptive fields of these neurons move towards and shrink around the attended item (Womelsdorf, Anton-Erxleben, Pieper, & True, 2006). Given the effect of attentional orienting on the distribution of spatial representation, it would not be surprising that shifts of attention can produce reliable misperception of item location in the unattended areas.

The consequences of attentional orienting for spatial representation are considerably less examined, compared to studies using processing efficiency as a measure, especially in the examination of attentional capture and the role of top-down control. One measure that examines the effect of attention on spatial representation uses saccadic eye movement trajectories. Specifically, in the presence of an attended irrelevant distractor, a saccade will alter its trajectory en route to a target such that its path bends away from the location of a salient distractor (e.g., McSorley, Haggard, & Walker, 2006; Sheliga, Riggio, & Rizzolatti, 1994; van der Stigchel & Theeuwes, 2005). Recently, Al-Aidroos and Pratt (2010) measured both saccadic RTs and saccadic trajectory deviations in a task in which the distractors did or did not share a critical colour feature with the targets. Mimicking the previous studies that used manual RTs, they found an ideal ACS with saccadic RTs, as mismatched distractor/target combinations produced no discernible distractor effect. Although the spatial measure showed that the ACS reduced the magnitude of the trajectory deviation caused by the mismatched distractor, it did not eliminate this effect. Al-Aidroos and Pratt concluded that whereas the response time measures of capture (i.e., measures of processing efficiency) reflect the effectiveness of top-down control, spatial measures of capture remain sensitive to the influence of bottom-up processes.

In the present study, we continue to examine the notion that the measures of spatial representation are more sensitive to the effect of attentional capture, and may reveal the imperfections of top-down control in eliminating the impact of salient distractors. We test this notion by employing the Attentional Repulsion Effect (ARE) discovered by Suzuki and Cavanagh (1997). In their basic paradigm, two peripheral cues (circles) were briefly presented along one of the diagonals (e.g., the cues would be above and right, and below and left, of fixation). Shortly after the cues disappeared, a Vernier stimulus, with one line appearing above fixation and one appearing below fixation, was briefly presented and then masked. Subjects were asked to determine if the top line was offset leftward or rightward in relation to the bottom line. Suzuki and Cavanagh found that subjects systematically misperceived the location of the top line relative to the bottom line in the opposite direction of the cues. For example, top-right and bottom-left cues caused subjects to perceive the top line as being offset leftward relative to the bottom line. Across a series of experiments, in which they varied cue eccentricity (2° to 8°), the number of cues (one or two), and cue–target SOA

(0 to 1500 ms), Suzuki and Cavanagh found the ARE to be consistent and robust. Later work showed that the ARE can be observed with shifts of attention caused by both visual (Pratt & Arnott, 2008) and auditory cues (Arnott & Goodale, 2006), in tasks requiring perceptual judgement as well as target-directed pointing responses (Pratt & Turk-Browne, 2003), and that it can affect the perception of both location and shape of objects (Fortenbaugh, Prinzmetal, & Robertson, 2011).

The attentional nature of ARE has been supported by the observation that it is obtained with onset and offset cues, as well as colour-singletons (Pratt & Arnott, 2008). Importantly, and also contrary to a sensory account of ARE, Kosovicheva, Fortenbaugh, and Robertson (2010) have reported that ARE does not depend on the size of the peripheral stimuli, but instead on the location of their centre of mass similar to how spatial attention is distributed around cued objects (Kravitz & Behrmann, 2008). Toba, Cavanagh, and Bartolomeo (2011) reported a task similar to the original ARE task, in which subjects perceive the unattended half of a horizontal line as smaller in size or reported the midpoint on the line to be located away from the location of a transient stimulus. Again, these findings are consistent with the idea that attentional orienting recruits resources in order to increase the spatial resolution at the attended location, leaving the unattended part of space at a relative disadvantage (Shalev & Tsal, 2002; Tsal & Shalev, 1996; Womelsdorf et al., 2006).

Overall, the ARE appears to be a sensitive and reliable measure of the attentional orienting towards the periphery. As such, and given the recent findings of Al-Aidroos and Pratt (2010), our prediction is that when an ACS is introduced into an ARE paradigm, mismatch cues might weaken but will not eliminate the repulsion effect. In other words, we expect that ideal contingent capture will not be found with the ARE because, unlike measures of processing efficiency, it is a more sensitive measure of attentional capture.

EXPERIMENT 1

To test the effectiveness of a control set on the ARE, we modified our typical ARE paradigm (DiGiacomo & Pratt, 2011; Pratt & Arnott, 2008; Pratt & Turk-Browne, 2003) to include a top-down goal based on colour. Unlike the other ARE studies that used a Vernier stimulus consisting of two vertical lines around fixation, our Vernier stimulus consisted of 10 lines arranged in two vertically aligned rows of five lines each (see Figure 1). On each row, four of the lines were in one colour (e.g., green) and one line was in a different colour (e.g., red). To follow this example, subjects would be told to determine if the top red line was to the left or right of the bottom red line. Presumably, this difficult search would induce a strong ACS for red (in this example).

