Rejecting salient distractors: Generalization from experience

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Abstract

Distraction harms performance in many important everyday tasks such as driving. Through the application of attentional control, distraction can be limited by directing attention towards important events and away from irrelevant events. Research investigating attentional control has typically asked whether attentional control is stimulus driven or goal driven, but recent work demonstrates that the nature of control depends on experience. Specifically, previous work found observers require item-specific experience with salient distractors to efficiently reject them (i.e., learned distractor rejection). The experiments presented here examine whether learned distractor rejection generalizes to novel distractors under the same conditions that encourage generalization of skill learning. In Experiment 1, observers searched for a target and ignored a salient colored distractor that appeared in half the trials. One group of observers experienced three different salient color-singletons each in a different block (homogeneous stimulus environment). Another group of observers experienced three different salient color-singletons intermixed across three blocks (heterogeneous stimulus environment). Observers in the heterogeneous environment effectively rejected a novel color-singleton whereas observers in the homogeneous environment did not, demonstrating that, as in skill learning, a heterogeneous stimulus environment encourages generalization of learned distractor rejection. Experiments 2 and 3 investigated whether learned distractor rejection, like skill learning, persists across the experiment. Experiments 2 and 3 found that after experiencing four salient color-singleton distractors, observers could effectively reject subsequent novel salient distractors. These results cast optimizing attentional control settings to the task environment as a form of rapid skill learning, demonstrating experience’s critical role in attentional control.
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The visual system lacks the ability to simultaneously identify every item in a visual array, so the visual system prioritizes behaviorally relevant items. Attention is the selective processing of items, and an important question in attentional research is how individuals choose where to allocate attention (i.e., attentional control). Obviously, individuals want to allocate attention to important items, but what makes an item important? Research on attentional control has investigated whether the visual system identifies an item’s importance via visual salience (stimulus-driven inputs) or observers’ goals (goal-driven inputs). Researchers supporting the stimulus-driven account claim that the visual system initially selects the most salient item in the environment (e.g., Theeuwes, 2010; Itti & Koch, 2000). Researchers supporting the goal-driven account claim the visual system initially selects items fitting observers’ current goals (e.g., Folk et al., 1992).

Evidence for the stimulus-driven account primarily derives from the additional-singleton paradigm (Theeuwes, 1992), in which observers search for a shape-singleton target among homogeneously shaped distractors. In half the trials, all distractors are the same color as the target, but in the other half, one distractor is a different color (i.e., color-singleton distractor). The target is never this oddly colored item, making it task irrelevant. Nonetheless, observers respond slower to the target when the color-singleton distractor is present than absent, indicating that the color singleton interfered with observers’ ability to allocate attention to the target (Theeuwes, 2010).

Although researchers typically portray attentional control as an immutable system that relies upon either stimulus-driven or goal-driven inputs, much research suggests experience
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mediates the balance between these inputs (for review see Vecera et al., 2014). For example, attention can be directed toward a target if the target appears in a consistent, predictable relationship with non-target distractors, an effect termed contextual cuing (Chun, 2000; Chun & Jiang, 1998). More immediate experience can affect attention, as when a target is discriminated more quickly when preceded by a similar target than a dissimilar target, as in priming of popout (e.g., Maljkovic & Nakayama, 1994, 1996, 2000; for review see Kristjánsson & Campana, 2010). The foregoing examples center on how experience influences target localization and discrimination; however, effective attentional selection also requires distractor rejection.

Experience appears to affect distractor rejection. For instance, Leber and Egeth (2006) trained observers with displays that either encouraged observers to search specifically for the target (i.e., feature-search mode; Bacon & Egeth, 1994) or encouraged observers to search for any unique item (i.e., singleton-detection mode; Pashler 1988). All observers then transferred to a test phase with displays, termed ‘option trials,’ in which search could be deployed in either feature-search mode or singleton-search mode. Leber and Egeth (2006) found that color singletons during the option trials did not interfere with observers’ allocation of attention if the observers previously trained with displays that encouraged them to search for a specific target. Color singletons during the option trials did interfere with observers’ allocation of attention if the observers previously trained with displays that encouraged them to search for unique items. Thus, past experience using a precise search strategy made observers’ attentional control less influenced by salience inputs, demonstrating that past experience adjusts whether observers’ visual systems weight stimulus-based or goal-based factors in attentional control.

Vatterott and Vecera (2012) investigated the role of distractor-rejection experience on attentional control. In Vatterott and Vecera’s (2012) experiment, observers started the
experiment with a training block that encouraged a precise search strategy. Specifically, observers searched for a target shape among heterogeneously shaped distractors. During this training phase, color-singleton distractors never appeared. Following the training phase, blocks of trials were presented in which a color-singleton distractor appeared in 50% of the trials. Importantly, the color of the singleton distractor changed each block. Varying the distractor color allowed Vatterott and Vecera (2012) to distinguish among three alternative mechanisms of attentional control. If search strategy alone was sufficient to effectively reject color-singleton distractors, then the color-singletons should never interfere with the allocation of attention. Alternatively, observers might need general experience rejecting any salient distractor. In this case, color-singletons in the early part of the first block might interfere with observers’ attentional allocation because they are novel, but observers learn to effectively reject them (say, in the second half of the first test block) and then effectively reject all following color-singleton distractors. Finally, observers might require experience rejecting each distinct color-singleton to effectively reject other singletons of the same color. In this scenario, each time the color of the singleton changes, the color-singleton will interfere with the allocation of attention in the early part of each block before observers have sufficient experience to effectively reject it. Vatterott and Vecera (2012) found support for the final hypothesis: Even when observers use feature-search mode, they must experience each color-singleton to effectively reject it. These results suggest that observers learn to reject distractors through item-specific experience. We refer to this item-specific learning as learned distractor rejection.

Recent research demonstrates that attentional control is not immutable and instead constantly adjusts to the environment (Cosman & Vecera, 2014; Leber & Egeth, 2006; Vatterott & Vecera, 2012), but little is known about how attentional learning compares to other types of
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Past work in our lab demonstrates that at least one type of attentional learning, learned distractor rejection, is item specific (Vatterott & Vecera, 2012). Skill learning also often exhibits highly specific learning, but this learning generalizes under the right circumstances, for example, when practice is variable (for review, see Schmidt & Bjork, 1992). The experiments in this article examine whether learned distractor rejection obeys the same form as skill learning. We will first investigate this by asking if learned distractor rejection generalizes to new distractors under the same circumstances that encourage generalization in skill learning.

