Experience dependent attentional tuning of distractor rejection

The world is filled with distractions, ranging from the abrupt appearance of an Internet pop up ad to the sound of a coffee grinder at the local bistro. A primary purpose of attention is to restrict processing to items relevant to our current behavior and to minimize interference from irrelevant distractors. A central issue in the attentional control literature has centered on the mechanisms of this restriction, with two rival hypotheses emerging to explain when attention is captured by distracting information. One account proposes that attention is stimulus driven and that salient distractors capture attention irrespective of one’s goals or attentional set (Theeuwes, 1992, 2010). Another account proposes that attention is driven by one’s goals and that attentional capture is contingent on one’s attentional set; only distractors matching a current attentional set will capture attention (e.g., Folk, Remington, & Johnston, 1992). Against this backdrop, much of the past 20 years of research has focused on distinguishing stimulus-driven capture from contingent capture, with a focus on which of these two modes of selection is the ‘default’ mode of attention (Kawahara, 2010).

Strong evidence for stimulus-driven capture has come from the additional singleton paradigm (Theeuwes, 1992). In this task, observers search for a shape singleton among homogenous distractors (e.g., search for a circle among diamonds); observers report the orientation of a line that appears inside the target shape. On half the trials, one of the distractors is a different color, making it a salient singleton distractor. Because the target is never the color singleton, an observer with perfect goal-driven control has no reason to attend to this additional singleton, and the presence of the additional singleton should not slow response times to the target. However, the presence of an irrelevant color singleton slows response times to the target (see Theeuwes, 2010, for an extensive review). Because the color singleton is irrelevant to an observer’s goal to
find the shape singleton, slowed RTs when the color singleton is present can be interpreted as stimulus-driven attentional capture.

There are limits to stimulus-driven capture, however. One important retort to the additional singleton paradigm in favor of goal-driven control came from Bacon and Egeth (1994), who demonstrated that a salient distractor would not capture attention when observers searched for a specific target, not simply a shape singleton target. Specifically, when searching for a target among heterogeneous distractors (e.g., a circle among squares, diamonds, and triangles), an irrelevant color singleton no longer captures attention. Bacon and Egeth reasoned that the specificity of the target’s shape was critical in determining capture. When searching for a shape singleton, observers may adopt a nonspecific target configuration and search for any unique item, that is, any singleton. This so-called singleton detection mode (Pashler, 1988) would allow for fast detection of a singleton target, but would also render an observer vulnerable to an irrelevant color singleton. Requiring observers to search for a target among heterogeneous distractors requires feature search mode, and searching for a specific feature (e.g., circle) appears to eliminate capture because the color singleton distractor no longer matches target properties (also see Folk et al., 1992).

Although Bacon and Egeth’s (1994) work highlighted the role of target specificity on attentional capture, subsequent work has demonstrated that attention is also affected by distractor attributes. For example, in priming of pop-out, Maljikovic and Nakayama (1994) not only demonstrated that observers were faster to respond to a target whose color repeated from the previous trial, they also found that observers were faster to discriminate the target when the distractor color repeated from the previous trial (see Kristjánsson & Campana, 2010). This result suggests that attention is affected by distractor features (namely, color).
Given this background, an outstanding question regarding attentional capture is how attention knows that a particular item is a distractor that should be suppressed. One straightforward possibility is that a well-specified target template, as that employed in feature search mode, dictates distractor suppression. Any item not matching the target template could be dismissed as a distractor. Support for this hypothesis comes from Leber et al. (2009) who found that if participants were trained to use a specific target template, color singletons failed to capture attention even after the color of the color singleton was switched. In contrast, we propose an alternative possibility: experience-dependent distractor rejection. Based on a wealth of findings that indicate attention is affected by recent experience, we propose that salient distractors must be encountered and must capture attention before they can be suppressed and rejected at some later time. In short, although a target template is likely to be important in configuring attention, attention may also need to tune itself to distractor properties to optimize selection.