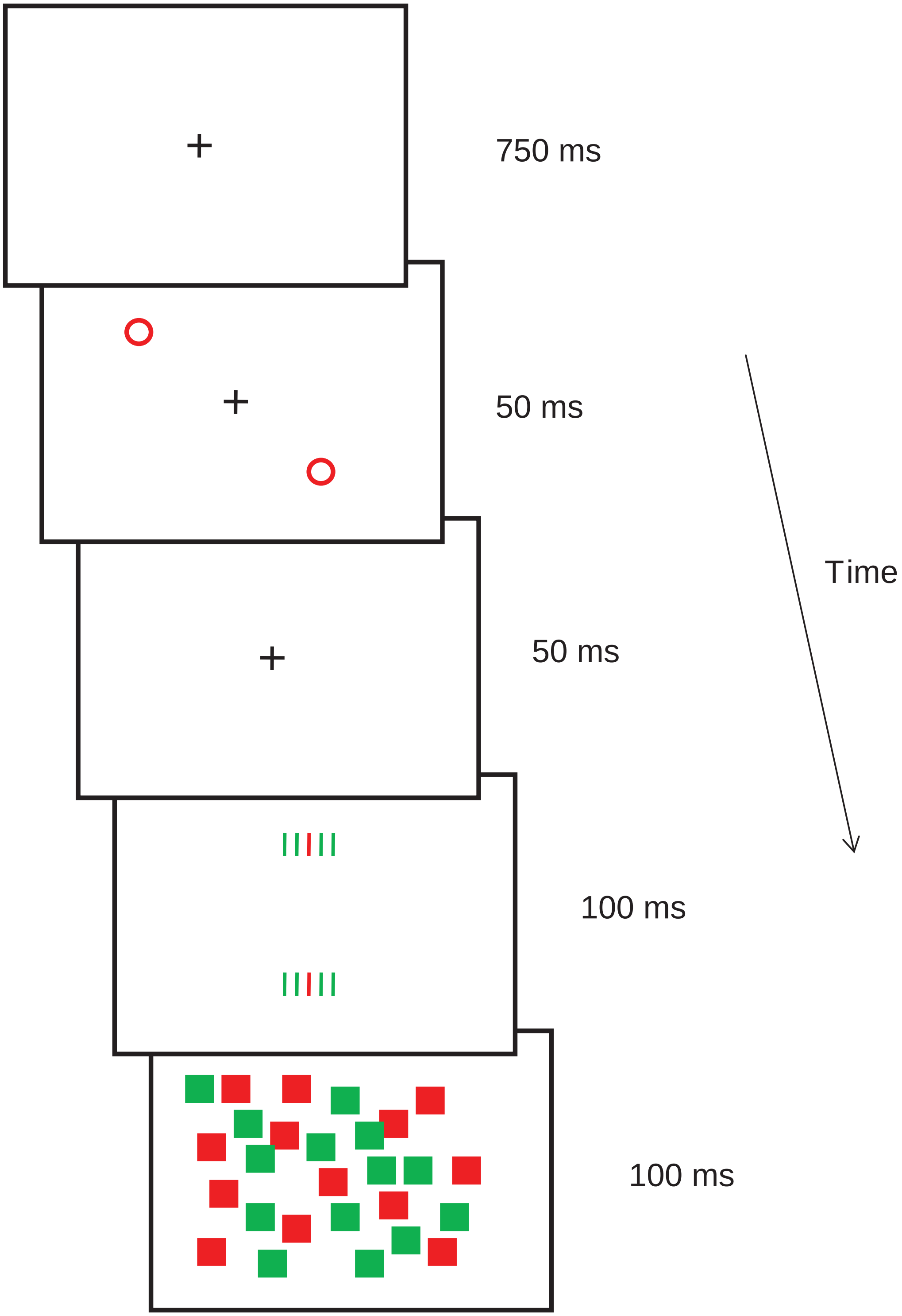

Figure 1. Sample trial sequence from Experiment 1. The timing is in milliseconds. In the actual experiment, the background was black. To view this figure in colour, please see the online issue of the Journal.

Whereas the control set for the Vernier stimulus would be consistent over a block of trials, match (e.g., red) and mismatch (e.g., green) cues would be randomly presented within each block.[1] Presumably, match cues should capture attention and induce an ARE. The question is whether the mismatch cues can be effectively blocked by the current ACS (resulting in no ARE) or will the filter allow for some stimulus-driven attentional capture (resulting in a measurable ARE)?

Method

Subjects. Sixteen undergraduate students at the University of Toronto participated in the experiment in exchange for course credit. All had normal or corrected to normal vision and none were aware of the purpose of the experiment. All the experimental protocols were approved by the Research Ethics Board of the University of Toronto.

Apparatus and procedure. The experiment was conducted with a PC computer and 19-inch CRT (1024 × 768) monitor in a dimly lit, sound attenuated room. A head- and chinrest kept the viewing distance constant at 44 cm. Subjects responded using a computer keyboard located directly in front of them on the desk.