Our previous work (Vatterott & Vecera, 2012) found evidence that learned distractor rejection was item specific when the salient distractors appeared in a blocked manner. In Experiment 1 of this article, we ask if such a more heterogeneous stimulus environment could produce a generalizable distractor rejection strategy. Work in the skill learning literature demonstrates that heterogeneous stimulus environments help individuals generalize learning to novel environments (e.g., Schmidt & Bjork, 1992). For example, Catalano and Kleiner (1984) studied observers’ ability to learn in a coincident-timing task. In this task, observers sat in front of a column of lights. The lights lit up one at a time starting with the light most distant from the observer; each light lit in turn until the light closest to the observer was lit, creating the perception of an object moving toward the observer at a constant rate. The observers’ task was to respond when the light closest to the observer lit. Observers could either practice this task in a training block where the timing between adjacent lights turning on was constant on each trial (the light moved at the same speed towards observers on each trial) or observers could be in a training block where the light moved at a different speed each trial. All observers then transferred to a test block where they completed the same task, but the light moved either faster or slower than observers had experienced in the training block. Observers from the varied-speed
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practice group performed better in the test than the constant-speed practice group. This experiment demonstrates the importance of heterogeneous practice for generalizing skills and suggests that if learned distractor rejection uses the same learning principles as skill learning, a heterogeneous distractor environment will enable observers to reject novel distractors without previously experiencing these specific distractors.

Observers in Vatterott and Vecera’s (2012) experiment experienced a single color-singleton in each block, providing observers with a homogeneous environment for learning to reject distractors. The current experiment tests whether a heterogeneous environment is better suited than a homogeneous environment for training observers to reject novel distractors. These experiments are largely modeled after Vatterott and Vecera (2012), with some key exceptions. In Experiment 1, half of the observers experienced a heterogeneous stimulus environment in which three different color-singletons appeared interspersed throughout three blocks (Mixed group). The other half of observers experienced a homogeneous stimulus environment in which a different singleton color appeared in each of three blocks (Blocked group), replicating Vatterott and Vecera (2012). Both groups were then tested with a novel distractor color in a final block of trials; this final block always contained a single distractor color, which appeared on half of the trials. If learned distractor rejection uses similar mechanisms as the skill learning described in Catalano and Kleiner (1984), then a novel color-singleton in the fourth block will initially interfere with the allocation of attention in the Blocked group, but not interfere with the allocation of attention in the Mixed group. If learned distractor rejection does not use the same learning principles as skill learning and is completely item specific, then the novel color-singleton will initially interfere with the allocation of attention in both groups.
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Experiment 1

Methods

Participants. Thirty-seven University of Iowa undergraduates completed the experiment for partial course credit. All reported normal or corrected to normal vision.

Apparatus. A Macintosh Mini computer using MATLAB and the Psychophysics Toolbox (Brainard, 1997) collected responses and presented the stimuli on a 17-in. CRT display. Observers sat approximately 60 cm from the display.

Stimuli and Procedure. Six colored shapes equally spaced around the circumference of an imaginary circle centered at fixation with a radius of 4.2° composed the displays. Fixation was a small white circle in the center of the screen. Each shape was roughly 2.5° square and contained a randomly vertically or horizontally oriented line (0.7° x 1°). The stimuli consisted of a target (circle) and five distractors (triangle, diamond, or square). The target position was chosen pseudo-randomly on each trial. The identity of each distractor was chosen pseudo-randomly on each trial, with the only constraint being that the distractors were not all the same identity. The target and all distractors were green (RGB 0, 255, 0) except on singleton present trials when one distractor was either red (RGB 255, 0, 0), yellow (RGB 255, 255, 0), purple (RGB 255, 0, 255), or orange (RGB 255, 150, 0). The color-singleton position was chosen randomly from among the distractors on each trial.

Each trial began with only the fixation point visible for 1,000 ms followed by the search display for 5,000 ms or until response. If an observer failed to respond within 5,000 ms, the observer was encouraged to respond faster and the trial was marked as incorrect. A beep informed observers of incorrect responses.
Observers pressed either the “z” or “m” key to indicate the orientation of the line within the target green circle. Key binding was counter-balanced across observers. The orientation of the line within the circle was chosen pseudo-randomly on each trial. Observers were instructed to respond as quickly and accurately as possible and that a differently colored item might appear on some of the trials, but this item would never be the target, so they should do their best to ignore it. Eye movements were not monitored, but observers were encouraged to maintain fixation.

All observers started the experiment with a 60-trial training block in which observers searched for the target circle among heterogeneously shaped green distractors. Following the training block, all observers completed four test blocks of 48 trials each. One of the distractors was differently colored (i.e., a color-singleton) in 50% of the trials. The color of the color-singleton remained the same throughout an entire test block, but changed between blocks in the Blocked group. See the right panel of Figure 1 for a depiction of this procedure. The same three colored color-singletons appeared intermixed in the first three blocks in the Mixed group. See the left panel of Figure 1 for a depiction of this procedure. A single novel color-singleton appeared in 50% of the trials of the fourth test block. The order of the color-singleton colors was counter-balanced across observers. A short self-paced rest break preceded each block.

Results

RTs more than five standard deviations above and two standard deviations below an observer’s mean of each condition, incorrect RTs, and RTs following an incorrect response were removed from the analysis. This trimming eliminated less than 0.005% of the data. Three observers from the Blocked group and two from the Mixed group were excluded due to accuracy 2.5 standard deviations below the average accuracy of all observers.
For the Blocked group, we compared RTs in the first and second halves of blocks 1-3 for trials in which color-singletons were present or absent (upper panel of Figure 2). We split RTs into the first and second halves of blocks because this convenient analysis adequately measured learned distractor rejection in past work (Vatterott & Vecera, 2012). To measure whether singleton distractors interfered more with the Blocked group’s allocation of attention early in blocks than late, we entered the RT data from blocks 1-3 into a 2x2 repeated measures ANOVA with Trial Position (RTs from the first or second half of a block) and Singleton Presence (singleton present or absent) as the factors. The ANOVA did not find an effect of Trial Position, $F < 1$, but did find a main effect of Singleton Presence, $F(1, 15) = 7.75, p < 0.05, \eta_p^2 = 0.34$. Longer RTs when the singleton was present (914 ms) than absent (877 ms) drove this main effect. Importantly, the ANOVA found a marginally significant interaction between Trial Position and Singleton Presence, $F(1, 15) = 3.85, p = 0.068, \eta_p^2 = 0.20$. Planned comparisons confirmed that observers responded slower when the color-singleton was present than absent in the first half of blocks, $t(15) = 2.84, p < 0.05$, but not the second half, $t < 1$. Thus, during the first half of blocks color-singletons interfered with the Blocked group’s allocation of attention, replicating Vatterott and Vecera (2012). This demonstrates that color-singletons interfered with the allocation of attention when novel in the first half of blocks but not in the second half when the color-singletons were more familiar.

