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Citation	Lien, M. C., Ruthruff, E., & Naylor, J. (2014). Attention capture while switching search strategies: Evidence for a breakdown in top-down attentional control. <i>Visual Cognition</i> , 22(8), 1105-1133. doi:10.1080/13506285.2014.962649
DOI	10.1080/13506285.2014.962649
Publisher	Taylor & Francis
Version	Accepted Manuscript
Terms of Use	http://cdss.library.oregonstate.edu/sa-termsofuse

Lien, M.-C., Ruthruff, E., & Naylor, J. (2014). Attention capture while switching search strategies: Evidence for a breakdown in top-down attentional control. *Visual Cognition*, 22(8), 1105-1133.

**Attention Capture While Switching Search Strategies:
Evidence for a Breakdown in Top-Down Attentional Control**

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Word Count: 10521 (including references)

Keywords: Attention Capture; Visual Search Strategy; Cognitive Control and Switching

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Abstract

Whereas capture experiments typically repeat a single task many times, real world cognition is characterized by frequent switching. Lien, Ruthruff, and Johnston (2010) reported that the attentional control system can rapidly and fully switch between different search settings (e.g., red to green), with no carryover and no inter-trial priming. The present study examined whether this impressive flexibility is possible even when the switch is not between different features along the same dimension, but between mutually incompatible search modes. On each trial, participants were prompted to find and identify the letter that was in a specific color (feature search mode) or was uniquely colored (singleton search mode). Within each block, search mode was either pure or mixed; the mixed blocks contained a fixed AABB search sequence (singleton-singleton-feature-feature) in Experiment 1 and a random sequence in Experiment 2. The target display was preceded by a non-informative cue display containing a non-target color singleton. In pure feature search blocks, these irrelevant singleton cues were generally unable to capture attention, replicating previous findings of “contingent capture.” In mixed blocks, however, irrelevant color singletons captured attention on feature search trials. This breakdown indicates a limitation in the sharpness of attentional control following mode switches, which might be common in the real world.

Attention Capture While Switching Search Strategies:

Evidence for a Breakdown in Top-Down Attentional Control

A full understanding of the processes that lead to visual/spatial attention allocation is of great interest to basic researchers as well as applied researchers, because of the potential impact on operators' performance. Most models acknowledge two distinct mechanisms of attentional control – voluntary and involuntary (e.g., Bundesen 1990; Duncan & Humphreys, 1989; Posner, 1980; Yantis, 2000). Voluntary attention control refers to deliberately attending to a stimulus whereas involuntary attention control refers to unintentionally allocate attention to a stimulus. These two control mechanisms allow us to adapt to our environment, which contains both predictable and unpredictable sources of visual information.

While there is general agreement regarding what factors drive voluntary attention control, there are two divergent views regarding involuntary attention control (for a review, see Ruz & Lupiáñez, 2002). Some researchers have claimed that involuntary attention is driven by stimulus salience (e.g., Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Hickey, McDonald, & Theeuwes, 2006; Schreij, Owens, & Theeuwes, 2008; Theeuwes, 1991, 1992, 1994, 2004). According to this *stimulus saliency view*, certain types of salient objects (e.g., a color singleton that contains unique color among homogenous background color objects or an abrupt onset) have the power to capture attention irrespective of current task goals (e.g., Abrams & Christ, 2003; Al-Aidroos, Guo, & Pratt, 2010; Burnham & Neely, 2008; Forster & Lavie, 2011; Yantis & Jonides, 1984). Other researchers, however, have argued that involuntary attention capture is contingent on the top-down goal (e.g., Folk & Remington, 1998, 1999; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). According to this *contingent capture view*, involuntary attention capture by an object occurs not because of its salience but rather because it

contains features that match what the observer is currently looking for (e.g., Ansorge & Heumann, 2003; Eimer & Kiss, 2008; Folk et al., 1992; Gibson & Kelsey, 1998; Lien, Ruthruff, & Cornett, 2010; Lien, Ruthruff, Goodin, & Remington, 2008; Noesen, Lien, & Ruthruff, 2014). The goal of our present study was not to resolve the debate but rather to better characterize the boundary conditions for contingent capture. More specifically, we examined whether it holds even when people must constantly switch between different search strategies, as might often be the case in the real world. Before we discuss our approach, we first overview previous evidence for the two divergent views of involuntary attention control.

Capture by Salience vs. Contingent Capture

Theeuwes (1991, 1992) reported that a salient color singleton captured attention even though it was presumably irrelevant to the observer's current task goal, suggesting capture driven solely based on bottom-up salience. In one of his experiments (1991, Experiment 2), participants indicated the orientation of the line segment embedded within a uniquely colored circle (red or green) or a unique shape (circle or square) among homogenous background distractors. For some trials, one of the background distractors had a unique feature in the irrelevant dimension: an irrelevant color singleton when searching for the target shape singleton or an irrelevant shape singleton when searching for the target color singleton. When participants searched for the target shape singleton, Theeuwes found that response time (RT) to the target was slowed by the presence of an irrelevant color singleton in a nontarget location. Interference, however, was not found in the presence of an irrelevant shape singleton when searching for a target color singleton. Theeuwes argued that attention priority is determined by object salience – the most salient object in the display (in his case, the color singleton rather than the shape singleton) involuntarily captures attention, irrespective of the current task goal (see also Hickey et al., 2006; Kim &

Cave, 1999; Theeuwes, 2004).

Folk et al. (1992) reached the opposite conclusion with a cuing paradigm, in which a target display was preceded by a non-informative cue display containing a salient singleton cue. The cue was either an abrupt onset cue (white dots around one of the 4 peripheral boxes) or a color singleton (sets of dots around all 4 peripheral boxes, only one of which was red). The target was defined either by having an abrupt onset (a single white “X” or “=” appeared in one of the 4 peripheral boxes) or by color (characters onsetted in each of the 4 peripheral boxes but only one was colored red). The cue was 25% valid and 75% invalid with respect to the target location, creating no incentive for participants to direct their attention to the cue. Folk et al. reasoned that if the salient cue captured attention, despite being non-informative, then one would expect faster RT to the target appearing in the same location as the cue (valid trials) than the target appearing in a different location as the cue (invalid trials). This difference in performance is known as a *cue validity effect*, which has been used as an index of attention capture by the cue. Critically, they found a significant cue validity effect only when the cue type and the target type matched (e.g., the color cue for the color target). They therefore argued that capture is not determined by stimulus salience but rather is contingent on the top-down task goal (see also Bacon & Egeth, 1994; Eimer & Kiss, 2008; Folk & Remington, 1998; Gibson & Kelsey, 1998; Lien, Ruthruff, & Cornett, 2010; Lien et al., 2008; Noesen et al., 2014).

The present study is inspired by informal anecdotes of attention capture by seemingly irrelevant objects in the real world (such as a bug scurrying across the carpet), which conflict with observations of pure “contingent” capture in the laboratory. This raises the question of what might be different about the real world that could account for the different results. One possible answer is that whereas capture experiments typically involve a single task, with a single

finding property (e.g., the color red), repeated hundreds of times, the real world is characterized by constant switching (either between different target-finding features or different task-sets). While driving, one might be watching the car in front, then checking the speedometer, then checking the time, then looking for a red light, etc. Perhaps contingent capture is prevalent under ideal conditions, but breaks down while switching. A related concern is that contingent capture might actually be a result of bottom-up priming of the repeated target-finding feature, rather than true top-down control (for reviews, see e.g., Awh, Belopolsky, & Theeuwes, 2012; Lamy & Kristjánsson, 2013; Theeuwes, 2013).

With this concern regarding repetition of attentional sets in mind, Lien, Ruthruff, and Johnston (2010) examined whether switching between different top-down task sets (e.g., from looking for red to looking for green) would undermine top-down control and thereby increase the likelihood of capture by task-irrelevant objects. They used a hybrid cuing/task switching paradigm. Participants were to identify the letter in the target color amongst letters in other colors. Establishing a top-down setting for the target color was necessary to perform the task correctly. Unlike most previous capture studies, however, target color changed from trial to trial, as indicated by a prompt appearing at the beginning of each trial – a single letter (e.g., “R” for red, “G” for green) inside the central box. Depending on the experiment, participants performed the tasks in a fixed, repeating AABB sequence (e.g., Red-Red-Green-Green) or a random sequence (unpredictable on a trial-by-trial basis). Prior to the target display, a cue display containing a salient cue (either a color singleton or an abrupt onset) appeared, which could potentially capture participants’ attention. As in Folk et al., (1992), the cue was non-informative (25% valid and 75% invalid). Lien et al. (2010) found a substantial cue validity effect for the task-relevant cue (the color singleton cue containing the target color) but not for distractor-color

singletons, neutral color singletons, and abrupt onsets. This pattern of results occurred regardless of the task sequence (fixed vs. random). Furthermore, there was no inter-trial priming: participants were able to completely ignore a cue in the target color from the previous trial. These authors concluded that even constant switching of control settings did not make the attention control system more vulnerable to capture by task-irrelevant objects.