Each trial began with a small white fixation cross (0.2° × 0.2°) location at the centre of a black display (Figure 1). After 750 ms, two cues (empty circles with a diameter of 1.4°) appeared along one of the diagonal axes, either at top-left and bottom-right (L-R), or top-right and bottom-left (R-L) diagonal. The cues were either both green or both red, and were centred 7.1° away from the fixation cross. The cues appeared for 50 ms followed by a 50 ms delay, and then the task-related stimulus array appeared and the fixation cross disappeared. The stimulus array consisted of five pairs of vertical lines, with each pair consisting of a line 1 pixel wide and 1.4° tall, with 6.8° distance between them. The horizontal distance between each pair was 0.20°, and the middle pair was centred vertically on the fixation cross. The lines of the stimulus array were either red or green, with four lines in both the top and bottom rows being in one colour

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[1] Each trial involved presentation of a pair of cues along one diagonal (e.g., top-left and bottom-right), and since observer's task in the ARE paradigm is localization of the top Vernier line relative to the bottom line, it is assumed that capture of attention by the top (e.g., resulting in rightward repulsion of the above Vernier) or bottom (e.g., resulting in leftward repulsion of the bottom Vernier) cues would have the same effect on the spatial bias. We remain agnostic as to whether on each trial attention was captured by both peripheral cues or by one only. Note, however, that Suzuki and Cavanagh (1997, p. 445) found stronger ARE with double cues compared to single cues, which is consistent with a capture-by-both-cues view (cf. Yantis & Johnson, 1990).

(distractors) and one line in both top and bottom rows being in the other colour (targets). There were five possible combinations of the stimulus array, with the first location indicating top row position and the second location indicating bottom row position: Far-left and far-right (FL-FR), near-left and near-right (NL-NR), centre and centre (C-C), near-right and near-left (NR-NL), and far-right and far-left (FR-FL). The stimulus array appeared for 100 ms, and then was replaced by a pattern mask for 100 ms made up of randomly positioned red and green squares. Subjects were instructed to ignore the cues and report whether the top target line was to the left ("z" key) or right ("/" key) of the bottom target line. After each response, or if 2000 ms had elapsed, there was a 1250 ms intertrial interval before the next trial started.

Design. The experiment consisted of two main blocks of 200 trials each. Within each block, the target and distractor colours for the stimulus array were kept consistent, and subjects were told the target colour at the start of each block. The colour of the two cues was randomized within each block, as was their diagonal locations. Also randomized within each block were the five sets of target pairs. The blocks were counterbalanced across subjects such that half searched for red targets in the first block and half search for green targets in the first block.

Results and discussion

Since the measure of interest in the ARE paradigm is perceptual (mis)localization of targets as a function of cue location, the dependent measure can be the proportion of "left" (or "right") responses in each condition. In the present experiment, the mean percentage of "left" responses was determined and was initially submitted to a 2 (ACS: Match or mismatch) $\times$ 2 (cue location: L-R or R-L) $\times$ 5 (target pair) analysis of variance (ANOVA; see Figure 2). Although there was no effect of ACS, $F(1, 15) < 1$, there were main effects for cue location, $F(1, 15) = 54.6$, $p < .001$, and for target pair, $F(4, 60) = 338.5$, $p < .001$. For cue location, there were fewer left responses with the top-left and bottom-right (L-R) cues (42.2%) than with R-L cues (57.6%), indicating the overall presence of an ARE. For target pair, the far-left and far-right (FL-FR) pair produced the most left responses (94.4%) and the FR-FL pair produced the fewest (4.6%). Interactions were found for ACS $\times$ Cue location, $F(1, 15) = 5.1$, $p < .05$, Cue location $\times$ Target pair, $F(4, 60) = 19.6$, $p < .001$, and ACS $\times$ Cue location $\times$ Target pair, $F(4, 60) = 3.5$, $p < .05$, but not for ACS $\times$ Target pair, $F(4, 60) < 1$.

The critical analysis for determining the effect of ACS on the ARE is when the top and bottom target lines are centred and directly aligned with