Because the Mixed group experienced multiple color-singletons distractors within each block, the block-half analysis we performed for the Blocked group would not be suitable (because the distractor statistics did not change across blocks). Instead of a block-half analysis, the lower panel of Figure 2 shows the Mixed group’s RTs as a function of block. To measure changes in distractor interference across the three blocks, we entered RTs into a 3x2 repeated
measures ANOVA with the factors Block Number (blocks 1, 2, and 3) and Singleton Presence (Singleton Present versus Absent) as the factors. The ANOVA found neither a main effect of Block Number, $F(2, 30) = 2.03, p > 0.14, \eta^2_p = 0.12$, nor a main effect of Singleton Presence, $F < 1$. Importantly, the ANOVA found a significant interaction between Block Number and Singleton Presence, $F(2, 30) = 7.41, p < 0.01, \eta^2_p = 0.33$. Planned comparisons found observers responded slower when the color-singleton was present than absent in the first block, $t(15) = 4.66, p < 0.01$, but not in the second block, $t < 1$, nor the third, $t(15) = 1.71, p > 0.1$. These tests indicate that color-singletons interfered with the allocation of attention in the first block when the color-singletons were novel, but observers learned to reject the color-singletons and they did not interfere with the allocation of attention in the second or third block when they were more familiar.

Novel color-singletons interfered with both groups’ allocation of attention, but both groups also learned to reject these color-singletons and the color-singletons did not interfere with the allocation of attention after observers were more familiar with them. Next, we investigated performance in the 4th block of the experiment, which was identical for both groups. In particular, we are interested in whether the stimulus environment changes observers’ ability to reject novel color-singletons. The block 4 RTs were entered into a 2x2x2 mixed measures ANOVA with the factors Trial Position (First block half versus Second), Singleton Presence (Present versus Absent) and stimulus environment (Blocked versus Mixed group). Block 4 RTs from both groups appear in Figure 3. The ANOVA found neither a main effect of Trial Position, $F < 1$, nor Singleton Presence, $F < 1$. There was no main effect of group, $F(1,30) = 1.86, p > 0.18, \eta^2_p = 0.26$. The ANOVA also found no interaction between Trial Position and Group, $F(1,30) = 2.58, p > 0.1, \eta^2_p = 0.08$, nor an interaction between Trial Position and Singleton
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Presence, $F(1, 30) = 1.43, p > 0.24, \eta_p^2 = 0.05$. The ANOVA found a marginally significant interaction between Singleton Presence and Group, $F(1, 30) = 3.92, p = 0.057, \eta_p^2 = 0.12$. Importantly, the ANOVA found a significant interaction between Trial Position, Singleton Presence, and Group, $F(1, 30) = 5.14, p < 0.05, \eta_p^2 = 0.15$. This interaction demonstrates that color-singletons had a different effect on RTs depending on Block Half and Group. Planned comparisons found that observers in the blocked group responded slower when the color-singleton was present in the first half of block 4 than when it was absent, $t(15) = 2.59, p < 0.05$. Observers in the blocked group did not respond slower when the color-singleton was present in the second half of the block, $t < 1$. Observers in the mixed group did not respond slower when the color-singleton was present in the first half of block 4, $t(15) = 1.62, p > 0.1$. Color-singletons also did not slow Mixed group responses during the second half of the block, $t < 1$. Importantly, color-singletons slowed the Blocked group’s responses more in the first half of block 4 than the Mixed group’s responses, $t(30) = 3.05, p < 0.01$. This was not true during the second half of block 4, $t < 1$. These tests indicate that color-singletons initially interfered with the Blocked group’s allocation of attention, but not the Mixed group’s. Thus, a heterogeneous stimulus environment, gave observers the ability to ignore a salient color-singleton distractor without previously experiencing this item.

Error rates from each condition appear in the base of the bars depicting RTs from that condition (see Figures 2-3). We transformed accuracy values via an arcsine square-root transformation (Freeman & Tukey, 1950), and submitted these values to the same ANOVAs as the RTs. First, we submitted the transformed accuracy values from blocks 1-3 of the Blocked group to a 2x2 repeated measures ANOVA with the factors Trial Position and singleton presence. The ANOVA found neither significant main effects nor interactions, all $F$s < 1. Next,
we submitted the transformed accuracy values from blocks 1-3 of the Mixed group to a 3x2 repeated measures ANOVA with the factors block and singleton presence. The ANOVA found neither a main effect of block, $F < 1$, nor a main effect of singleton presence, $F(1, 15) = 2.14, p > 0.16, \eta_p^2 = 0.12$. The ANOVA also failed to find an interaction between block and singleton presence, $F(2, 30) = 1.57, p > 0.22, \eta_p^2 = 0.09$. Finally, we submitted the block 4 transformed accuracy values to a 2x2x2 mixed measures ANOVA with the factors Trial Position, singleton presence, and Group. The ANOVA found no main effect of Trial Position, $F(1, 30) = 2.60, p > 0.11, \eta_p^2 = 0.08$, nor a main effect of singleton presence, $F < 1$. The ANOVA did find a significant interaction between singleton presence, Trial Position, and Group, $F(1, 30) = 9.45, p < 0.005, \eta_p^2 = 0.24$. Follow-up comparisons indicate that higher accuracy in singleton present than singleton absent trials of the blocked group during the first half of the block drove this interaction, $t(15) = 2.61, p < 0.05$. We believe the response-terminated displays kept observers’ accuracy at ceiling, which hindered our ability to find significant accuracy differences across the conditions.

Above, we bin RTs into the first and second half of blocks, and we think of these block halves as representing early and late stages of learning to control attention. This division adequately reveals learned distractor rejection, but implies that when observers initially experience a novel color singleton distractor, it interferes with their allocation of attention, and observers then switch to an attentional state where the color singleton does not interfere with their allocation of attention. If learned distractor rejection obeys the same form as skill learning, then learning occurs gradually across experience. Because learned distractor rejection likely occurs continuously, we wanted an analysis that reflects this continuous learning. The power law of practice aptly describes skill learning (Newell & Rosenbloom, 1981; also see Anderson, 1982;
Logan, 1988; but see Heathcote, Brown, & Mewhort, 2000). We used a power function to describe learned distractor rejection as a continuous learning process. Specifically, we estimated the parameters of power functions fit to each observer’s data from the singleton present and absent conditions (Chun & Jiang, 2003). We fit our data to the function, $\text{RT} = \beta \cdot \text{Trial#}^{-\alpha}$, where RT is response time and Trial# is the number of experiences an observer has with a particular singleton condition. For instance, an observer’s first experience in a singleton present trial during a particular block is Trial# 1, and an observer’s third experience in a singleton absent trial during a particular block is Trial# 3. The parameter $\beta$ represents performance at the beginning of a block for a particular condition. The parameter $\alpha$ represents how quickly performances changes (learning rate) in a particular condition. We predict that novel color singletons initially slow RTs by interfering with the allocation of attention and this slower initial performance in singleton-present trials will be captured by a larger $\beta$ parameter in singleton present than singleton absent trials. We also predict that observers will quickly learn to ignore novel color singletons, and this learning will be represented by an $\alpha$ greater than zero in the singleton present condition.