However, one could argue that the kind of switch required in Lien, Ruthruff, and Johnston (2010) – between different target colors – was actually a relatively easy change to instantiate. One need only change a single parameter setting. Their finding of minimal switch costs (averaging 35 ms across Experiments 2 and 3) supports this point. Perhaps capture by task-irrelevant objects would emerge with a much more complicated and difficult switch. The present study addressed this issue, looking for evidence of capture by task-irrelevant objects when participants switched between different search modes. We examined two commonly proposed modes, known as singleton search and feature search.

Singleton Search Mode vs. Feature Search Mode

To reconcile the discrepancy between the salience capture view proposed by Theeuwes and his colleagues (e.g., Hickey et al., 2006; Schreij et al., 2008; Theeuwes, 1991, 1992, 2004) and the contingent capture proposed by Folk and his colleagues (e.g., Folk & Remington, 1998, 1999; Folk et al., 1992, 1994), Bacon and Egeth (1994) considered two possible search modes people might utilize while searching for a target – singleton search mode and feature search mode. When the target is different from a homogenous background on one dimension or feature (i.e., is a singleton, as in Theeuwes, 1991, 1992), participants could, in principle, search for the specific discontinuity that defines the target (e.g., the unique color when the target is a red circle among homogenous green circles). However, a strategy of searching for any discontinuity might

actually produce faster target localization. Use of such a *singleton search mode* to find the target, therefore, would make the observer susceptible to capture by all singletons – even task-irrelevant ones – as found by Theeuwes (1991, 1992). When the target is not a singleton, but is defined by a specific feature (e.g., redness), participants could not use singleton detection mode and would instead need to search only for that specific feature; this strategy is known as *feature search mode*.

To test whether the capture is driven purely by salience even when singleton search mode is not feasible, Bacon and Egeth (1994) followed Theeuwes' (1991, 1992) design but ensured that the target was no longer a shape singleton. Instead of presenting only one target shape singleton in the display (a circle among homogenous diamonds) as in Theeuwes' study, Bacon and Egeth (1994; Experiment 2) included two or three target shapes containing the same line segment orientation (e.g., three target circles with a vertical line segment amongst four distractor diamonds). Similarly, in Experiment 3, they included additional unique non-target shapes (e.g., one target circle, one distractor triangle, one distractor square, and four distractor diamonds). Thus, singleton search mode in either experiment would be ineffective or even produce errors. After eliminating the use of the singleton search mode, they found that the irrelevant color singleton no longer interfered with target search performance (see also Gaspelin, Ruthruff, Lien, & Jung, 2012; Lamy & Egeth, 2003).

The Present Study

The present study examined whether rapidly changing search modes (singleton search vs. feature search) makes the attentional system more vulnerable to capture by salient but irrelevant stimuli. The switch between different search modes would appear to be much more challenging than merely changing colors (Lien et al., 2010; but see also Belopolsky, Schreij, & Theeuwes,

2010), because the switch occurs at a higher level (strategy rather than feature). Whereas a feature switch could involve a simple change in a single parameter, a strategy switch could not. It also might be representative of many real world scenarios, in which one is looking for a particular thing (e.g., the speedometer or a red stop light), then looking for anything (movement that might indicate a possible hazard), then back to looking for a particular thing.

We manipulated the target display to promote a specific search mode, such that adopting the correct search mode for each trial was necessary to find the target. As shown in Figure 1, our displays contained four peripheral boxes, equidistant from a central fixation box. For the singleton search trials, one of the letters was colored while the others were white. Thus, the target letter was defined by being a color singleton. For the feature search trials, one of the letters was drawn in the target color and others were drawn in different distractor colors. Thus, the target letter was defined by having a specific color feature. Participants were to find the only colored letter in the singleton search trials or the target-colored letter in the feature search trials. Note that use of feature search mode would not help during singleton search (except on the $\frac{1}{4}$ of trials where the target singleton happened to have that color); likewise, singleton search would be useless during feature search trials.

Participants indicated whether the target letter was a “T” or “L” by pressing a corresponding key. The target display always contained L’s and T’s in all four positions (always two of each), so a search for the target identity (L/T) would not help to locate the target. The key to our method is that the search mode varied from trial to trial, which required that the search mode be announced at the beginning of each trial. As in Lien, Ruthruff, and Johnston (2010), we used a symbol as a prompt, which remained on the screen for 1,200 ms. For singleton search mode trials, the target-defining-feature prompt for the upcoming trial was a white “=” sign;

participants were to look for the only colored letter (color singleton). For feature search mode trials, the target-defining-feature prompt for the upcoming trial was a white letter: “R”, “G”, “B”, or “Y” for red, green, blue, and yellow, respectively. Participants were to look for the prompted colored letter among other colored letters. Thus, those feature search prompts indicated not only the specific search mode but also the color of the upcoming target. Since our main focus was on switches between search modes (not between colors), each participant was assigned only one of the four target colors for all the feature search trials (e.g., always red).

Each trial began with the aforementioned prompt display, followed by a cue display containing a salient, irrelevant stimulus that might capture attention. We assessed capture for perhaps the most commonly studied type of salient stimulus: color singletons. The color-singleton cue was always in a non-target color in both Experiments 1 and 2; therefore, we call it an *irrelevant color singleton cue*. The cue appeared randomly in one of the four peripheral locations. Thus, the cue location was the same as the target location on 25% of trials (the valid condition) and different on 75% of trials (the invalid condition). Given four target locations, this frequency gives participants no incentive to voluntarily shift attention to the cue location. We measured the cue validity effect (invalid minus valid) on RT as an index of the extent to whether color singletons involuntarily capture attention. Experiment 1 varied the search mode across trials according to an alternating-runs sequence (a fixed sequence of AABB) whereas Experiment 2 varied the search mode randomly from trial to trial (announced by a prompt at the beginning of each trial).

Experiment 1

Experiment 1 was designed to examine (a) whether people can rapidly change their search modes and how much cost in performance (e.g., RT) it occurs when doing so, and (b)

whether this change increases the vulnerability to capture by salient-but-irrelevant stimuli.

Participants looked for either the only colored letter in the display (singleton search mode) or the letter in a pre-specified color while ignoring other colors (feature search mode). In pure blocks, participants performed only one search mode or the other repeatedly (i.e., no switching was required). In mixed blocks, they performed those search modes in an alternating-runs sequence (AABB; e.g., singleton–singleton–feature–feature). Thus, the search mode repeated on half of the trials and switched on half of the trials.

Both the stimulus saliency view and the contingent capture view would predict capture by color singleton cues in singleton search trials (because they are both salient and match top-down settings of finding the only colored object), so the main question is what would happen in feature search trials. If salient, irrelevant stimuli have the inherent power to capture attention, then cue validity effects from irrelevant color singletons should be observed regardless of whether the mode switched or repeated. But if attentional capture is exclusively contingent on top-down attentional settings, then little or no cue validity effects should be found because the cue always contained a non-target color.

An intermediate possibility is that the irrelevant color singleton cues fail to capture attention in the pure, feature search blocks (i.e., contingent capture), but succeed in the mixed blocks; that is, changing search strategies in the mixed blocks might renders the attentional system more vulnerable to being captured by salient but irrelevant stimuli. This pattern seems especially likely on switch trials, when one might expect a weaker set for the new search mode and a residual set for the previous search mode. However, if attentional settings can be quickly and completely reconfigured in response to an abstract search mode prompt (as reported by Lien, Ruthruff, & Johnston, 2010), then no capture by irrelevant color singleton cue would be

observed for the feature search trials in mixed blocks, even when the mode switches.

Method

Participants. Ninety-two undergraduate students from Oregon State University participated in exchange for extra course credit. Their mean age was 20 years (range: 18-29; 64 females and 28 males). Twenty-three participants randomly assigned to respond to each of red, green, blue, and yellow letters in the feature search trials (see below for details regarding the target color assignment in the feature search trials). All reported having normal or corrected-to-normal acuity. They also demonstrated normal color vision using the Ishihara Test for color deficiency.