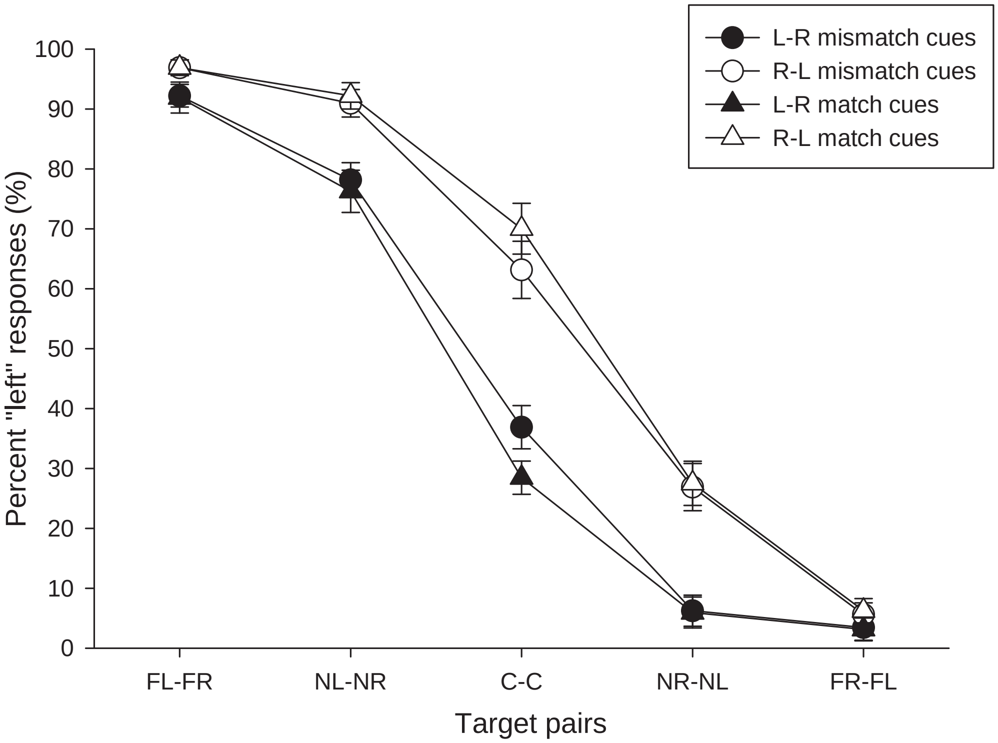

Figure 2. Mean percentage of "left" responses for Experiment 1. Target pairs consisted of (respectively, for the Vernier above and below fixation) far-left and far-right (FL-FR), near-left and near-right (NL-NR), centre and centre (C-C), near-right and near-left (NR-NL), and far-right and far-left (FR-FL). Cues could either appear at top-left and bottom-right (L-R) or top-right and bottom-left (R-L) locations, either with the same colour as the target (ACS-matching) or the distractor (ACS-mismatching). The errors bars are 95% confidence intervals (Cousineau, 2007).

each other (i.e., the C-C target pair). This analysis used a 2 (ACS) × 2 (cue location) ANOVA. Once again, there was no main effect of ACS, $F(1, 15) < 1$. There was a main effect of cue location, $F(1, 15) = 53.9$, $p < .001$, indicating the presence of an ARE as there were fewer left responses with L-R cues. Importantly, there was an ACS × Cue location interaction, $F(1, 15) = 7.5$, $p < .05$, as the ARE was larger with match cues (41.6%) than for mismatch cues (26.2%). Separate two-tailed t-tests confirmed that both match, $t(15) = 8.3$, $p < .001$, and mismatch, $t(15) = 4.5$, $p < .001$, produced AREs.

The results from the first experiment are straightforward; although the ACS did modulate the amount of capture as measured by the ARE, the filter was not ideal and the mismatch cues still produced a reliable repulsion effect. This finding is consistent with the ACS effect on a spatial measure of saccadic performance, trajectory deviations, found by Al-Aidroos and Pratt (2010). Thus, it appears that control sets are not entirely effective in eliminating the effect of attentional capture.

EXPERIMENT 2

Although we reason that looking for traces of attentional capture on spatial representation is a more sensitive measure that allows for examining the limits of ACSs, two alternative interpretations of the findings of Experiment 1 should be considered. First, since the distractor line pairs that surrounded the target pair in Experiment 1 always had the same colour, making the target pair easy to "pop out", it is possible that subjects adopted a more general search strategy based on salience, instead of an ACS for a specific colour. Previous studies have shown that when the relevant visual target is known to be salient (e.g., a colour singleton), then an irrelevant salient distractor also enjoys this bias towards salience, and will be more effective in capturing attention (e.g., Bacon & Egeth, 1994; Yantis & Egeth, 1999). Therefore, it should be established that the imperfect role of ACS was not simply due to a general bias towards salient items. To test for this possibility, in this experiment the accompanying distractor lines were heterogeneous in colour, instead of all being the same colour. It is important to note that given the role of feature-specific inhibition in top-down control, as well as the importance of feature-based grouping of distractors in the process of inhibition, this manipulation might undermine the impact of ACS observed in Experiment 1, because without the predictability and homogeneity of the distractor lines, filtering against a specific colour is no longer possible (Treisman, 1982; Treisman & Sato, 1990). Consequently, if instead of a strategic search for salience, results of Experiment 1 were dependent on the inhibition of irrelevant feature, the effect of ACS might be reduced or eliminated in the present experiment.

The second alternative interpretation is based on the fact that abrupt onset was not only a property of the irrelevant cues, but it was also a feature that marked presentation of target array and, therefore, was a task relevant feature (see Burnham, 2007). To ensure that the attentional capture by the mismatching cues were not because they possessed the onset feature, in the present experiment, every pair of cues was accompanied by a pair of control cues, which appeared along the opposite diagonal. If attentional capture by the peripheral cues depends on their unique onset, then no trace of capture should be observed in the present experiment.

Method

Subjects. Fourteen undergraduate students at the University of Toronto participated in the experiment in exchange for course credit. All had normal or corrected to normal vision and none were aware of the purpose of the experiment.

