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# All Set! Evidence of Simultaneous Attentional Control Settings for Multiple Target Colors

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Although models of visual search have often assumed that attention can only be set for a single feature or property at a time, recent studies have suggested that it may be possible to maintain more than one attentional control setting. The aim of the present study was to investigate whether spatial attention could be guided by multiple attentional control settings for color. In a standard spatial cueing task, participants searched for either of two colored targets accompanied by an irrelevantly colored distractor. Across five experiments, results consistently showed that nonpredictive cues matching either target color produced a significant spatial cueing effect, while irrelevantly colored cues did not. This was the case even when the target colors could not be linearly separated from irrelevantly cue colors in color space, suggesting that participants were not simply adopting one general color set that included both target colors. The results could not be explained by intertrial priming by previous targets, nor could they be explained by a single inhibitory set for the distractor color. Overall, the results are most consistent with the maintenance of multiple attentional control settings.

*Keywords:* attention, attentional control settings, spatial cueing, contingent capture



The allocation of spatial attention is subject to both voluntary and involuntary processes. For example, when driving a car in traffic, attention can be voluntarily shifted to the car in front, the speedometer, or upcoming traffic lights. Additionally, attention may shift involuntarily in response to an unexpected event, such as a pedestrian stepping onto the road or the lights of a passing police car. Early research into attentional orienting saw these two processes as distinct (Posner & Snyder, 1975; Posner, 1980). Voluntary attentional shifts, also termed *endogenous attention shifts*, were considered entirely top-down and dependent on the goals of the observer. On the other hand, involuntary, or exogenous, orienting was thought to be entirely bottom-up or stimulus-driven. That is, the capacity of an object to capture attention involuntarily was determined solely by the external properties of that object (Jonides & Yantis, 1988; Theeuwes, 1991, 1992; Yantis & Jonides, 1984, 1990).

However, other research has suggested that involuntary shifts of attention are not completely stimulus driven, but are in fact subject to top-down control. Folk, Remington, and Johnston (1992), for example, found that abrupt onset distractors captured attention when participants were searching for an abrupt onset target, but not when they were searching for a color singleton target. Conversely, color singleton distractors only captured attention when the target was also a color singleton. To account for these findings, Folk et al. proposed that the exogenous attention system is governed by attentional control settings (ACSs), which are tuned toward the relevant features or properties of the target. The role of ACSs is to ensure that attention is allocated to objects or locations that may have significance to the current task. The visual field is initially analyzed preattentively and in parallel, and attention is involuntarily allocated to any items containing the features or properties specified by the ACS. Accordingly, the capture of attention is contingent on the goals of the observer; hence, they refer to their theory as contingent attentional capture.

Following the study by Folk et al. (1992), evidence for the role of ACSs in attentional capture has grown (e.g., Ansorge, Horstmann, & Carbone, 2005; Atchley, Kramer, & Hillstrom, 2000; Burnham, 2007; Chen & Mordkoff, 2007; Folk et al., 1992; Folk, Remington, & Wright, 1994; Horstmann & Ansorge, 2006; Lien, Ruthruff, & Cornett, 2010). The majority of these studies have tested whether an ACS for a single relevant feature can overcome distraction from a salient irrelevant feature, and only relatively few studies have explored whether the limits of ACSs extend beyond setting for a single feature. The aim of the present study was to explore whether spatial attention can be guided by ACSs for multiple colors at once.

## Attentional Control Settings

Research into ACSs has shown that attention can be tuned toward a variety of different properties and features, such as object