Apparatus and Stimuli. Stimuli were presented on IBM-compatible microcomputers. The average viewing distance was about 55 cm. Within each trial, four visual displays were presented in succession (see Figure 1). The fixation display consisted of five white boxes: A center box surrounded by four peripheral boxes placed at the corners of an imaginary square (top-left, bottom-left, top-right, and bottom right). Each peripheral box was equidistant from the center box (7.66° , center to center) and from adjacent peripheral boxes (10.81° , center to center). Each box was $2.39^\circ \times 2.39^\circ$, drawn with thin (0.10°) white lines.

The second display was the prompt display, announcing the color of the upcoming target to be identified. The prompt display consisted of the fixation display with a white symbol “=” (for singleton search trials), or a white letter “R,” “G,” “B,” or “Y” (for feature search trials in which the target was red, green, blue, and yellow, respectively) in the center box. The symbol and letters, in Arial font, were 1.04° in width, 1.35° in length, and 0.12° thick.

The third display was the cue display. This display was similar to the fixation display, except that one of the peripheral boxes was colored red (CIE [Yxy]: 21.3, 0.64, 0.33), green (CIE

[Yxy]: 22.78, 0.30, .60), blue (CIE [Yxy]: 9.59, 0.15, 0.08), or yellow (CIE [Yxy]: 92.78, 0.42, 0.51). The singleton's color was randomly determined but subject to the restriction that it was never the same color as the target on that trial (for both singleton and feature search trials), making it task-irrelevant. The cue appeared equally often in each of the 4 peripheral boxes and did not reliably predict the target location (25% valid and 75% invalid, with four target locations).

The fourth stimulus event was the target display, consisting of the fixation display plus the addition of a letter inside each of the four peripheral boxes. Each hemifield (left vs. right visual field) contained one "T" and one "L". The target letters, in Arial font, were 1.04° in width, 1.35° in length, and 0.12° thick. For the singleton search trials, one letter in the target display was one of those four colors (red, green, blue, or yellow) while other letters being white. Therefore, the target was always a color singleton for those trials. The target color was randomly determined, subject to the restriction that each color occurred equally often and that it was never the same as the immediately preceding color singleton cue. For the feature search trials, the four letters were displayed in four different colors (i.e., it was never a color singleton, unlike the singleton search trials). The target color was constant throughout the entire experiment for each participant. Equal numbers of participants were assigned to the red, green, blue, and yellow target colors. As in the singleton search trials, the target color was never the same as the immediately preceding color singleton cue.

Design and Procedure. As shown in Figure 1, each trial began with the presentation of the fixation display for 500 ms. Then, a prompt display announcing the search mode of the upcoming target (i.e., a color singleton or a specific color feature) appeared for 1,200 ms, followed by the cue display (always containing an irrelevant color singleton cue) for 50 ms. The

fixation display then reappeared for 100 ms, followed by the target display for 50 ms. Thus, the interval between cue onset and target onset was 150 ms. The fixation display then reappeared and remained on the screen until participants responded. Auditory tone feedback (100 ms) followed incorrect responses, whereas silence (100 ms) followed correct responses. Immediately after the feedback, the next trial began with the 500-ms fixation display.

There were two different block types –pure vs. mixed. In the pure blocks, participants received only singleton search trials or only feature search trials (repetition trials only). In the mixed block, participants were required to switch between two search modes in a repeating AABB sequence. Participants first performed two practice blocks of 24 trials each – one block was a pure singleton search block and the other was a pure feature search block. They then performed 6 experimental blocks of 88 trials each, with two blocks being pure singleton search blocks (S), two blocks being pure feature search blocks (F), and the remaining two blocks being mixed blocks (M). There were 2 possible block sequences: F-S-F-M-S-S-M-F or S-F-S-M-F-F-M-S, with the first two entries referring to the practice blocks. These sequences were fully counterbalanced across participants.

Participants were instructed to press the “C” key of a standard keyboard, which was labeled “L,” with their left-index finger when they saw the target letter “L” and to press the “B” key, which was labeled “T,” with their right-index finger when they saw the target letter “T”. They were asked to respond quickly and accurately. After each block, a summary of mean RT and accuracy were displayed, and participants were encouraged to take a short break. The next block began only when participants pressed a key to continue.

Results

Trials were excluded from analysis if RT was less than 100 ms or greater than 2,000 ms

(0.24% of trials). The first trial in each experimental block was also excluded. Error trials and trials immediately following an error trial were excluded from RT analyses. Data were analyzed as a function of group (red, green, blue, or yellow for feature search; a between-subject variable), cue validity (valid vs. invalid), block type (pure vs. mixed), mode transition (repeat vs. switch), and search mode (singleton vs. feature). The latter four were within-subject variables. Table 1 shows, for retained trials, the mean RT and proportion of error (PE).

Because block type and mode transition are not orthogonal, they cannot be included in the same analysis of variance (ANOVA). Thus, we conducted two different ANOVAs. The first ANOVA assessed the switch effect on capture and therefore included trials from the mixed blocks only. The second ANOVA assessed the mixing effect on capture and therefore included repetition trials only. *P*-values were adjusted using the Greenhouse-Geisser epsilon correction for nonsphericity, where appropriate. An alpha level of .05 was set for determining statistical significance. Reported confidence intervals were based on a 95% confidence interval, shown as the mean \pm the confidence interval half-width.

Switch Effects (Mixed Block Trials Only). In these analyses, data were analyzed as a function of group (red, green, blue, or yellow), cue validity (valid vs. invalid), mode transition (repeat vs. switch), and search mode (singleton vs. feature). Figure 2, top panel shows mean RT for each condition, averaged across groups and cue validity. Our primary interests in this data analysis were the switch cost and the cue validity effect for the two search modes. Therefore, we report only those effects below. A complete summary of the ANOVA is given in Appendix A.

The RT data showed a significant switch cost of 53 ms (repeat = 643 ms; switch = 696 ms). The switch cost on RT was larger for feature search trials (64 ms) than for singleton search trials (42 ms). A significant cue validity effect of 25 ms on RT was observed (valid = 657 ms;

invalid = 682 ms). The cue validity effect was significantly larger for the singleton search trials (40 ± 10 ms) than for the feature search trials (13 ± 11 ms). The search-mode repetition trials produced a significantly larger cue validity effect (35 ± 8 ms) than the search-mode switch trials (16 ± 13 ms). This interaction effect did not differ between singleton search mode and feature search mode, $F(1, 88) = 1.55, p = .22, \eta_p^2 = 0.02$. For singleton search, the cue validity effect was 48 ± 10 ms and 18 ± 18 ms for mode repetition and mode switch trials, respectively, $t(91) = 2.84, p < .01$. For feature search, the cue validity effect was numerically larger, albeit non-significantly, for mode repetition trials (22 ± 13 ms) and mode switch trials (12 ± 19 ms), $t < 1.0$. Further t -tests showed that cue validity effects were significant in all conditions, $t_s(91) \geq 2.07, p_s < .05$, except for the feature-search switch trials, $t(91) = 1.21, p = .2302$.

The PE data pattern was similar to the RT data pattern described above. A switch cost of .023 on PE was observed (repeat = .079; switch = .102). PE was .018 higher for the feature search trials (PE = .100) than for the singleton search trials (PE = .082). A validity effect of .022 was also obtained (PEs were .102 and .080 for the invalid and valid cue trials, respectively).

Mixing Effects (Repetition Trials Only). Data from repetition trials were analyzed as a function of group (red, green, blue, or yellow), cue validity (valid vs. invalid), block type (pure vs. mixed), and search mode (singleton vs. feature). Figure 3, top panel shows the cue validity effect on RT for each condition, averaged across groups (the RT for the mixed, switch condition was included in Figure 3 for comparison). Our primary interest in this data analysis was how the cue validity effect for the two search modes varied across block types. Therefore, we report only those effects below. The complete summary of the ANOVA is given in Appendix B.

For the RT data, the overall mean RT on repetition trials was 51 ms slower in the mixed blocks (643 ms) than the pure blocks (591 ms). This mixing cost (i.e., the slowing of mode

repetitions due to being performed within a block that also contains switches) was significantly larger for the singleton search trials (difference = 64 ms) than for the feature search trials (difference = 39 ms). A significant cue validity effect of 32 ms was observed (valid = 601 ms; invalid = 633 ms). The cue validity effect was significantly larger for the singleton search trials (47 ± 7 ms) than for the feature search trials (16 ± 8 ms). The 3-way interaction between cue validity, search mode, and block type was not statistically significant, $F(1, 88) = 1.55, p = .22, \eta^2_p = .02$. Further t -test analyses showed that the cue validity effect for singleton search trials was similar between pure blocks (47 ± 8 ms) and mixed blocks (48 ± 10 ms), $|t| < 1.0$. However, the cue validity effect for the feature search trials increased significantly from 9 ± 5 ms in the pure block to 22 ± 13 ms in the mixed block, $t(91) = -2.16, p < .05$. All cue validity effects were significantly different from zero, $ts(91) \geq 3.41, ps < .001$.