Apparatus and procedure

The apparatus was exactly the same as that used in Experiment 1. The procedure was also the same except that two changes were made. First, when the two red or green diagonal cues appeared (e.g., at top-left and bottom-right; L-R), so did two same-shaped grey cues in the opposite diagonal locations (e.g., at top-right and bottom-left). The luminance level of red/green cues (41 $\mathrm{Cd/m^2}$) was set higher than the grey cues (27 $\mathrm{Cd/m^2}$), to ensure the relative salience of the former. Second, the Vernier target array consisted of five differently coloured lines in the top row and five differently coloured lines on the bottom row. In addition to the green and red lines used in the prior experiment, yellow, blue, and white coloured lines were also used in this experiment. For half the subjects the targets were the red lines and for the other half of the subjects the targets were the green lines. As before, the target lines occurred in predetermined pairs, far-right and far-left (FR-FL), near-right and near-left (NR-NL), centre and centre (C-C), near-left and near-right (NL-NR), and far-left and far-right (FL-FR), and colour of the remaining nontarget lines in each row were randomly determined from the remaining four colours. Each colour only appeared for one line in each row.

Design. Subjects were randomly assigned to either the red target or green target condition. As before, the experiment consisted of two main blocks of 200 trials each. Within each block, the colour of the red and green cues was randomized, as was the diagonal locations of the red or green cues. Also randomized within each block were the five sets of target pairs.

Results and discussion

The mean percentage of "left" responses for each subject was determined for each condition, and these data were initially submitted to a 2 (ACS: Match or mismatch) × 2 (cue location: Top-left and bottom-right or top-right and bottom-left) × 5 (target pair) ANOVA (see Figure 3). Although there was no effect of ACS, $F(1, 13) = 2.2$, $p > .16$, there were main effects for cue location, $F(1, 13) = 6.47$, $p < .03$, and for target pair, $F(4, 52) = 92.4$, $p < .001$. For cue location, there were fewer left responses with L-R cues (38.8%) than with R-L cues (43.1%), indicating the overall presence of an ARE. For target pair, the FL-FR pair produced the most left responses (84.0%) and the FR-FL produced the fewest (7.1%). Aside from a marginal interaction for Cue location × Target pair, $F(4, 52) = 3.7$, $p < .09$, no other interactions reached significance (Fs < 1).

As before, the critical analysis for determining the effect of ACS on the ARE is when the top and bottom target lines are directly aligned with each other (i.e., the C-C target pair). This analysis used a 2 (ACS) × 2 (cue

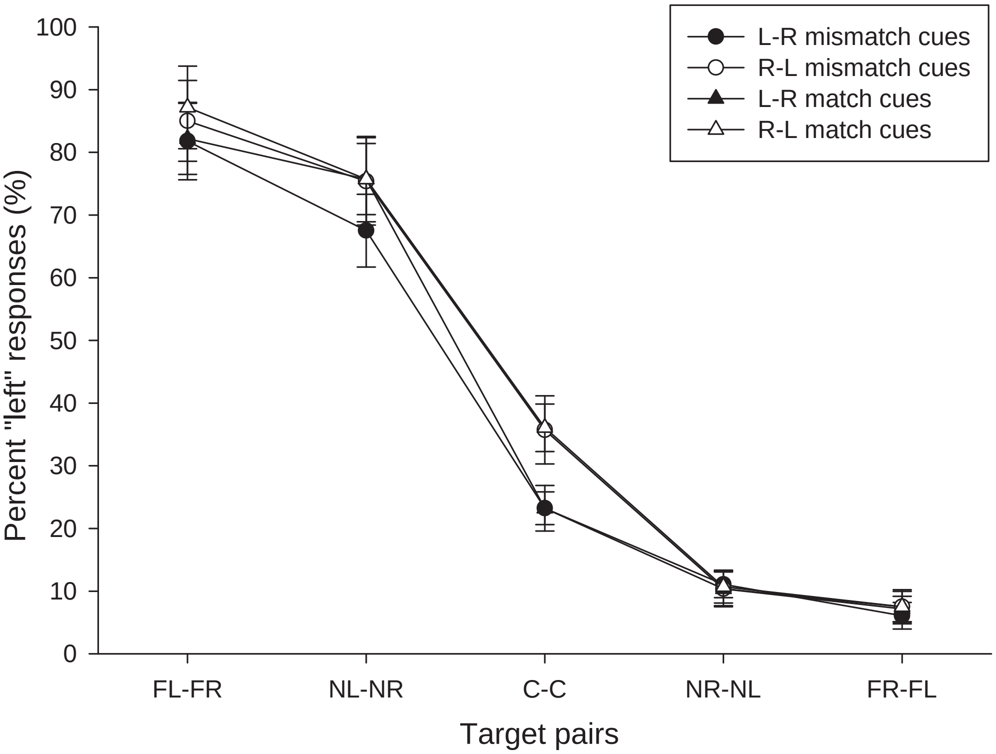

Figure 3. Mean percentage of "left" responses for Experiment 2. The errors bars are 95% confidence intervals (Cousineau, 2007).

location) ANOVA. Once again, there was no main effect of ACS, $F(1, 13) < 1$. There was a main effect of cue location, $F(1, 13) = 8.1$, $p < .02$, indicating the presence of an ARE as there were fewer left responses with L-R cues (23.2%) than for R-L cues (35.9%). Critically, there was no ACS × Cue location interaction, $F(1, 13) < 1$, as the 12.8% ARE effect with match cues was almost identical to the 12.5% ARE found with mismatch cues. Separate two-tailed *t*-tests confirmed that both match, $t(13) = 3.5$, $p < .01$, and mismatch, $t(13) = 2.7$, $p < .02$, produced AREs.