To investigate these possibilities, observers performed a basic feature search task by searching for a circle among diamonds, squares, and triangles. Observers first learned the target template in a training block in which no color singleton distractor appeared. Following the training block, observers completed four test blocks in which a color singleton distractor appeared on half of the trials. Diverging from previous work, we presented a different colored singleton distractor in each block. For example, the first block might contain a red color singleton, the second a purple color singleton, and so on. If a specific target template is sufficient for generating distractor suppression, the response times to the target should be unaffected by the presence of a singleton distractor, replicating Bacon and Egeth’s (1994) well-known results. However, if efficient distractor rejection not only requires a specific target template, but also requires learning to reject specific distractors, then we should observe attentional capture when
observers initially experience a color singleton distractor. Specifically, in the first block in which a distractor appears, observers should be slower to respond when the color singleton distractor is present than when it is absent. Further, our design allows us to examine the generalization of any learned distractor rejection to novel color singletons in the following blocks. If exposure to any color singleton distractor is sufficient to learn distractor rejection, then we should observe no capture in blocks 2, 3, and 4. Alternatively, if distractor-specific experience is required for distractor rejection, then we should observe capture any time a new color singleton appears; specifically, we should observe capture at the beginning of all of the blocks.

**Experiment 1**

**Method**

*Participants.* Sixteen University of Iowa undergraduates participated for course credit. All reported having normal or corrected-to-normal vision.

*Stimuli and procedure.* We presented stimuli and collected responses on a Macintosh Mini computer using MATLAB and the Psychophysics Toolbox (Brainard, 1997); displays appeared on a 17-in. CRT screen. Observers sat 60 cm from the screen.

Stimuli were 6 colored shapes presented equally spaced around the circumference of an imaginary circle centered at fixation with a radius of 4.2°. The fixation was a small white circle. Each item measured approximately 2.5° square. Each shape contained a white line, which was randomly oriented either vertically or horizontally. Each line measured 0.7 x 1°. There was one target (circle) and five distractors (triangle, square, diamond) in each display. The identity of each distractor item was chosen randomly. The target was green and the distractors were all green when the color singleton distractor was absent from the display; when a singleton
distractor appeared it could be red (RGB 255, 0, 0), yellow (RGB 255, 255, 0), purple (RGB 255, 0, 255), or orange (RGB 255, 150, 0).

The observers reported the orientation of the line that appeared inside the green circle as quickly and accurately as possible. Observers responded “z” if it was a vertical line and “m” if it was a horizontal line. Observers were informed that there might be a differently colored item present during some of the trials, but because the target was always green, they should ignore these items. Eye movements were not monitored, but observers were encouraged to maintain fixation. Each trial began with a fixation dot, visible for 1000 ms. Next, the search display appeared and remained visible for 5000 ms or until response. When observers failed to respond within 5000 ms, they were encouraged to respond faster, and the trial was marked as incorrect. A beep was played following an incorrect response.

Observers first completed a 60 trial training block in which they searched for the green circle among heterogeneously shaped distractors in the absence of any color singletons. Following the training block, observers completed four test blocks of 48 trials each as illustrated by Figure 1. The test blocks were identical to the training block except that one of the distractors was a color singleton on half the trials. Each block had a differently colored color singleton. We counterbalanced the color singletons across the four block positions. Each block was preceded by a short, self-paced rest break.

**Results & Discussion**

Reaction times (RTs) exceeding 3 standard deviations from an observer’s mean, incorrect RTs, and RTs following an incorrect response were removed from the analysis. This trimming eliminated less than 2% of the data.
The results appear in Figure 2. To evaluate if a new color singleton initially slowed responses to the target, RTs were entered into a 2x2 repeated measures ANOVA, with trial order (RTs from the 1\textsuperscript{st} or 2\textsuperscript{nd} half of a block), and singleton presence (present versus absent) as factors. We found a main effect of trial order, $F(1, 15) = 4.80, p < .05$, with slower RTs in the first-half of blocks than the second and a marginally significant main effect of singleton presence, $F(1, 15) = 3.62, p < .08$, with slower RTs in singleton present than singleton absent trials. Most important, these main effects were subsumed by a two way interaction between trial order and singleton presence, $F(1, 15) = 21.72, p < .001$. Planned comparisons found that RTs were longer in the presence of a singleton than in its absence during the first half of blocks, $t(15) = 5.26, p < .001$, but not in the second half of blocks, $t(15) = 1.49, p > .16$.