For the PE data, PE was .020 higher for the feature search trials (PE = .084) than for the singleton search trials (PE = .064). PE was also .009 higher in the mixed blocks (PE = .079) than the pure blocks (PE = .070). A significant cue validity effect of .016 on PE was observed (valid = .066; invalid = .083). The cue validity effect on PE was .014 higher for the mixed block (PE = .024) than the pure block (PE = .010). The cue validity effect on PE was also .027 higher for the singleton search trials (PE = .030) than the feature search trials (PE = .003).

Discussion

Using a fixed, repeating AABB sequence, Experiment 1 examined (1) whether people can rapidly change search mode, and (2) whether changing search modes increases the vulnerability to capture by irrelevant color singleton cues. Each participant switched between singleton search mode (looking for the only colored letter) and feature search mode (looking for the pre-defined colored letter among other distractor colors). They could either perform those

search modes repeatedly within blocks (the pure blocks) or interchangeably within blocks (the mixed blocks). As discussed above, because the defined-target-feature was different for these two search modes, it was necessary to adopt the proper search mode for the upcoming trial in order to correctly perform the task. In both types of searches, the cue display always contained a salient but irrelevant color singleton cue (i.e., never the same color as the upcoming target, in both singleton search and feature search trials).

With respect to the first question we attempted to answer, the cost of switching search modes was 53 ms on RT and .023 on PE, with the cost on RT being larger for the feature search mode (64 ms) than singleton search mode (42 ms). The cost on RT was larger than the cost observed in Lien, Ruthruff, and Johnston (2010; 41 ms and 29 ms in Experiments 2 and 3, respectively) where participants switched between color features (e.g., from red to green). However, the cost observed in the present study is still modest compared to the switch cost observed in traditional task switching studies (>100 ms cost) where participants switch between two cognitive tasks with different stimulus-response mapping rules (e.g., between judging whether a digit larger/smaller than 5 and odd/even; e.g., Roger & Monsell, 1995). We will discuss this issue more fully in the General Discussion.

The primary question of the present study was whether switching search modes increases the vulnerability to capture by irrelevant color singleton cues. In particular, we aimed to determine whether capture by irrelevant color singletons occurs on feature search trials, which normally produce little or no evidence of capture (e.g., Folk et al., 1992; Lien et al., 2008; Lien, Ruthruff, & Johnston, 2010). On pure feature search trials, a small but significant cue validity effect was observed (9 ± 5 ms). The effect increased significantly from the pure block (containing only search mode repetitions) to the mixed-block mode repetitions (22 ± 13 ms), $t(91) = -2.16$, $p <$

.05). Thus, mixing did in fact increase the susceptibility to capture. This effect of switching search modes might indicate that the attentional control setting for a search mode cannot be completely flushed when a different search mode is required for the next trial. As a consequence, one might have expected even greater cue validity effects within the mixed blocks on feature-search switch trials than feature-search repetition trials. In actuality, the cue validity effects for the feature-search trials were intermediate for the switch trials in the mixed block (12 ± 19 ms), falling in-between pure block and mixed-block repetition trials (and not significantly different from either, $|t_s| < 1.0$). Note that this trend was not observed in Experiment 2 where a random sequence was used. One speculation, though, is that foreknowledge of search mode repetition in the repeating AABB sequence in Experiment 1 might have caused participants simply rely on the previously established top-down task control setting instead of re-establishing it. As a consequence, the strength of the top-down task set would be weaker for the repetition trials than the switch trials. However, this post-hoc explanation is based on a statistically non-significant effect, so it should be regarded cautiously.

One interesting result of Experiment 1 was that while the cue validity effect for the singleton-search trials in the mixed blocked was significantly larger for the repetition trials (48 ± 10 ms) than for the switch trials (18 ± 18 ms), $t(91) = 2.84, p < .01$, the effect was not different from the effect in the pure blocks (47 ± 8 ms), $|t| < 1.0$. This finding suggests that responding to a singleton target in trial N-1 facilitated the response to a singleton target in trial N. This singleton-repetition priming effect has found to be similar in magnitude regardless of whether the irrelevant feature of the current target display was the same or different from the previous trial (e.g., a red circle among 8 green circles vs. a red circle among 8 blue circles, respectively, followed by a red circle among 8 green circles; e.g., Lamy, Bar-Anan & Egeth,

2008; Lamy, Bar-Anan, Egeth, & Carmel, 2006; Lamy & Zoaris, 2009). Furthermore, Leber and Egeth (2006a) have shown that practice on singleton search mode (e.g., searching for a unique shape) relative to feature search mode (e.g., searching for a circle among other shapes) increased capture by irrelevant color singletons (20 ms vs. 6 ms, respectively) when participants searched for the circle singleton among squares during the test phase (see also Leber & Egeth, 2006b, for a similar effect observed in a rapid serial visual presentation [RSVP] paradigm). Thus, previously-established attentional control settings might elicit lingering effects on capture by irrelevant objects on subsequent trials (see the General Discussion for further discussion).

Experiment 2

Experiment 1 used a repeating AABB sequence in the mixed blocks, giving participants foreknowledge of the upcoming search mode. It is conceivable that they fall into a sort of preparation rhythm, without deliberately preparing for and establishing the search mode prior to each trial (e.g., Gotler, Meiran, & Tzelgov, 2003; Lien, Ruthruff, & Kuhns, 2006). Arguably, a random sequence of search modes would be more representative of many real-world scenarios and perhaps – due to less predictability – be even more demanding. Experiment 2 therefore attempted to replicate the results of Experiment 1 but with a random sequence of search modes.

Method

Participants. There were 80 new participants, drawn from the same participant pool as in Experiment 1. None had participated in the previous experiment. Their mean age was 20 years (range: 18-33; 51 females and 29 males). Equal numbers of participants (20 each) were assigned to the red, green, blue, and yellow target color during feature search. All reported having normal or corrected-to-normal acuity. They also demonstrated normal color vision using the Ishihara Test for color deficiency.

Apparatus, stimuli, and procedure. The tasks, stimuli, and equipment were the same as in Experiment 1, except that the sequence of search modes in the mixed block was random.

Results

The data analysis was similar to that of Experiment 1. Application of the RT cutoffs eliminated 0.39% of trials. Table 2 shows the mean RT and PE for each condition. As in Experiment 1, we conducted two different ANOVAs – one for the switch effect on capture including trials from the mixed blocks only and the other one for the mixing effect on capture including repetition trials only.

Switch Effects (Mixed Block Trials Only). In these analyses, data were analyzed as a function of group (red, green, blue, or yellow), cue validity (valid vs. invalid), mode transition (repeat vs. switch), and search mode (singleton vs. feature). Figure 2, bottom panel shows the mean RT for each condition, averaged across groups and cue validity. Again, our primary interests in this data analysis were the switch cost and the cue validity effect for the two search modes. Therefore, we report only those effects below. A complete summary of the ANOVA is given in Appendix A.

For the RT data, a significant switch cost of 38 ms was observed (repeat = 674 ms; switch = 712 ms). As in Experiment 1, the switch cost on RT was larger for the feature search trials (cost = 47 ms) than the singleton search trials (cost = 29 ms), $F(1, 76) = 5.65, p < .05, \eta_p^2 = .07$. A cue validity of 32 ms on RT was observed (valid = 677 ms; invalid = 709 ms). The cue validity effect was significantly larger for the singleton search trials (40 ± 12 ms) than for the feature search trials (23 ± 10 ms).

As in Experiment 1, the 3-way interaction between search mode, validity, and mode transition was not significant on RT, $F < 1.0$. For the singleton search trials, the cue validity

effect was similar between repetition trials (46 ± 17 ms) and switch trials (33 ± 18 ms), $t < 1.0$.

Likewise, for the feature search trials, the cue validity effect was similar between repetition trials (20 ± 19 ms) and switch trials (27 ± 18 ms), $t < 1.0$. Further t -test analyses revealed that those cue validity effects were significantly different from zero, $t_s(79) \geq 2.05$, $p_s < .05$.

As in the RT data, PE showed a switch cost of .011 (repeat = .062; switch = .074).

Mixing Effects (Repetition Trials only). Data including only repetition trials were analyzed as a function of group (red, green, blue, or yellow), cue validity (valid vs. invalid), block type (pure vs. mixed), and search mode (singleton vs. feature). Figure 3, bottom panel shows the cue validity effect on RT for each condition, averaged across groups (the mixed, switch condition was also included in Figure 3 for comparison). Again, our primary interest in this data analysis was how the cue validity effect for the two search modes varied across block types. Therefore, we report only those effects below. The complete summary of the ANOVA is given in Appendix B.