Finding equal traces of attentional capture for ACS-matching and -mismatching cues are inconsistent with the idea that results of Experiment 1 resulted from adopting a general strategy that benefited salient items. On the contrary, these results suggest that knowledge of the distractor colour may have been crucial in observing an effect of ACS in Experiment 1. Knowing the distractor colour may have enabled top-down filtering against it (Treisman & Sato, 1990), especially given that cue and distractor lines could be perceptually grouped based on colour similarity, leading to easier inhibition of the mismatching cues (cf. Duncan & Humphreys, 1989; Treisman, 1982). Unlike Experiment 1, the distracting Vernier lines in the second experiment could not be grouped together based on common colour.

It is possible that this lack of grouping prevented subjects from successfully inhibiting the irrelevant colour and, subsequently, from inhibiting the mismatching cues. Additionally, the red/green cues captured attention even without possessing unique onset advantage.

Of course, there is no evidence from the present study that the particular set of stimuli used would have produced ideal control over capture with a measure of processing efficiency (e.g., RT). To examine this question, we conducted the next experiment.

EXPERIMENT 3

Using RT, a measure of processing efficiency, ACSs have often been found to be essentially perfect. More specifically, with mismatch cues, RTs to targets at cued and uncued locations are typically not statistically different and, in many cases, are virtually identical (e.g., Folk et al., 1992, 1994; Folk & Remington, 1998; Gibson & Amelio, 2000; Gibson & Kelsey, 1998; Remington & Folk, 2001). If indeed measures of processing efficiency are differently sensitive to the effectiveness of ACS on stimulus-driven attentional capture, then using the same stimuli from the previous experiment in RT-based task should result in a more effective ACS than found with the spatially based ARE.

Method

Subjects. Twenty undergraduate students at the University of Toronto participated in the experiment in exchange for course credit. All had normal or corrected to normal vision and none were aware of the purpose of the experiment.

Apparatus and procedure. The apparatus was exactly the same as that used in the previous experiment. The initial display, cues, delay, and intertrial interval were also the same as used in Experiment 1. Unlike the central target array used before, in this experiment two targets appeared in the same diagonal locations as the cues (cued trials) or along the opposite diagonal axis (uncued trials). The targets were filled-in circles, with both being either red or green. At the start of each block, subjects were informed that they should press the spacebar as quickly as possible if they detected targets of a certain colour (e.g., red) and to withhold responding if they detected targets of the other colour (e.g., green). Thus, the ACS was instantiated through a go/no-go task. Also unlike the previous task, there was no mask and the targets remained visible until a response was made or 2000 ms elapsed.

Design. There were 100 trials in each of two blocks, and within each block the location of the cues, the colour of the cues, the locations of the targets, and the colour of the targets were equally likely. Counterbalanced across subjects was the block order, as half the subjects responded to red targets in the first block and the other half responded to green targets in the first block.

Results and discussion

The mean RTs for each subject were calculated and a 2 (ACS: Match or mismatch) $\times 2$ (trial type: Cued or uncued) ANOVA was conducted on the data (see Figure 4). The was no main effect for ACS, $F(1, 19) < 1$, but a reliable cueing effect did emerge, $F(1, 19) = 7.9$, $p < .05$, with RTs for cued trials being faster than uncued trials. Importantly, there was also a significant ACS × Trial type interaction, $F(1, 19) = 10.5$, $p < .005$. Separate two-tailed t-tests confirmed a significant cueing effect with match trials, $t(19) = 5.3$, $p < .01$, cueing effect $= 17.5$ ms, but no such effect with mismatch cues, $t(19) < 1$, cueing effect $= -1.3$ ms.

The results from this experiment show a nearly ideal ACS, as the match cues generated a 17.5 ms cueing effect whereas the mismatch cues produced nearly identical RTs on cued and uncued trials (uncued trials were 1.25 ms quicker than cued trials). As noted previously, this very effective attentional