We first estimated the power function parameters of data from blocks 1-3 independently for each observer in the Blocked group. The average best-fit power functions appear in Figure 4. To evaluate the fit of the power functions, we computed each subject’s relative root mean square error (RMSE) comparing the residuals of our best-fit power functions and a model that says RT does not change across experience. The singleton present condition produced an average RMSE.

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1 We do not argue that the power function fits our data best. In fact, we have fit an exponential decay function and a power function with an additional parameter that allows the asymptote to vary from zero (Logan, 2002). Both the exponential decay function and three-parameter power function replicate the pattern of results reported here. We use the two-parameter power function because of its long history of reliably describing skill learning.
of 0.95. The singleton present condition produced an average RMSE of 1.01. β, the parameter representing initial performance was greater in the singleton present than absent condition, t(15) = 3.18, p < 0.01. α, the parameter representing learning rate was greater than zero in the singleton present condition, t(15) = 3.64, p < 0.01, but not in the singleton absent condition, t < 1. These analyses indicate that when observers initially encountered a color singleton, it slowed response times, but observers gradually learned to ignore this color singleton, replicating the coarser block-half analysis above.

Next, we estimated the parameters of power functions fit to block 4 of observers from both groups. The average best-fit power functions appear in Figure 5. The Blocked group produced an average RMSE of 1.02 in the singleton present condition and 1.03 in the singleton absent condition. The mixed group produced an average RMSE of 1.02 in the singleton present condition and 1.02 in the singleton absent condition. In the Blocked group, the parameter representing initial performance, β, was greater in the singleton present than absent condition, t(15) = 2.67, p < 0.05. The parameter representing learning rate, α, was significantly greater than zero in the singleton present condition, t(15) = 3.77, p <0.01, but not singleton absent condition, t < 1. In the Mixed group, β did not differ in the singleton present and absent conditions, t < 1. α was not significantly greater than zero in either the singleton present or absent conditions, t(15) = 1.48, p > 0.15 and t(15) = 1.05, p > 0.31, respectively. Comparing the two groups, β from the singleton present condition was not significantly greater in the Blocked than Mixed group, t(30) = 1.75, p > 0.09. α from the singleton present condition was also not significantly greater in the Blocked than Mixed group, t(30) = 1.66, p > 0.09. Although the between group comparisons failed to reach significance, these analyses largely replicate the data pattern seen in our bin based
analyses and demonstrate that stimulus environment changes our ability to reject novel color singleton distractors.

**Discussion**

Experiment 1 finds that experience with heterogeneous salient distractors enables observers to ignore novel salient distractors (theMixed environment), whereas experience with homogeneous salient distractors does not (the Blocked environment). Thus, learned distractor rejection obeys at least one principle observed in skill learning: heterogeneous practice encourages generalization of learning (Schmidt & Bjork, 1992).

Two possible mechanisms could explain the generalization observed in this experiment. First, observers might have learned a more precise target template through practice (Bacon & Egeth, 1994). For instance, it could be that observers learn to reject distractors not by learning to ignore a specific color value, but by narrowing their target template (Becker, Folk, & Remington, 2010); in our experiment, observers might begin by searching for a circle of any color and narrow their target template by experiencing salient color singletons. For example, experiencing a red color singleton might teach observers that the target is not red. The increased variability in the heterogeneous stimulus environment might encourage more drastic narrowing of the target template. Second, observers could have learned to reject distractors, irrespective of the precision of the target template. The heterogeneous stimulus environment might encourage observers to create more generalizable distractor rejection templates (Arita, Carlisle, & Woodman, 2012). For instance, observers might learn to reject specific distractor colors, but the heterogeneous stimulus environment causes observers to create less specific distractor rejection templates. These less precise distractor rejection templates make novel distractors more likely to fall within the color
range specified by the rejection templates, and leave observers immune to interference by novel distractors.

The power function fitting analysis used in Experiment 1 demonstrates the gradual nature of learned distractor rejection and ties learned distractor rejection to the power law of practice (Newell & Rosenbloom, 1981). The power law of practice describes learning in tasks from cigar rolling (Crossman, 1959) to categorization (Nosofsky & Palmeri, 1997). Our finding that the power law of practice appears consistent with learned distractor rejection suggests that the same learning principles that govern tasks such as cigar rolling also govern the unrelated task of distractor rejection. This indicates that we do not simply instate an attentional control state by selecting a search mode (Bacon & Egeth, 1994) or by choosing a target template (Desimone & Duncan, 1995). Instead, attentional control is gradually honed across experience (Logan, 2002; Chun & Jiang, 2003; Cosman & Vecera, 2014). The attentional control system should not be thought of as a monolithic cognitive system ruled by either stimulus-driven or goal-driven inputs. Instead, the attentional control system constantly adapts to the task, changing the priorities of stimulus and goal-driven inputs (Vecera et al., 2014). Thus, the attentional control system adaptively configures itself to the current task environment just as motor control systems gradually configure to the task of cigar rolling.

In Experiment 1, the overall distractor statistics observed by Blocked and Mixed groups were identical: for both groups, over the first three blocks, the distractor color was chosen from three alternatives with equal probability. The statistics differ only in the sequence of colors. One explanation for why generalization is better with heterogeneity is that learning is recency based and performance in the final block of the experiment depends primarily on the statistics of the distractors in the penultimate block. If recency drives learning, one might expect it to be
impossible for observers to learn a generalizable distractor rejection strategy in a blocked distractor environment.

Conflicting with this account, past work from our lab (Vecera et al., 2014) found that when observers learn to ignore a particular salient distractor, they maintain this learned distractor rejection template over the course of a few blocks in the experiment. If observers retain a learned distractor rejection template over the course of the experiment and these templates have any imprecision such that a green distractor rejection template leads to the rejection of all greenish distractors, then as observers gain experience with different distractors they will be more likely to immediately reject novel distractors. Additionally, from the perspective of skill acquisition, one would expect the learning we observe to be persistent and not purely recency based.