Results were similar to those in Experiment 1. For the RT data, RT for the repetition trials was 68 ms significantly slower in the mixed blocks (674 ms) than the pure blocks (606 ms). The increased RT in the mixed blocks compared to the pure blocks was larger for the singleton search trials (difference = 83 ms) than for the feature search trials (difference = 52 ms). A significant cue validity effect of 30 ms was observed (valid = 625 ms; invalid = 655 ms). The cue validity effect was significantly larger for the singleton search trials (46 ± 10 ms) than for the feature search trials (13 ± 11 ms). However, the cue validity effect did not interact with block type, $F < 1.0$, nor did validity and block type interact with search mode, $F < 1.0$. Further t -test analyses showed that the cue validity effect for the singleton search trials was similar between pure and mixed blocks (46 ± 8 ms and 46 ± 17 ms, respectively), $|t| < 1.0$. The cue validity effect

for the feature search trials increased numerically, albeit nonsignificantly, from 7 ± 8 ms in the pure block to 20 ± 19 ms in the mixed block, $t(79) = -1.24$, $p = .2191$. The cue validity effect in each condition was significantly different from zero, $t_s(79) \geq 2.05$, $p_s < .05$, except the effect observed in the feature-search trials of the pure block, $t(79) = 1.83$, $p = .07$.

The PE data showed a pattern similar to the RT data. PE was .010 higher in the mixed block (PE = .062) than in the pure block (PE = .052). A mixing cost of .023 on PE was observed in the singleton search trials (mixed block = .068; pure block = .045), but was reversed (-.004) for the feature search trials (mixed block = .056; pure block = .060). The cue validity effect of .016 was obtained on PE (valid = .049; invalid = .065). The cue validity effect was .019 larger for the singleton search mode (PE = .025) than for the feature search mode (PE = .006).

Discussion

Experiment 2 used a random sequence of search modes in the mixed blocks; therefore, participants had no foreknowledge regarding the upcoming search mode and had to use the prompt on each trial to rapidly prepare for the upcoming target display. Surprisingly, participants were nevertheless able to rapidly switch search modes, producing only a 38 ms switch cost on RT and .011 on PE, with the cost on RT being larger for the feature search mode (47 ms) than the singleton search mode (29 ms). This cost was significantly smaller than the cost of 53 ms observed in Experiment 1 where a fixed AABB sequence was used, $t(170) = 2.14$, $p < .03$. This pattern replicated previous task switching studies, showing smaller switch cost with a random sequence than a fixed AABB sequence (e.g., Lien, Ruthruff, & Kuhns, 2008).

The main question in this experiment was whether changing search modes would increase the vulnerability to capture by irrelevant color singleton cues in feature search trials. The results suggest that it did. Notably, the cue validity effect was small and nonsignificant for

the feature search, repetition trials in the pure block (7 ± 8 ms). When there was a need to switch search mode randomly in the mixed block, the cue validity effect for the feature search, repetition trials increased, although non-significantly (20 ± 19 ms), $t(79) = -1.24$, $p = .2191$. However, the need to switch modes did cause a significant increase in validity effects on the switch trials (27 ± 18 ms), $t(79) = -2.08$, $p < .05$. Thus, even though participants were able to rapidly switch search modes, showing relatively small switch costs, newly established control settings for the feature search mode were not strong enough to prevent capture by the irrelevant color singleton cue.

General Discussion

We examined whether switching search strategies made the attentional system more vulnerable to capture by salient-but-irrelevant stimuli. Lien et al. (2010) reported that the attentional control system is able to rapidly and fully switch between different target settings, at least in the relatively simple case of changing colors (e.g., red target to green target). The broad theoretical issue addressed in the present study is to what extent such an impressively quick and complete reconfiguration of the task setting would also be evident with a more demanding attentional control set switch – changing between fundamentally different search strategies (feature vs. singleton). As noted above, this kind of switch might occur frequently in real-world settings.

We manipulated the target display in a cuing paradigm to require either singleton search mode (looking for the only color singleton) or feature search mode (looking for the pre-specified color). Within the mixed blocks, the search mode sequence was either fixed (Experiment 1; AABB) or random (Experiment 2). Note that using the feature search mode in the singleton search display would be ineffective, and vice versa. Thus, adopting an appropriate search mode

is necessary to perform the task accurately. The question is whether switching between different search modes from trial to trial would make the attentional system more vulnerable to capture by a salient-but-irrelevant stimulus (a color singleton) in the cue display.

Main Findings of the Present Study

There were three major findings in the present study. First, switching between mutually incompatible search modes results in only modest costs in target performance, with the cost being slightly but significantly larger in the fixed, repeating AABB sequence (53 ms in Experiment 1) than the random sequence (38 ms in Experiment 2), $t(170) = 2.14, p < .03$. Replicating previous task-switching studies, the latter result provides an empirical validation of the hypothesis that random sequences promote stronger advance preparation compared to fixed, repeating sequences (also see Lien et al., 2008).

Second, we observed contingent capture in the pure search blocks. Capture by the color singleton cue in the singleton search trials was large in both the pure blocks and the mixed blocks, as one would expect given that the “color singleton” was relevant to the top-down set in this context. The capture effect observed in singleton search trials provides a nice upper baseline on how much capture could be observed by color singletons on feature search trials (where they become completely irrelevant). The pooled pure-block data from Experiments 1 and 2 revealed that the validity effect elicited by the irrelevant color singleton cue was much greater in singleton search (averaging 46 ms) than in feature search (averaging 8 ms), $t(171) = 11.20, p < .0001$. The failure of attention capture by irrelevant color singleton cue in the pure, feature search trials nicely replicated previous studies on contingent capture using a fixed top-down attentional set (e.g., Ansorge & Heumann, 2003; Eimer & Kiss, 2008; Folk et al., 1992; Lien, Ruthruff, & Cornett, 2010; Lien et al., 2008). The fact that the effect is slightly above zero might reflect that

participants were not completely able to suppress singleton search during the pure feature search blocks.

Third, and most importantly, while the irrelevant color singleton cue failed to strongly capture attention during feature search within pure blocks, it did capture attention during feature search within mixed blocks. In Experiment 1, where the search mode alternated in a fixed, repeating AABB sequence, a significant cue validity effect was observed in the feature search, repetition trials (22 ± 13 ms). Thus, we observed a substantial degree of capture even though the color singletons were completely task-irrelevant (recall that the color singleton cue could never have the target color participants were looking for on that trial). In fact, this validity effect was about 46% of the validity effect observed in the singleton search, repetition trials (48 ± 10 ms), where one would expect the color singleton to strongly capture attention because it matched the top-down attentional set. These findings replicated with the random sequences of search modes used in Experiment 2 (20 ± 19 ms). Similar results were observed for the feature search, switch trials (12 ± 19 ms in Experiment 1; 27 ± 18 ms in Experiment 2). Overall, the present findings indicate that mixing search modes increases the susceptibility to capture by salient, irrelevant stimuli.

To further test this claim, we analyzed the pooled data from feature search trials in Experiments 1 and 2. A *t*-test analysis on the cue validity effect revealed greater overall capture in mixed blocks (averaged across repetition and switch trials; 20 ms) than pure blocks (8 ms), $t(171) = -2.79, p < .01$. These results further support the claim that fluctuating search modes from trial to trial increased the vulnerability to unwanted attention capture by salient, irrelevant objects.

Bottom-Up Priming vs. Top-Down Driven

Several researchers have recently raised concerns regarding the two dichotomous views of involuntary attentional capture (i.e., salience capture vs. contingent capture) and have argued that neither view alone can account for the lingering effects of past visual selection (for reviews, see e.g., Awh et al., 2012; Lamy & Kristjánsson, 2013; Theeuwes, 2013). For instance, some studies have found that searching for a specific target feature facilitated searching for the same target feature subsequently, known as the bottom-up inter-trial priming effect (e.g., Maljkovic & Nakayama, 1994; Theeuwes, 2010).

Folk and Remington (2008), however, found that the inter-trial priming effect occurs only when “parameters of the control settings are left unspecified by the nature of the task.” Adopting the color-singleton target condition from Folk et al. (1992), Folk and Remington (2008) examined whether capture by a color singleton precue on trial N depended on the target color on trial N-1. The cue display consisted of 4 sets of dots around 4 peripheral boxes; only one set (the cue) was colored (either red or green, randomly determined). The target display contained an “X” or “=” in each of the peripheral boxes, three of which were white and one was either red or green (the target). Thus, both the cue and target were color singletons. Participants identified the color singleton target (X or =) in Experiment 1 or made go/no-go response based on a pre-specified target color in Experiment 2 (e.g., green for go and red for no-go). In Experiment 1, they found a larger cue validity effect when the current cue color matched the previous target color than when it did not. This inter-trial priming effect, however, was abolished in Experiment 2 where the target feature was pre-specified for each participant. They concluded that although top-down attentional control is subject to bottom-up inter-trial priming, the override occurs only when the target feature is unspecified. Consistent with this position, Lien, Ruthruff, and Johnston (2010) also found no evidence of bottom-up capture when target feature was specified.