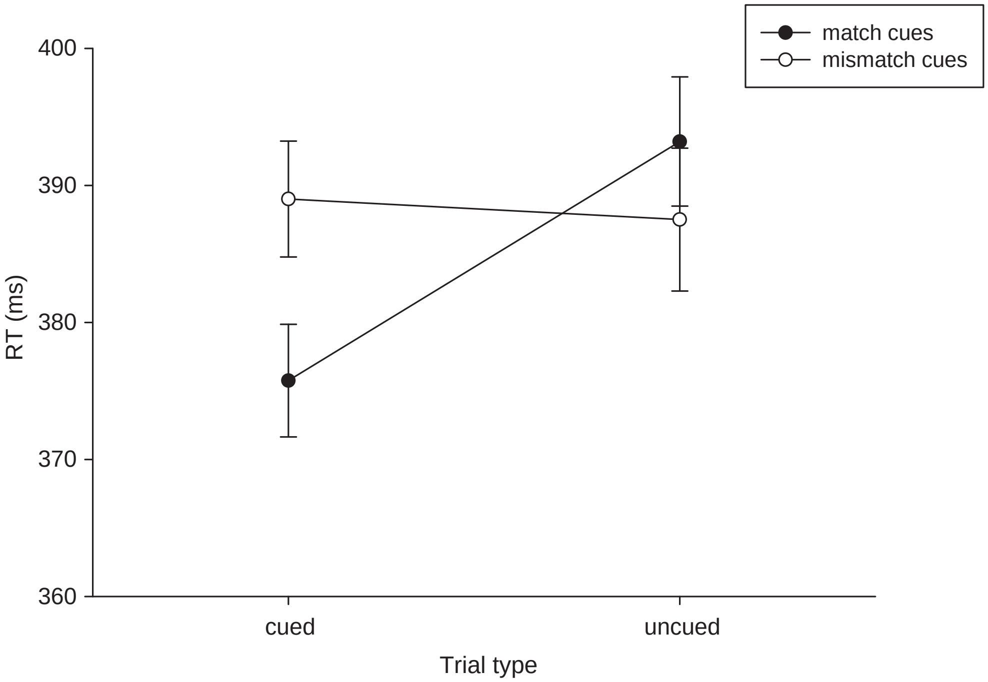

Figure 4. Mean reaction times for Experiment 3. The errors bars are 95% confidence intervals (Cousineau, 2007).

filter has been shown to be reflected in other measures of processing efficiency (e.g., Al-Aidroos, Harrison, & Pratt, 2010; Folk et al., 2002; Folk & Remington, 1998).

It should be mentioned that the scope of Experiment 3 was narrow, in the sense that we do not assert the two sets of findings provided by Experiments 1 and 3 represent two separate aspects of the same task. Instead, in Experiment 3, we primarily aimed to test whether the same visual stimuli (i.e., peripheral cues having the exact eccentricity, luminance, colour, exposure duration, etc.) used in Experiments 1 can be filtered out, as far as processing efficiency (RT) is concerned. This test seemed particularly necessary in light of previous work revealing the importance stimulus characteristics in the interaction between top-down and bottom-up attentional processes (see, e.g., Lamy, 2005, Exp. 3). Thus, this experiment attempted to transform the task used in the first two experiments into an experiment that measured processing efficiency, while preserving key stimulus characteristics. Although the differences that emerged from that transformation limits the scope of Experiment 3, it provides supports for the notion that measures of processing efficiency and spatial representation are differently sensitive to the effect attentional orienting.

GENERAL DISCUSSION

Previous work on top-down control of attentional prioritization suggests that knowledge of a critical target feature can eliminate involuntary shifts of attention towards the location of salient distractors that do not possess the same feature (e.g., Folk et al., 1992, 1994; Folk & Remington, 1998). The success of feature-based ACSs in filtering out distractors, however, has become evident primarily when using measures of processing efficiency (e.g., RT, attentional blink, etc.). Using the ARE paradigm (Suzuki & Cavanagh, 1997), which examines traces of attentional capture on spatial representation of visual targets, the present study examined the effect of distractors that either matched or mismatched an ACS. In line with previous reports of the ARE, we found systematic misperception of target location away from the peripheral distractor (Arnott & Goodale, 2006; Pratt & Arnott, 2008; Pratt & Turk-Browne, 2003; Suzuki & Cavanagh, 1997). Critically, this effect was caused by distractors that both matched and mismatched the ACS (Experiments 1–2). Consistent with the effectiveness of ACSs on measures of attentional control based on processing efficiency, we found an effect of ACS using the same stimuli with an RT measure (Experiment 3). These findings suggest that when looking at processing/performance efficiency, ACSs seem to eliminate the cost of a salient distractor, but they do so without eliminating distractors' influence on spatial representation of the display.

The present study complements the findings of Al-Aidroos and Pratt (2010) concerning the effect of control sets on saccadic RTs and trajectories. In both studies, the advantage of having a control set was confined to the efficiency of performance, the distractors continued to distort the spatial representation of the display. One might argue, however, that these findings merely indicate the crucial role of location in selection of items and its superiority over other features, such as colour, in guiding attention (Chen, 2009; Lamy & Tsal, 2001; Nissen, 1985). That is, under conditions of spatial uncertainty, location of a salient distractor is processed in parallel with the target without the ability to filter out on the basis of colour (although see Bundesen, 1991). If this is the case, then spatial certainty concerning target location should eliminate the effects of distractors. This is contrary to the findings of Al-Aidroos and Pratt (2010, Exp. 2) that previewing the target location did not eliminate the deviations of saccades away from the distractors. Further, in the ARE paradigm used in the present study, subjects also had relative foreknowledge of the location of task-relevant stimuli; target stimuli always appeared within an area horizontally subtending $\pm 0.4^\circ$ around the vertical meridian, whereas distractor items were centred $\pm 5^\circ$ beyond the vertical meridian. Therefore, the weakness of ACSs in controlling the spatial influence of distractors does not appear to be due to spatial uncertainty for target stimuli.