Experiment 2 was designed to resolve the apparent conflict between the result of Experiment 1, which suggests that learning is short lived, and results of Vecera et al. (2014), which suggests that learning persists for the duration of the entire experiment. Perhaps generalization may occur in principle with homogeneous environments, but there simply was not a sufficient number of homogeneous environments in Experiment 1 or a sufficient number of trials to observe generalization. To test this hypothesis, in Experiment 2, we presented a sequence of six, not four, homogeneous environments, and we extended the length of each block from 48 to 144 trials. Observers searched for a circle among heterogeneously shaped distractors over six blocks. A color-singleton appeared in half the trials, and the color of the color-singleton distractor was blocked. If learned distractor rejection is purely recency based, then increasing the number of trials and different color-singletons will not improve observers’ ability to effectively ignore color-singleton distractors without previously experiencing them.

**Experiment 2**
Experiment 2 investigated whether learned distractor rejection is purely recency based or if learned distractor rejection, like skill learning, persists across longer time scales. To distinguish between these hypotheses, we expanded the color-singleton distractor set from four colors to six and extended the length of each block to 144 trials. Observers will begin the experiment with a 60 trial training-block as in Experiment 1, and by the end of the fourth block of trials, observers will have performed 636 trials searching for a constant target shape. By performing many trials, we hope to provide observers with a highly trained target template and robust distractor rejection templates, producing a strong test of distractor rejection templates’ ability to persist across the experiment. If learned distractor rejection is purely recency based, then each time thesalient color-singleton changes color, it should interfere with observers’ allocation of attention, irrespective of the number of color-singletons previously experienced. If learned distractor rejection is robust and persistent, then color singletons will lose their ability to interfere with the allocation of attention as observers progress through the experiment, even after changes in the singleton’s color.

**Methods**

*Participants.* 22 observers completed the experiment for partial course credit. All reported normal or corrected to normal vision.

*Apparatus.* Experiment 2 used the same apparatus as Experiment 1.

*Stimuli and Procedure.* Experiment 2 used the same methods as in Experiment 1 except for the following changes. Observers completed six blocks of trials instead of four, which means the observers experienced two additional color-singleton distractors (six total) and the test blocks were lengthened to from 48 to 144 trials. The two additional color-singleton colors were blue (RGB 0, 0, 255) and teal (RGB 0, 255, 255).
Results

We used the same data trimming techniques as in Experiment 1. This trimming eliminated less than 0.005% of the data. Four observers were excluded due to accuracy 2.5 standard deviations below the mean accuracy of all observers.

Because our power law fitting analysis robustly expresses the continuous nature of learned distractor rejection, we report only this analysis in Experiments 2 and 3. A bin based analysis produces the same pattern of results, but is not included to minimize redundancy.

In the Blocked group of Experiment 1, observers’ RTs in the singleton present and absent conditions converged after about 15 trials in each condition (see Figure 4). Observers’ performance changed as a function of experience in these initial trials, but after the two functions converge, performance did not change as a function of experience, and noise produced the remaining variability. Experiment 2 uses 144 trial blocks, increasing the proportion of data representing trials after the singleton present and absent conditions converge and decreasing the proportion of data representing pre-convergence performance. As one might expect, the initial trials of a block provide the most information for constraining a power function fit. To demonstrate this point, we conducted a simple simulation with noisy synthetic data generated from a power function. This simulation showed that modeling the data with more of the (noisy) tail led to poorer recovery of power-function parameters. The explanation for this phenomenon is that as the power function flattens, noise in the data overwhelms the signal. To combat this phenomenon, in Experiment 2 we fit power functions to only the first 24 singleton present and absent trials (the same number as Experiment 1).

Experiment 2 investigates whether learned distractor rejection is recency based or if learning persists across the experiment. To examine whether learning persists across the
Experience and distractor rejection

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experiment, we fit separate power functions to observers’ data from blocks 1-2, blocks 3-4, and blocks 5-6. The average best-fit power functions fit appear in Figure 6. The average RMSE from functions fit to blocks 1-2 data sequences was 0.96 in the singleton present condition and 0.99 in the singleton absent condition. The average RMSE from blocks 3-4 was 0.98 in the singleton present condition and 0.99 in the singleton absent condition. The average RMSE from blocks 5-6 was 1.02 in the singleton present condition and 1.0 in the singleton absent condition. To investigate whether learning persists across the experiment we used the parameter representing initial performance, $\beta$, in a 3x2 repeated measures ANOVA with the factors Singleton Condition (Present; Absent) and Block Order (blocks 1-2; blocks 3-4; blocks 5-6). The ANOVA found a main effect of Singleton Condition, $F(1,17) = 7.07, p < 0.05, \eta_p^2 = 0.29$. The ANOVA also found a main effect of Block Order, $F(2, 34) = 4.38, p < 0.05, \eta_p^2 = 0.32$. An interaction subsumed both these main effects, $F(2,34) = 7.22, p < 0.01, \eta_p^2 = 0.57$, indicating that $\beta$ changed across singleton condition and Block. Planned comparisons found $\beta$ was greater in the singleton present than absent conditions of blocks 1-2 and blocks 3-4, $t(17) = 3.08, p < 0.01$ and $t(17) = 3.08, p < 0.01$, respectively. $\beta$ was not greater in the singleton present than absent condition of blocks 5-6, $t < 1$. These tests indicate that color singletons initially slowed RTs in blocks 1-2 and blocks 3-4, but not blocks 5-6.

Next, we investigated whether the parameter representing learning rate, $\alpha$, varied across the experiment. $\alpha$ was greater than zero in the singleton present condition of blocks 1-2, $t(17) = 3.94, p = 0.001$, blocks 3-4, $t(17) = 5.78, p < 0.001$, and blocks 5-6, $t(17) = 3.72, p < 0.01$. $\alpha$ was also greater than zero in the singleton absent condition of blocks 1-2, $t(17) = 3.37, p < 0.01$ and blocks 5-6, $t(17) = 4.04, p < 0.001$. $\alpha$ was not greater than zero in blocks 3-4, $t(17) = 1.65, p > 0.11$. $\alpha$ values greater than zero in the singleton absent conditions indicate that observers
Experience and distractor rejection

improved performance even in trials without a color singleton. Importantly, the amount intra-block learning changed across the experiment as expressed by greater $\alpha$ values in the singleton present condition of blocks 1-2 than blocks 5-6, $t(17) = 2.88 \ p = 0.01$, and greater $\alpha$ values in the singleton present condition of blocks 3-4 than blocks 5-6, $t(17) = 2.49, p < 0.05$. The $\alpha$ values from the singleton present condition did not differ between blocks 1-2 and blocks 3-4, $t < 1$.