Since the target feature in the present study was pre-specified (e.g., always “red”), we would not necessarily expect capture by irrelevant salient objects for the feature-search switch trials due to inter-trial priming. Nevertheless, we conducted analyses to assess inter-trial priming. Specifically, the cue validity effect for feature-search switch trials in the mixed blocks was analyzed as a function of whether the cue color was the same or different as the target color on the preceding singleton-search trial. The variable had no discernable impact on the overall cue validity effect on RT averaged across Experiments 1 and 2 (same: 17 ms; different: 20 ms), $F < 1.0$. The interaction between this variable and experiment was also not significant, $F < 1.0$ (Experiment 1: same = 14 ms, different = 9 ms; Experiment 2: same = 21 ms, different = 33 ms). Further analyses revealed that the effect was also not significant for each individual experiment, $F_s < 1.0$. Follow-up analyses excluding “same” color trials produced results similar to the original analyses.¹ Thus, there was no evidence that the capture by the cue in the feature-search switch trials was influenced by the target color on the preceding singleton-search trial. These findings indeed are consistent with Folk and Remington’s (2008) results and suggest that bottom-up, inter-trial priming has little influence on the top-down attentional control when the target-defined feature is known in advance (see also Lien, Ruthruff, & Johnston, 2010; see Lamy & Kristjánsson, 2013, for a review). Past experience, such as pre-established search mode or stimulus features, might sometimes have a profound influence on current task performance. Nevertheless, such carry-over appears to be relatively weak when the task requires the establishment of a specific target-defining feature.

A similar kind of inter-trial priming might have also applied on singleton search trials within mixed blocks. Note that, on $\frac{1}{4}$ of these trials, the singleton cue had the color of the target from the previous feature search trial. To examine this possible effect, we analyzed the

singleton-search trials in the mixed blocks – collapsed across repetition and switch trials – as a function of whether the cue matched to the target-defining feature for the feature-search trials or not. Results showed that this variable had little or no impact on cue validity effects in both experiments, $F_s < 1.0$ (the effect was 34 ms vs. 33 ms. for same vs. different in Experiment 1, and was 41 ms vs. 37 ms, respectively, in Experiment 2). Therefore, there was again no evidence of inter-trial priming. Consequently, the substantial capture by the cue observed in the singleton-search trials for the mixed blocks cannot be attributed to attentional biases prompted by a residual top-down task set adopted for the feature-search trials.

Relations to Task-Switching Studies

While Lien, Ruthruff, and Johnston (2010) found evidence that participants were remarkably successful in reprogramming their attentional set to correspond to the prompt for the current trial, we found a case where a breakdown of top-down control occurs. In that study, participants were required to switch target colors (e.g., red to green). The present study, however, required a more demanding kind of switching between two incompatible modes – singleton search (searching for the only colored target) and feature search (searching for a specific target color). Results from the present study support the claim that top-down settings are not strong enough to override the capture by salience when processing demands for switching are sufficient high.

Although the processing demand for switching in the present study was relatively high relative to Lien, Ruthruff, and Johnston (2010), the switch cost observed in the present study (indexed by an increased in RT and/or PE in the switch trials comparing to the repetition trials in the mixed blocks) was still modest compared to the switch cost observed in traditional task-switching studies using bivalent stimuli, affording performance of two active tasks (> 100 ms;

e.g., a digit “6” for the parity task vs. the magnitude task; Lien & Ruthruff, 2004; Roger & Monsell, 1995). As pointed out above, traditional task-switching studies require participants to switch between two cognitive tasks with different stimulus-response mapping rules (e.g., between judging whether a digit larger/smaller than 5 and odd/even). In the present study, however, the stimulus-response mapping rule was the same (i.e., the same responses to the letter “L” or “T”) for both singleton and feature search modes, but the target-finding property changed. Once the target-finding search strategy was identified (the unique color singleton for the singleton-search trials or the prespecified target color for the feature-search trials), the same stimulus-response mapping rule (the letter “L” or “T”) applied on all trials.

Thus, it can be argued that switch costs depend much more strongly on changes in the mapping rule rather than changes in the finding property. Since bivalent stimuli in task-switching studies have the potential to trigger two active mapping rules, resulting in activation of competing responses and the need to inhibit the inappropriate mapping rule and/or the inappropriate response (see e.g., Kuhns, Lien & Ruthruff, 2007; Lien et al., 2006; Roger & Monsell, 1995). Crosstalk between mapping rules was unlikely to occur in the present study because, once attention was directed to the target, the target itself could afford only one active mapping rule (the letter “L” or “T”).

After conducting the present experiments, we became aware of a set of unpublished rapid serial visual presentation (RSVP) experiments that also showed costs of switching between feature search and singleton search (Leber, 2003). Instead of assessing capture in the cuing paradigm, Leber measured the accuracy of detecting a single target letter within a 20-letter stream. Participants performed either feature search (e.g., a red target among heterogeneously-colored distractors) or singleton search (e.g., a red target among grey distractors). Leber found

large costs of switching search modes – for both feature-search trials and singleton-search trials – at early target positions (e.g., Position 4), even with a long preparation interval.

Conclusion

The present study looked for evidence of a breakdown in top-down control by instructing participants to switch between two different search modes, commonly used in finding targets in previous attention capture studies. We found that the need to switch between search modes weakened top-down control settings, leaving the attentional system more vulnerable to capture by salient-but-irrelevant objects. The present findings suggest an explanation for why capture experiments frequently do not show capture based on salience, yet people report instances of such capture in the real world. For example, people often notice a bug or rodent running across the floor, even though they were presumably not looking for such a thing. Perhaps frequent switching of search modes, which often occurs in real world settings, results in much weaker control settings than is possible in many laboratory experiments (where the same control settings are typically used for hundreds of trials in a row), which opens the door to capture by salience. Other factors might also contribute. For example, real world capture might occur during moments where one has no control setting at all (i.e., the “default” setting proposed by Folk et al., 1992). It is also worth noting that the seemingly ubiquitous capture in the real world might be partially illusory: people reliably notice when they are captured, but not when they fail to be captured (as in inattention blindness). The instances of capture by salience might be vastly outweighed by failures of capture.

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Appendix A

A Summary Table for the ANOVAs on Response Time and Proportion of Error for Mixed Block Trials as a Function of Group (Red, Green, Blue, or Yellow), Cue Validity (Valid vs. Invalid), Mode Transition (Repeat vs. Switch), and Search Mode (Singleton vs. Feature) in Experiments 1 and 2.

Effect	<i>df</i>	Response Time			Proportion of Error		
		<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	η_p^2
Experiment 1							
Group (G)	3,88	6.30	<.001	.18	7.32	<.001	.20
Cue Validity (V)	1,88	38.24	<.0001	.30	14.65	<.001	.14
Mode Transition (T)	1,88	111.86	<.0001	.56	19.84	<.0001	.18
Search Mode (S)	1,88	<1.0	—	—	6.34	<.05	.07
G × V	3,88	1.26	.29	.04	<1.0	—	—
G × T	3,88	1.06	.37	.04	1.54	.21	.05
G × S	3,88	13.99	<.0001	.32	14.63	<.0001	.33
V × T	1,88	7.70	<.01	.08	<1.0	—	—
V × S	1,88	4.05	<.05	.04	3.52	.06	.04
T × S	1,88	9.18	<.01	.09	<1.0	—	—
G × V × T	3,88	<1.0	—	—	1.42	.24	.05
G × V × S	3,88	<1.0	—	—	2.75	<.05	.09
G × T × S	3,88	<1.0	—	—	<1.0	—	—
V × T × S	1,88	1.55	.22	.02	<1.0	—	—
G × V × T × S	3,88	1.69	.18	.05	<1.0	—	—
Experiment 2							
Group (G)	3,76	1.93	.13	.07	1.29	.28	.05
Cue Validity (V)	1,76	49.44	<.0001	.39	3.14	.08	.04
Mode Transition (T)	1,76	71.33	<.0001	.48	5.73	<.05	.17
Search Mode (S)	1,76	4.11	<.05	.05	<1.0	—	—
G × V	3,76	1.07	.37	.04	<1.0	—	—
G × T	3,76	4.11	<.01	.14	1.01	.39	.04
G × S	3,76	5.82	<.01	.19	5.31	<.01	.07
V × T	1,76	<1.0	—	—	2.68	.11	.03
V × S	1,76	6.04	<.05	.07	2.60	.11	.03
T × S	1,76	5.65	<.05	.07	3.65	.06	.05
G × V × T	3,76	1.30	.28	.05	<1.0	—	—

$G \times V \times S$	3,76	<1.0	—	—	<1.0	—	—
$G \times T \times S$	3,76	2.71	.05	.10	<1.0	—	—
$V \times T \times S$	1,76	<1.0	—	—	<1.0	—	—
$G \times V \times T \times S$	3,76	<1.0	—	—	<1.0	—	—

Appendix B

A Summary Table for the ANOVAs on Response Time and Proportion of Error for Repetition Trials as a Function of Group (Red, Green, Blue, or Yellow), Cue Validity (Valid vs. Invalid), Block Type (Pure vs. Mixed), and Search Mode (Singleton vs. Feature) in Experiments 1 and 2.