In light of these findings, it seems that the spatial measures such as ARE and deviations in saccadic trajectories may be more sensitive in capturing the resistance of stimulus-driven attentional processes to top-down control. The fact that we found an ARE regardless of the compatibility of the cues with a concurrent control set suggests that resources for increasing the spatial resolution at the location of the distractor were recruited despite any top-down control processes (Shalev & Tsal, 2002; Tsal & Shalev, 1996; Womelsdorf et al., 2006). This finding has key implications for the debate concerning the top-down and bottom-up factors involved in visual attention. Importantly, although there is agreement over the general notion that salient distractors introduce a processing cost regardless of top-down control, there is less agreement over the nature of this processing cost. One central point of contention is whether the processing cost of a salient distractor consists of a covert shift of attention, as opposed to a nonspatial filtering cost (Folk & Remington, 2010; Folk, Remington, & Wu, 2009; Theeuwes, 2010). In light of the evidence supporting the possibility of ideal ACSs, it has been argued that distractors incompatible with the ACS do not cause spatial orienting of attention (Folk & Remington, 1998; Folk et al., 1992, 1994). Consequently, previous reports from other tasks showing delayed responses to a target due to the presence of a concurrent, salient distractor (e.g., Theeuwes, 1991, 1992; although see Theeuwes et al., 2000) were viewed as open to the alternative interpretation of nonspatial filtering cost (Folk & Remington, 1998). The present findings, by contrast, provide strong support for the idea that salient stimuli can produce covert spatial shifts of attention through bottom-up processes despite the knowledge of task-relevant features.

It should be noted, nonetheless, that not only did we find a difference in RTs as a function of the match with ACS (Experiment 3), but also a difference in the degree of the ARE caused by matching and mismatching cues (Experiment 1). Thus, the covert shifts of attention caused by the matching and nonmatching distractors might involve different depths of processing. The study by Remington and Folk (2001) specifically demonstrated that when attention is moved to the location of a distractor, an irrelevant feature of the distractor does not influence the response. The authors used an experiment in which the task-relevant feature of a red target letter was determined at the start of each trial (identity: "L" or "T" vs. orientation: Clockwise or counterclockwise). One of the four possible target locations was cued using a noninformative red peripheral cue (i.e., cue always matched the ACS). A target then appeared along three white distractors (drawn from white, upright "E"s and "F"s; or, white, tilted "L"s and "T"s) in the four placeholders. Each of the two manual responses was assigned to two values on the different task dimensions (e.g., right key press: Clockwise orientation or "L") in order to assess the interference of the relevant and irrelevant feature at the cued location. Results revealed that both the relevant and irrelevant features of the target caused response interference, whereas only the relevant feature of the cued distractor (orientation or identity, depending on the trial) caused interference. These results suggest that the depth at which an attended ACS-incompatible distractor is processed is less than how the target is processed. The ability to disengage from a distractor without its in-depth perceptual analysis may be the reason why processing efficiency remains intact with an ACS. Similarly, smaller ARE caused by the ACS-mismatching distractors in the present study could be explained by a shallower processing of these distractors due to top-down inhibition (Experiments 1).

We suggest that the relatively small effect of ACS found in the first experiment disappeared in Experiment 2 because the observers were no longer able to set a filter against the known distractor colour. Specifically, grouping the distractor Vernier lines and the mismatching cues might have made this filtering possible (Duncan & Humphreys, 1989; Treisman, 1982; Treisman & Sato, 1990). Thus, the results of Experiments 1 and 2 suggest that an ACS that operates exclusively based on the knowledge of the target feature may be ineffective in preventing salient distractors from influencing the spatial localization of objects. This conclusion is particularly important in light of the observations that ACSs sets are more strongly driven by the knowledge of the target feature than by the knowledge of the irrelevant feature (e.g., Pratt & McAuliffe, 2002).

The idea that ACS influences processing depth gains support from the observation that the same neurons in the primary visual cortex can respond to a visual stimulus based on its basic visual features and based on attentional selection (Roelfsema, Tolboom, & Khayat, 2007). This suggests a close interaction between bottom-up and top-down processes that is observable at the earliest stages of processing, and can account for the varying processing depth across stimuli that match or mismatch the goal-related priorities, and consequently, for the diverse effects of top-down control on the processing of salient distractors. Viewing the shifts of attention towards the matching and mismatching distractors as different is also compatible with the rapid disengagement interpretation of the temporal benefit of ACS (see Theeuwes, 2010; Theeuwes et al., 2000). Disengaging from an item that possesses a relevant feature is, by comparison, less efficient because of the level of processing dictated by the ACS.

In sum, we propose that the two consequences of attentional capture (i.e., reduced processing efficiency and changes in spatial representation) should both be considered in studying the interaction between top-down and bottom-up processes of attentional selection. At present, the spatial indices of attention seem to suggest that attentional orienting does occur towards the salient items regardless of top-down control, whereas the temporal measures seem to suggest a fundamental difference between processing the two kinds of distractors.

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