To examine the generality of this pattern of results, we analyzed RTs from the first half of each block with a 2x4 repeated measures ANOVA with singleton presence (present vs. absent) and block (1, 2, 3, and 4) as the factors. There was no interaction between singleton presence and block, demonstrating that capture did not depend on if observers were in the first or any other block, $F(3, 15) < 1$. Importantly, this test also indicates that capture did not significantly diminish over the experiment as illustrated by table 1. This analysis demonstrates that observers did not learn general distractor rejection in the first block and even suggests that observers need experience with each individual color singleton to effectively suppress them.

The mean error rate was 2.7%. Arcsine-transformed error rates were submitted to the same 2x2 repeated measures ANOVA as the response times. The only significant effect was from trial order, which found that observers were less accurate in the first half of blocks than the second, $F(1, 15) = 5.84, p < .03$, paralleling the RT results.
The present pattern of results strongly supports experience-dependent attentional tuning for distractor rejection. Although observers spent 60 trials searching for a well-specified target and, presumably, being in feature search mode, this experience with the target alone was insufficient to prevent capture by an irrelevant color singleton. Of course, one might argue that 60 trials were insufficient to fully enter feature search mode and exhibit distractor. However, by the beginning of the fourth block observers had encountered the target in the absence of a singleton distractor on 132 trials. Nevertheless, a new color singleton captured attention and slowed RTs at the beginning of the fourth block, which argues against mere target exposure as being sufficient for distractor rejection.

Perhaps a more pressing concern with Experiment 1 is that the initial encounter with a new color singleton was perfectly confounded with the rest breaks. If attentional control was loosened or interfered with by a rest break, attention would be captured more readily at the beginning of a block than later in the block, and the current results might have nothing to do with encountering a new color singleton. Although past studies have reported persistence of attentional control settings across rest breaks and even weeklong delays (Leber & Egeth, 2006; Leber et al., 2009), in Experiment 2 we introduced new color singletons both following a break and mid block.

**Experiment 2**

In Experiment 2, we used a training block identical to that in Experiment 1, but we used two test blocks of 96 trials instead of four test blocks of 48 trials. In a single block of 96 trials, the first 48 trials of a block had one color singleton present on half the trials and the second set of 48 trials had a different color singleton present on half the trials. Critically, the second color singleton was not preceded by a rest break. This design allows us to compare capture from a new
color singleton following a rest break to capture from a new color singleton that did not follow a rest break.

**Method**

*Participants.* Sixteen University of Iowa undergraduates participated for course credit. All had normal or corrected-to-normal vision.

*Stimuli and Procedure.* The stimuli and procedure are the same as Experiment 1 except for the following. There was no error beep to alert observers of incorrect responses and blocks were comprised of 96 trials. This led to only two rest breaks in the experiment (one following the training block and one splitting the test blocks). Importantly, in the first quarter of blocks, observers experienced a new color singleton after coming out of a rest break. During the third quarter of blocks, observers experienced a new color singleton mid block, not following a rest break.

**Results & Discussion**

We treated RTs as in Experiment 1, and this trimming excluded less than 2% of the data. The mean RTs appear in Figure 3. We analyzed the data with a 4 x 2 within subjects ANOVA, with color singleton presence (present vs. absent), and trial order (1st quarter, 2nd quarter, 3rd quarter, or 4th quarter) as factors. There was a main effect of trial order, $F(3, 45) = 4.28, p < .01$, likely driven by longer RTs in the first quarter of trials than the latter quarters of trials. There was no overall main effect of singleton presence, $F(1, 15) = 2.9, p > .10$. Most important, there was an interaction between trial order and singleton presence, $F(3, 45) = 2.75, p = .05$, which paralleled the interaction in Experiment 1. Planned comparisons confirmed that observers were slower when the singleton was present than when it was absent during the first quarter of blocks, $t(15) = 2.39, p < .02$, but not in the second quarter, $t(15) < 1$, ns., consistent with Experiment 1. Planned
comparisons also found observers slower during singleton present trials than absent trials in the third quarter of blocks, $t(15) = 2.47, p < .02$, but not during the fourth quarter, $t(15) < 1$, ns. These results from the last two quarters demonstrate that a new color singleton captured attention even when that color singleton was not preceded by a rest break. Further, after sufficient experience with a color singleton (during the second and fourth quarter of blocks), distractors were effectively rejected and did not capture attention.