Effect	<i>df</i>	Response Time			Proportion of Error		
		<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	η_p^2
Experiment 1							
Group (G)	3,88	8.06	<.0001	.22	9.13	<.0001	.24
Cue Validity (V)	1,88	115.77	<.0001	.57	14.00	<.001	.14
Block Type (B)	1,88	132.19	<.0001	.60	4.29	<.05	.05
Search Mode (S)	1,88	<1.0	—	—	13.35	<.001	.13
G × V	3,88	<1.0	—	—	1.45	.24	.59
G × B	3,88	1.68	<.18	.05	1.13	.34	.04
G × S	3,88	24.55	<.0001	.46	20.54	<.0001	.41
V × B	1,88	3.26	.07	.04	4.70	<.05	.05
V × S	1,88	41.45	<.0001	.32	11.95	<.001	.12
B × S	1,88	16.48	<.0001	.16	2.27	.09	.07
G × V × B	3,88	<1.0	—	—	4.70	<.05	.05
G × V × S	3,88	1.86	.14	.06	3.23	<.05	.10
G × B × S	3,88	2.16	.10	.07	<1.0	—	—
V × B × S	1,88	1.59	.21	.02	<1.0	—	—
G × V × B × S	3,88	1.19	.32	.04	<1.0	—	—
Experiment 2							
Group (G)	3,76	2.49	.07	.09	2.16	.10	.08
Cue Validity (V)	1,76	58.23	<.0001	.43	11.75	<.001	.13
Block Type (B)	1,76	187.31	<.0001	.71	5.92	<.05	.07
Search Mode (S)	1,76	1.01	.32	.01	<1.0	—	—
G × V	3,76	1.75	.16	.06	<1.0	—	—
G × B	3,76	<1.0	—	—	<1.0	—	—
G × S	3,76	2.89	<.05	.10	4.58	<.01	.15
V × B	1,76	<1.0	—	—	<1.0	—	—
V × S	1,76	20.95	<.0001	.22	5.96	<.05	.07
B × S	1,76	20.97	<.0001	.22	10.64	<.01	.12
G × V × B	3,76	1.16	.33	.04	<1.0	—	—
G × V × S	3,76	<1.0	—	—	<1.0	—	—

$G \times B \times S$	3,76	<1.0	—	—	<1.0	—	—
$V \times B \times S$	1,76	<1.0	—	—	<1.0	—	—
$G \times V \times B \times S$	3,76	1.83	.15	.07	<1.0	—	—

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We thank Artem Belopolsky, Charles Folk, Andy Leber, and one anonymous reviewer for comments on earlier versions of the manuscript.

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Footnotes

1. We also compared the cue validity effect for the feature-search trials in the mixed and pure blocks after eliminating the trials where the cue color matched the target color of the preceding singleton-search trials (i.e., “same” trials). The cue validity effect was similar between both blocks in Experiment 1 (9 ms for both blocks), $t < 1.0$, but was larger in the mixed than pure blocks (33 ms vs. 7 ms, respectively) in Experiment 2, $t(79) = -2.54$, $p = .0132$. Thus, the observed increased capture in the feature-search switch trials within the mixed block in Experiment 2 cannot be attributed to the fact that the cue color in the feature-search trials sometimes matched the target color on the preceding singleton-search trials. It is even less likely to explain the increased capture observed on feature-search repetition trials in the mixed blocks for both Experiments 1 and 2.

Table 1.

Mean Response Times (RTs) in Milliseconds and Proportion of Errors (PEs) in Experiment 1 as a Function of Cue Validity (Valid vs. Invalid), Block Type (Pure vs. Mixed), Trial Type (Repeat vs. Switch), and Search Mode (Singleton vs. Feature).

	Valid		Invalid		<i>Validity Effect</i>	
	RT	PE	RT	PE	<i>RT</i>	<i>PE</i>
Pure Block						
Singleton						
Repeat	561 (8)	.048 (.005)	608 (9)	.070 (.005)	47 (4)	.022 (.005)
Feature						
Repeat	594 (10)	.082 (.008)	603 (10)	.078 (.007)	9 (3)	-.004 (.005)
Mixed Block						
Singleton						
Repeat	624 (12)	.052 (.008)	672 (12)	.088 (.009)	48 (5)	.036 (.009)
Switch	681 (15)	.080 (.011)	699 (13)	.108 (.009)	18 (9)	.028 (.010)
Feature						
Repeat	627 (13)	.083 (.011)	649 (12)	.093 (.008)	22 (7)	.010 (.010)
Switch	695 (17)	.104 (.011)	707 (13)	.118 (.010)	12 (10)	.014 (.011)

Note: The standard error of the mean is shown in parentheses.

Table 2.

Mean Response Times (RTs) in Milliseconds and Proportion of Errors (PEs) in Experiment 2 as a Function of Cue Validity (Valid vs. Invalid), Block Type (Pure vs. Mixed), Trial Type (Repeat vs. Switch), and Search Mode (Singleton vs. Feature).

	Valid		Invalid		<i>Validity Effect</i>	
	RT	PE	RT	PE	<i>RT</i>	<i>PE</i>
Pure Block						
Singleton						
Repeat	579 (11)	.034 (.004)	624 (11)	.056 (.004)	46 (4)	.022 (.004)
Feature						
Repeat	608 (11)	.059 (.006)	615 (12)	.060 (.005)	7 (4)	.001 (.005)
Mixed Block						
Singleton						
Repeat	662 (15)	.055 (.009)	708 (15)	.082 (.008)	46 (9)	.027 (.011)
Switch	697 (18)	.065 (.010)	730 (15)	.076 (.007)	33 (9)	.011 (.011)
Feature						
Repeat	653 (14)	.050 (.008)	673 (14)	.062 (.006)	20 (9)	.012 (.009)
Switch	697 (17)	.078 (.008)	724 (15)	.075 (.007)	27 (9)	-.003 (.008)

Note: The standard error of the mean is shown in parentheses.

Figure Captions

Figure 1. An example event sequence for the valid condition and the target green for the feature search trials in Experiment 1. In the real experiment, the singleton box was colored. In this example cue display, the top-left box was colored red, while the others were colored white. In the target display of the singleton search trials, the letter was colored green in the top-left box and white in the other three boxes. In the target display of the feature search trials, the letter was colored green in the top-left box, red in the top-right box, blue in the bottom-left box, and yellow in the bottom-right box.

Figure 2. Mean response times (RT) in Experiment 1 (top panel) and Experiment 2 (bottom panel) as a function of search mode (singleton vs. feature) and search mode transition (repeat vs. switch) in the mixed blocks. The data were averaged across the cue valid and invalid trials. Error bars represent the standard error of the mean.

Figure 3. Cue validity effects on mean response times (RT) in Experiment 1 (top panel) and Experiment 2 (bottom panel) as a function of search mode transition (repeat vs. switch) in the pure and mixed blocks for singleton search trials and feature search trials. Note that there were only repetition trials in the pure block. The cue validity effect was measured by subtracting mean RT in the invalid trials from mean RT in the valid trials. Error bars represent the standard error of the mean.