**Discussion**

Experiment 2 found that when a novel color singleton was introduced at the beginning of blocks 1-4, attentional control failed to suppress the singleton. However, after about 15 experiences with the color singleton, observers were able to effectively reject the color singletons and color singletons ceased to interfere with the allocation of attention, replicating our previous results (Vatterott & Vecera, 2012) and the Blocked group of Experiment 1. In the initial trials of blocks 5 and 6, a novel color singleton did not interfere with the allocation of attention, in contrast to the initial trials of blocks 1-4. This finding suggests that learned distractor rejection, like skill learning, is not entirely recency based because even in a homogeneous stimulus environment, observers can learn to effectively reject salient color-singletons without previously experiencing these items. Thus, observers do retain some form of learning that persists over the time course of the experiment, indicating that learned distractor rejection operates over multiple time scales: the short time scale of learning to suppress a novel color singleton early in blocks 1-4, and the long time scale of learning to suppress a novel color singleton at the start of blocks 5 and 6.

Experiment 2 has a limitation, however, in that we cannot determine whether long time-scale learning arises from the greater number of distractor colors rejected or from the greater overall number of trials performed. That is, either performing more trials generally or
experiencing more color-singleton distractor identities might have led to inter-block learning, which was expressed through the ability to immediately reject novel color singleton distractors in blocks 5 and 6. Experiment 3 sought to decouple these two factors by maintaining block length, but limiting the number of different color-singletons.

Experiment 3

Experiment 3 sought to examine what factor enabled observers in Experiment 2 to reject novel color-singleton distractors without previously experiencing them—whether it was the number of different distractor identities experienced or the overall number of trials. To distinguish between these two factors, observers in Experiment 3 performed the same experiment as Experiment 2, but the color singleton’s color remained constant in blocks 1-4. Then observers experienced new color singletons in blocks 5 and 6. If performing more trials enabled observers to immediately reject salient color-singletons, then observers should immediately reject color singletons in blocks 5 and 6. If experiencing more color singletons enabled observers to immediately reject salient color-singletons, then color-singletons should initially interfere with the allocation of attention in blocks 5 and 6 because observers will only have experienced one color-singleton going into block 5 and two color-singletons going into block 6.

Methods

Participants. Twenty observers completed the experiment for partial course credit. All observers reported normal or corrected to normal vision.

Apparatus. Experiment 3 used the same apparatus as Experiments 1 and 2.

Stimuli and Procedure. Experiment 3 used the same methods as Experiment 2 except that the color-singleton did not change color throughout blocks 1-4. Then, observers experienced new
color-singletons in blocks 5 and 6. Thus, in total, observers experienced new color-singletons in blocks 1, 5, and 6. This design change resulted in only three different color-singleton colors. Experiment 3 used red, orange, and purple as the color-singleton colors.

**Results**

We used the same data trimming techniques as Experiments 1 and 2. This trimming eliminated less than 0.005% of the data. We excluded two observers for mean accuracy 2.5 standard deviations below the grand average accuracy.

We used the same fitting procedure as Experiment 2. To identify whether an observer’s ability to ignore novel color singletons depends on general task experience or the number of different color-singleton distractors previously experienced, we fit power functions to blocks 2-4 and blocks 5&6. The average best-fit power functions from blocks 2-4 and blocks 5&6 appear in the upper and lower panels of Figure 7, respectively.

The average RMSE in blocks 2-4 was 0.95 in the singleton present condition and 0.95 in the singleton absent condition. The average RMSE in Blocks 5&6 was 0.94 in the singleton present condition and 1.02 in the singleton absent condition.

In blocks 2-4, $\beta$, the parameter representing initial performance, did not differ in the singleton present and absent conditions, $t < 1$. Demonstrating that novel color singletons initially interfered with observers ability to allocate attention, in blocks 5&6, $\beta$ was marginally greater in the singleton present than absent condition, $t(17) = 2.01$, $p = 0.06$. In blocks 2-4, $\alpha$, the parameter representing learning rate, was not greater than zero in the singleton present condition, $t(17) = 1.87$, $p > 0.07$, nor in the singleton absent condition, $t(17) = 1.10$, $p > 0.28$. Demonstrating that observers learned to ignore the color singleton in blocks 5&6, $\alpha$ was greater than zero in the singleton present condition, $t(17) = 3.18$, $p < 0.01$. $\alpha$ was also greater than zero in singleton
absent condition of blocks 5&6, $t(17) = 2.42, p < 0.05$. Importantly, $\alpha$ was greater in the singleton present condition of blocks 5&6 than the singleton present condition of blocks 2-4, $t(17) = 2.94, p < 0.01$. $\beta$ was also greater in the singleton present condition of blocks 5&6 than the singleton present condition of blocks 2-4, $t(17) = 2.23, p < 0.05$.

We also fit a power function to data from blocks 1,5,&6. $\beta$ was greater in the singleton present condition of blocks 1,5,&6 than the singleton absent condition, $t(17) = 2.22, p < 0.05$. $\alpha$ was greater than zero in the singleton present condition, $t(17) = 3.43, p < 0.01$. $\beta$ was greater in the singleton present condition of blocks 1,5,&6 than blocks 2-4, $t(17) = 2.82, p = 0.01$. $\alpha$ was also greater in the singleton present condition of blocks 1,5,&6 than blocks 2-4, $t(17) = 3.43, p < 0.01$. Thus, including block 1 does not change the basic data pattern.

**Discussion**

Experiment 2 demonstrated that observers could learn to effectively reject novel color-singletons even with previous homogeneous distractor experience. Experiment 3 sought to clarify whether additional task experience or experience with a greater number of color-singleton identities enabled observers to immediately reject novel color-singleton distractors. Experiment 3 found that novel color singletons in blocks 5&6 interfered with the allocation of attention, but familiar color singletons in blocks 2-4 did not. Thus, unlike Experiment 2 where color singletons did not initially interfere with the allocation of attention in blocks 5&6, color singletons in the same blocks did initially interfere with the allocation of attention in Experiment 3. Because the only difference between Experiment 2 and 3 is the number of color singletons previously experienced, the results indicate that experience with multiple color-singleton identities enabled observers in Experiment 2 to immediately reject novel color-singletons.
Before entering blocks 5 and 6, observers performed 60 practice trials and four 144 trial blocks (636 total trials). This large amount of task experience did not prevent novel color singletons from interfering with the allocation of attention. Although, extensive task experience might prevent novel color singletons from interfering with the allocation of attention, even without experiencing many distinct colors, Experiment 3 demonstrates that this experience would have to be extremely extensive.