We analyzed arcsine transformed accuracy data with the same 4x2 repeated measures ANOVA as the RTs. There was a marginally significant effect was of trial order, $F(3, 45) = 2.76, p = .054$, but pairwise comparisons failed to find any significant differences in accuracy between the blocks, $ps > .60$. Other than this, the pattern of the accuracy data largely reflected the RT data with lower accuracy when participants first experienced a color singleton.

The results of Experiment 2 indicate that the initial encounter with a color singleton produces capture, irrespective of that singleton’s position in a sequence of trials. Moreover, this capture occurs despite stimulus conditions that typically produce a highly selective attentional state in which capture, measured in aggregate RTs, is absent.

**General Discussion**

These experiments investigated the underpinnings of effective distractor rejection. Although previous results indicated that highly salient color singleton distractors could be rejected during a search task that required the target to be specified precisely, we found that a precise target template was not sufficient to prevent capture. Instead, observers were slower to discriminate a target in the face of a task-irrelevant color singleton—a hallmark signature of attentional capture—when the singleton first appeared during the course of the experiment. When searching for a specific shape among heterogeneous distractors, an irrelevant color singleton distractor
slowed RTs when this distractor was first encountered. However, the distractor no longer slowed RTs after observers had a short amount of experience rejecting this distractor. Importantly, we also found that capture persisted across blocks. Experience with distractor rejection does not appear to generalize to all color singletons but is instead specific to the rejected item.

Our results compliment a growing literature demonstrating that experience broadly influences visual attention. Most relevant for the present experiments are results from Leber and colleagues, who demonstrated that observers who are trained into feature search mode maintain that search mode even when the search displays change and the search can be performed as a simpler singleton search (Leber & Egeth, 2006; Leber, Kawahara, & Gabari, 2009). These findings suggest that a well specified, precise target template might be carried across an experiment and can shape attentional capture. Our results suggest that a substantial component of so-called feature search mode involves learned distractor rejection. We hypothesize that the carry over of feature search mode in previous work (e.g., Leber et al., 2009) is due to distractor rejection. Had the singleton distractor changed color when the search displays changed, our experience dependent distractor rejection account predicts that, initially, the learned feature search would have been insufficient to prevent capture by the new singleton. We are currently testing this prediction.

In sum, we interpret our results as suggesting that attentional control does not involve a simple dichotomy between stimulus-driven and goal-driven control. The role of experience must be taken into account because goal-driven control can only be instantiated until after sufficient experience with salient items in the display. Prior to this, stimulus-driven control might predominate.
References
Table 1

<table>
<thead>
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Figure Captions

**Figure 1.** Sequence of events for experiment 1. Each search display was preceded by a 1,000 msec fixation point (not pictured) and then appeared on the screen for 5,000 msec or until response. Color singleton’s appeared in 50% of the trials. Color of the color singleton changed between blocks (48 trials).

**Figure 2.** Response times (ms) as a function of trial order (1st half of blocks vs. 2nd half of blocks) and singleton presence (present vs. absent) across the four blocks of the experiment. Error rates of each condition are reported at the base of the bars. Error bars represent 95% within subject confidence intervals (Loftus & Masson, 1994).

**Figure 3** Response times (ms) as a function of trial order (1st quarter-4th quarter) and singleton presence (singleton present vs. singleton absent). Note: the important comparison here is the presence of capture in both the 1st quarter of the blocks and the 3rd quarter of the blocks. Error rates of each condition are reported at the base of the bars. Error bars represent 95% within subject confidence intervals (Loftus & Masson, 1994).