Figure 1

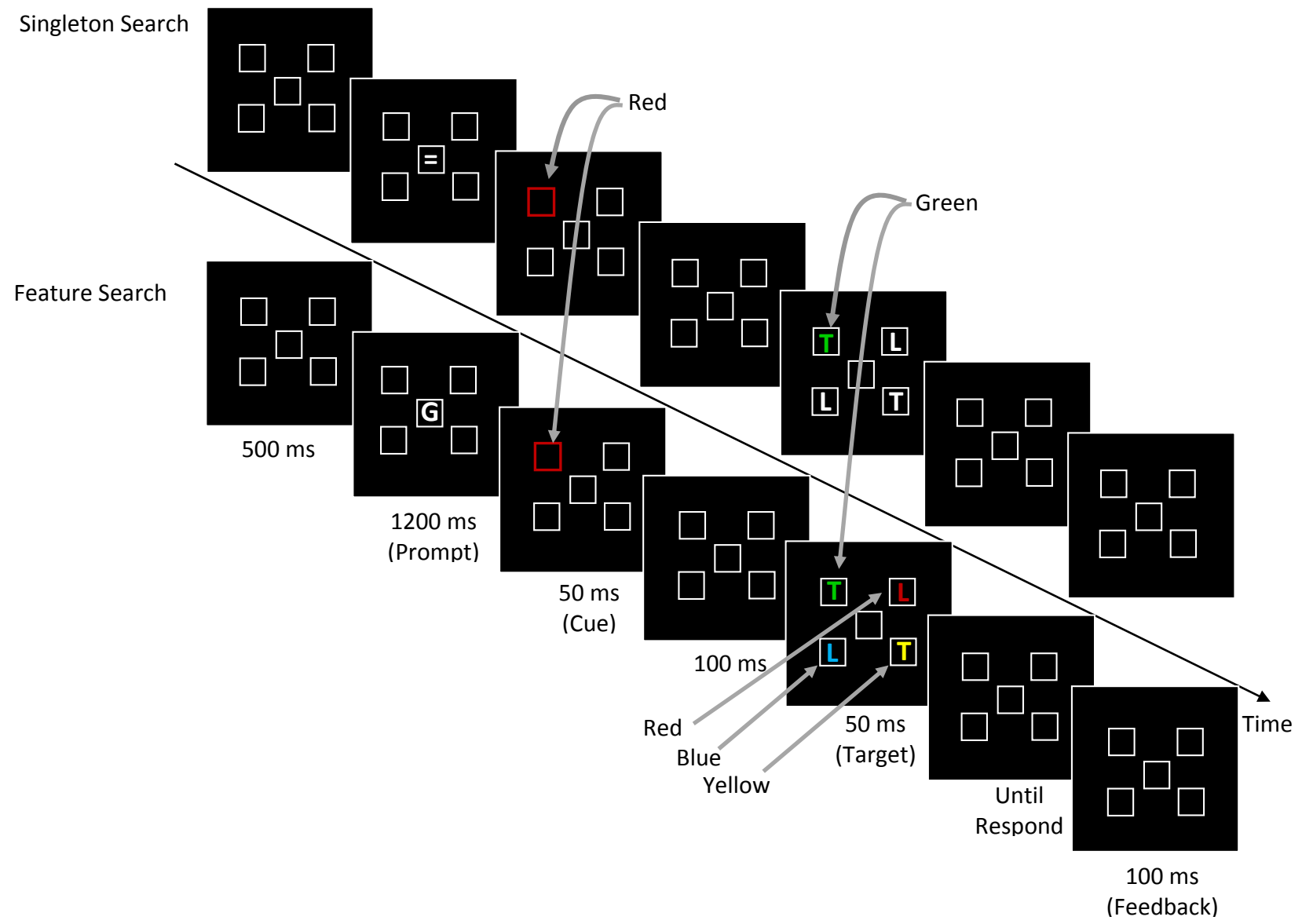


Figure 2

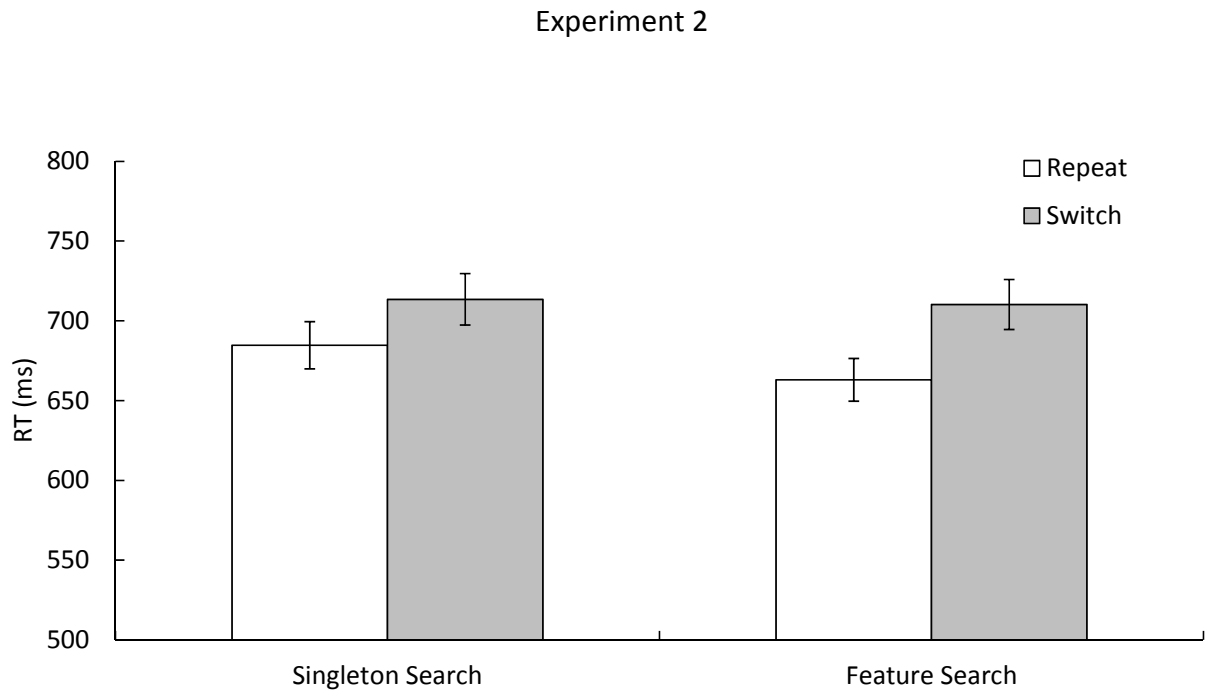
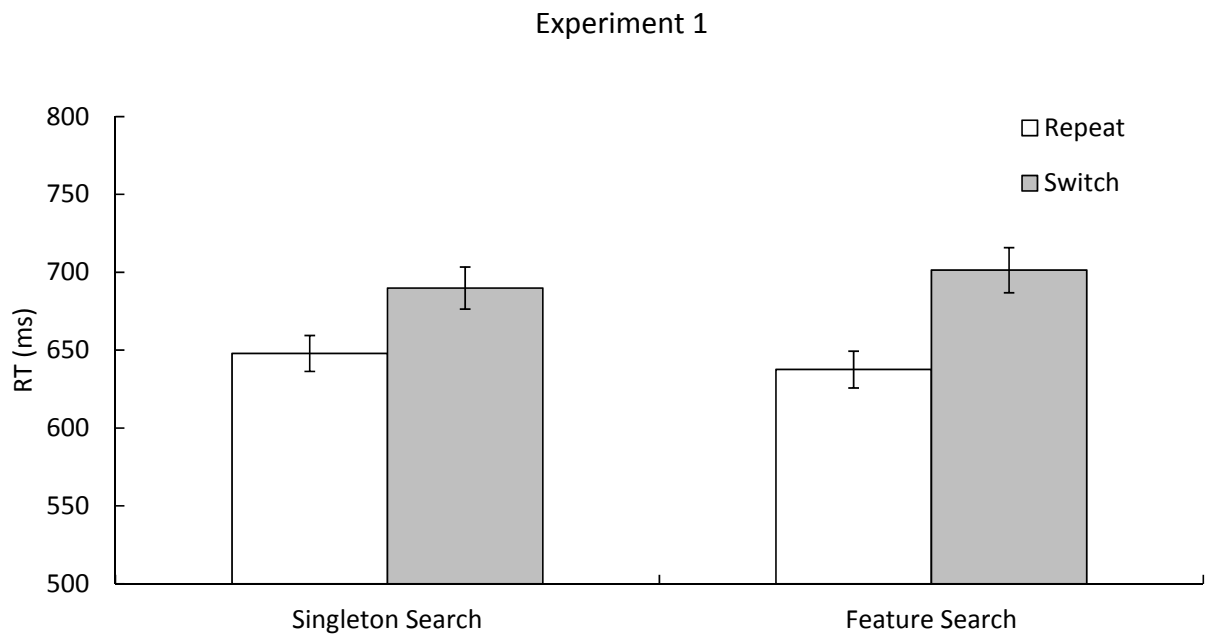


Figure 3