**General Discussion**

The experiments reported here sought to examine observers’ ability to reject novel, salient distractors when performing a relatively demanding visual search task. The experiments contribute to our understanding of the different factors that influence our ability to reject novel items. Past work has demonstrated that task strategy influences our ability to effectively reject items as observers do not effectively reject items unless the task encourages observers to search for specific targets rather than unique items (Bacon & Egeth, 1994; Leber & Egeth, 2006). Previous work from our lab found observers also need item-specific distractor experience to effectively reject distractors (Vatterott & Vecera, 2012). The current experiments examined the conditions that enable observers to generalize distractor rejection to novel distractors.

In Experiment 1, we first examined how a heterogeneous distractor environment might enable observers to reject novel color-singleton distractors without previously experiencing these items. Previous work on learning demonstrated that heterogeneous stimulus environments encourage more generalizable skill learning (Schmidt & Bjork, 1992). We investigated whether learned distractor rejection shares this aspect of learning. Experiment 1 found heterogeneous distractor experience did enable observers to immediately reject novel color-singleton
distractors, demonstrating that the temporal statistics of the stimulus environment is a critical factor to learning effective distractor rejection.

Experiments 2 and 3 examined whether extensive task experience and practice with multiple singleton distractor identities enables observers to reject color singleton distractors without previous experience. Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977) found extensive experience searching for the same targets among the same distractors enabled observers to immediately guide attention to the target. Although Schneider and Shiffrin never investigated whether novel distractors could disrupt attentional guidance, their work suggests that general task experience might enable observers to effectively reject distractors without previously experiencing them. We examined this possibility in a homogeneous distractor environment. Experiment 2 found that observers were able to effectively reject novel color singletons following four blocks with four different distractor colors. Either general task experience or experience with many different color-singleton identities could enable observers in Experiment 2 to immediately reject novel color-singletons. We designed Experiment 3 to distinguish between these possibilities and elucidate the conditions that enable observers to effectively reject novel color-singleton distractors. In Experiment 3, observers performed blocks 1 – 4 with the same color-singleton identity then experienced novel color-singletons in blocks 5 and 6. These novel color-singletons in blocks 5 and 6 initially interfered with observers’ allocation of attention, indicating that experience with a greater number of color singleton identities was necessary for the suppression of novel color singletons in Experiment 2.

Experiment 1 found that learned distractor rejection, consistent with other forms of skill learning, more readily generalizes after a heterogeneous stimulus environment than a series of homogeneous stimulus environments. All the experiments here also found that the power law of
practice aptly describes learned distractor rejection. These two results suggest that the same principles governing skill learning (Newell & Rosenbloom, 1981; Schmidt & Bjork, 1992) apply to learning attentional control. One interesting difference between the data presented here and typical data demonstrating skill learning is how quickly observers reach near asymptotic performance in our task. Observers rapidly learn to ignore salient distractors over the course of about 8 to 12 trials where many skill learning tasks exhibit exponential increases in task performance after hundreds of trials (Wifall, McMurray, & Hazeltine, 2014). We believe the simplicity of distractor rejection generates the rapid learning observed here. There is an active debate as to whether a power function or an exponential function better describes learning related RT reductions (Heathcote, et al., 2000). We do not mean to enter this debate. Instead, we simply intend to demonstrate that a core phenomenon of skill learning (the power law of learning) also describes learned distractor rejection. This demonstration supports the idea we have promoted in past work (Wilder, Mozer, & Wickens, 2011; Vecera et al., 2014) that attentional control is not a monolithic system that always biases attention towards either salient or task-relevant items. Instead, the attentional control system, like motor control systems, is always in a state of flux, constantly adjusting to maximize success, whether success is defined by a reward (Anderson, Laurent, & Yantis, 2011), or by ignoring a salient distractor.

Our results have important implications for current theories of attentional control. Müller's feature dimension weighting hypothesis (Müller, Heller, Ziegler, 1995) claims that observers weight feature dimensions when selecting where to allocate attention. For example, when observers search for a specific shape, they place greater attentional priority on the shape dimension than color. A strict interpretation of Müller's feature dimension weighting hypothesis predicts that once observers experience one color-singleton distractor, they should bias
attunional priorities away from the color dimension and effectively reject all future color-singletons, but this is not the case (Zehetleitner, Goschy, Müller, 2012; Vatterott & Vecera, 2012). Instead, observers must tune attention away from multiple color values. Experiment 1 qualified this and suggests trial-to-trial heterogeneity of distractor colors guides attentional priorities away from distractor colors generally. Taken together, Experiments 2 and 3 indicate that even with trial-to-trial homogeneity, extensive experience with more than four color-singletons is also sufficient to guide attentional prioritization away from all possible distractor colors.

Existing accounts of overcoming attentional capture can be reconciled with the current set of results. For instance, Theeuwes (1992) postulated that distractors more salient that the target always capture attention (for review see Theeuwes, 2010). Observers then redirect attention towards task-relevant items by disengaging attention from distractors. It is possible that observers increase disengagement speeds as they gain experience with salient distractor identities. The current set of results allow for experience-dependent changes in disengagement speeds. Folk and Remington (1998) proposed that salient items do not capture attention. Instead, salient distractors compete for attention, slowing the allocation of attention to the target, and extending RTs. It is possible that experience with a distractor reduces salient distractors ability to compete for attention. There have also been multiple demonstrations of priming in attentional control, (Kristjánsson & Campana, 2010; Lamy, Carmel, Egeth, & Leber, 2006; Olivers & Humphreys, 2003; Pinto, Olivers, & Theeuwes, 2005). We believe our results are largely consistent with these rapid experience-dependent changes in attentional control since the novelty of a salient distractor is similar to not encountering a salient distractor identity in the recent past. Although, we note that the influence of a heterogeneous distractor environment and of
experiencing many previous salient color singletons operates on a much longer time scale than typically seen in priming.

Horstmann’s work on novelty and attentional capture (2002; 2005) compliments our results. In these papers, Horstmann demonstrates a novel item’s power to capture observers’ attention. We believe our results derive from a similar mechanism. Horstmann proposed the expectancy match hypothesis (Horstmann 2005; Becker & Horstmann, 2011), which posits that unexpected items automatically capture observers’ attention. Experiment 1 compliments Horstmann’s results by demonstrating that a heterogeneous distractor environment changes observers’ expectancies such that novel color-singletons are no longer unexpected. Experiment 2 and 3 found experiencing more than four color-singleton distractors has the same effect.

Baldi and Itti (2010) proposed that Bayesian expectations could determine stimulus saliency. Under this account, more unexpected events are more salient. This model improves upon other models of saliency by quantifying saliency as not only the uniqueness of an item within a single image (Itti & Koch, 2000), but also as the uniqueness of an item across images. A model such as Baldi and Itti’s would likely produce similar results as those seen here. In Experiment 1, the heterogeneous environment could decrease the system’s expectations of what salient distractors might appear in the future and thus create less of an expectancy violation when a novel color-singleton appears. Also experiencing a multitude of different color-singleton identities might make the model less “surprised” when it experiences yet another novel color-singleton. However, purely rational accounts such as Baldi and Itti (2010) have a challenge in explaining the volume of practice that is needed for altering expectations.

Our results combine with the growing literature demonstrating that experience plays a substantial role in attentional control (Awh et al., 2012; Vecera et al., 2014). Each experiment
presented here adds important understanding to this literature. For instance, Experiment 1 demonstrates the role of learning context in experience's influence on attentional control. Experiments 2 and 3 then specify how distractor experience influences attentional control. Specifically, experiencing a multitude of different salient distractor identities encourages observers to strengthen goal-driven inputs to attentional control. These results demonstrate that multiple time scales of learning influence attentional control. For instance, observers use learning on short time scales to quickly learn to ignore a salient distractor after around 12 experiences with the item. Observers also use learning on longer time scales to learn to ignore novel color singletons after experiencing a previous heterogeneous distractor environment. Together these results are congruent with our hypothesis that experience changes observers’ reliance on stimulus-driven and goal-driven contributions to attentional control. Early in a task, observers heavily rely on stimulus-driven input, but as they gain experience with distractors, observers’ attentional control increasingly relies on goal-driven factors.
References


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Figure Captions

Figure 1. The left panel depicts the sequence of events for the Experiment 1 Blocked group. A 1,000 ms fixation dot preceded each search display (not pictured). The search display appeared on the screen for 5,000 ms or until response. Color-singleton distractors appeared in 50% of the trials. The color-singleton’s color changed each block. The right panel depicts the sequence of events for the Experiment 1 Mixed group. A 1,000 ms fixation dot preceded each search display (not pictured). The search display appeared on the screen for 5,000 ms or until response. Color-singletons distractors appeared in 50% of the trials. Three different color-singletons appeared intermixed within each of the first three blocks. A single novel color-singleton appeared in Block 4.

Figure 2. The upper panel depicts Blocked group RTs (in milliseconds) from blocks 1-3 as a function of Trial Position (first half of the block versus second half of the block) and singleton presence (singleton present versus singleton absent). The lower panel depicts Mixed group RTs (in milliseconds) as a function of block (blocks 1, 2, & 3) and singleton presence (singleton present versus singleton absent). Error rates from each condition appear in the base of each bar. Error bars represent 95% within-subject confidence intervals (Loftus & Masson, 1994; Baguley, 2012).

Figure 3. Experiment 1 RTs (in milliseconds) from block 4. The left panel depicts RTs from block 4 of the Blocked group as a function of Trial Position (first half of the block versus second half of the block) and singleton presence (singleton present versus absent). The right panel depicts RTs from block 4 of the Mixed group as a function of Trial Position and singleton presence. Error rates appear in the base of the bars. Error bars represent 95% within-subject confidence intervals (Loftus & Masson, 1994; Baguley, 2012).
Figure 4. Experiment 1 Blocked group average best-fit power functions; fit to RTs from blocks 1-3. The x-axis indexes the number of experiences an observer has with singleton present or absent trials within a block. For instance, the first singleton present trial in a given block is experience one. Error bars represent 95% within-subject confidence intervals of the data predicted by each observer’s best-fit power function (Loftus & Masson, 1994; Baguely, 2012). The individual points depicted this in this figure are RTs averaged across observers and blocks 1-3.

Figure 5. Experiment 1 average best-fit power functions; fit to both groups’ block 4 RTs. The upper panel depicts the Blocked group’s block 4 average best-fit power functions. The lower panel depicts the Mixed group’s block 4 average best-fit power functions. The x-axis indexes the number of experiences an observer has with singleton present or absent trials within a block. Error bars represent 95% within-subject confidence intervals of the data predicted by each observer’s best-fit power function (Loftus & Masson, 1994; Baguely, 2012). The individual points depicted this in this figure are RTs averaged across observers in block 4.

Figure 6. Experiment 2 average best-fit power functions. The upper panel depicts the average best-fit power functions from blocks 1-2. The middle panel depicts the average best-fit power functions from blocks 3-4. The lower panel depicts the average best-fit power functions from blocks 5-6. The x-axis indexes the number of experiences an observer has with singleton present or absent trials within a block. Error bars represent 95% within-subject confidence intervals of the data predicted by each observer’s best-fit power function (Loftus & Masson, 1994; Baguely, 2012). The individual points depicted this in this figure are RTs averaged across observers and blocks.
Figure 7. Experiment 3 average best-fit power functions. The upper panel depicts the average best-fit power functions from blocks 5&6. The lower panel depicts the average best-fit power functions from blocks 2-4. The x-axis indexes the number of experiences an observer has with singleton present or absent trials within a block. Error bars represent 95% within-subject confidence intervals of the data predicted by each observer’s best fit power function (Loftus & Masson, 1994; Baguely, 2012). The individual points depicted this in this figure are RTs averaged across observers and blocks.
FIGURE 2

Experiment 1

Blocked Group: Blocks 1-3

Response Times (ms)

First Half of Blocks

3.47% 2.95%

Second Half of Blocks

3.05% 3.13%

Mixed Group: Blocks 1-3

Response Times (ms)

Block 1

2.60% 4.03%

Block 2

2.58% 4.48%

Block 3

3.88% 2.87%
FIGURE 3

Experiment 1

Blocked Group: Block 4

Response Times (ms)

<table>
<thead>
<tr>
<th></th>
<th>1st Half of Block</th>
<th>2nd Half of Block</th>
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<tr>
<td>Singleton Present</td>
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<td>4.17%</td>
</tr>
<tr>
<td>Singleton Absent</td>
<td>4.17%</td>
<td>2.60%</td>
</tr>
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</table>

Mixed Group: Block 4

Response Times (ms)

<table>
<thead>
<tr>
<th></th>
<th>1st Half of Block</th>
<th>2nd Half of Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singleton Present</td>
<td>4.17%</td>
<td>3.03%</td>
</tr>
<tr>
<td>Singleton Absent</td>
<td>2.08%</td>
<td>0.17%</td>
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</tbody>
</table>
FIGURE 5

Experiment 1
Blocked Group; Block 4

Mixed Group; Block 4

Response Times (ms)

# Experiences

Singleton Present
Singleton Absent
Experiment 2

Blocks 1-2

Blocks 3-4

Blocks 5-6

- Singleton Present
- Singleton Absent