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onsets and offsets (Atchley et al., 2000; Folk & Remington, 1998), movement (Folk et al., 1994), size (Becker, 2008), color (e.g., Ansorge & Heumann, 2003; Ansorge et al., 2005; Folk & Anderson, 2010; Folk, Leber, & Egeth, 2002, 2008; Folk & Remington, 1998; Lamy, Leber, & Egeth, 2004), and even category (Leblanc & Jolicœur, 2007; Wyble, Bowman, & Potter, 2009). Initially, Folk et al. (1992, 1994) suggested that ACSs could only be set to one of two broad categories: *dynamic discontinuities* (changes occurring over time, such as the onset or movement of an object) or *static discontinuities* (changes occurring over space, such as color or shape singletons). Thus, if observers were searching for one static discontinuity (such as a color singleton target), other static discontinuities (such as an anomalous shape) would capture attention, but dynamic discontinuities would not. However, further research indicated that the tuning of ACSs could also be more fine-grained, operating at the featural level. For example, Folk and Remington (1998) found that when participants were required to search for a red target and ignore green and white distractors, they could tune their ACS specifically to the color red. Red cues presented prior to the target captured spatial attention, but green cues did not (see also Ansorge et al., 2005; Folk & Anderson, 2010; Folk et al., 2002, 2008). Whether the attentional system is broadly or finely tuned depends on the goals of the observer and on how the target is differentiated from distractors (Bacon & Egeth, 1994; Folk & Anderson, 2010; Folk & Remington, 1998). If the target is a singleton, ACSs can be set at the level of property or discontinuity. However, if the target can only be differentiated on the basis of individual features, then observers must adopt the potentially more resource-intensive *feature-search mode* (Bacon & Egeth, 1994).

## Setting for Color

Because it is readily amenable to experimental manipulation, color has proven to be a useful tool for studying the mechanisms and parameters of ACSs. Many models of visual search suggest that some form of color information is available preattentively and can be used to guide shifts of attention, although the precise nature of this process is still debated. Wolfe's (1994, 2007; Wolfe, Cave, & Franzel, 1989) *Guided Search model* proposes that color information is preattentively coded into four broad categorical channels—red, green, yellow, and blue. Top-down control acts to weight information from one channel more than information from other channels, thereby biasing attention toward objects containing this color. Other models suggest that attention can be tuned toward more fine-grained colors. For example, Navalpakkam and Itti (2006) showed that participants could search efficiently for red targets of intermediate saturation from among red distractors of high and low saturation. The results indicated that, when necessary, attention can be tuned to quite specific regions of color space.

*Linear separability theory* suggests that set for color depends on the relationship between the target and distractor colors. Search for a color target will be efficient as long as the target can be linearly separated from the distractor colors by drawing a single line through CIE color space (Bauer, Jolicœur, & Cowan, 1996; D'Zmura, 1991). For example, if a red target is presented among yellow and orange distractors, a single line can be drawn through color space that segregates red from both orange and yellow. Thus, the red target will "pop-out" from among distractors. However, it would not be possible to separate an orange target from red and yellow distractors, and search for these intermediate targets has been shown to be inefficient (Bauer et al., 1996; D'Zmura, 1991). According to a related theory, the *relational guidance account* (Becker, 2008, 2010; Becker, Folk, & Remington, 2010), ACSs are tuned toward the direction that best separates the target from the distractors in feature space (i.e., larger, redder, more tilted). For example, for a red target among yellow and orange distractors, the ACS will be tuned toward "redder" objects, and the "reddest" item will capture attention.

## Setting for Multiple Colors

Although attentional set for color has received much interest in the literature, until recently there has been little consideration of whether attention could be set for more than one color simultaneously. Wolfe (1994, 2007) speculated that it is not possible to set for more than one color category at a time. This speculation was based on the finding that search for the conjunction of two colors (such as a red-green object among blue-red and blue-green objects) is not efficient (Wolfe et al, 1990). Adamo, Pun, Pratt, and Ferber (2008) suggested that participants may be capable of adopting different ACSs for different spatial hemifields, however, follow-up studies suggest that their findings may have reflected cognitive processes occurring after spatial attention has been allocated to the cued location (Adamo, Pun, & Ferber, 2010; Parrott, Levinthal, & Franconeri, 2010).

Some studies suggest that setting attention for multiple colors is possible, but it is dependent on linear separability. D'Zmura (1991) found efficient search for two colored targets that were linearly separable from distractors. Menneer et al. (Menneer, Cave, & Donnelly, 2009; Menneer, Donnelly, Godwin, & Cave, 2010) and Stroud, Menneer, Cave, Donnelly, and Rayner (2011) explored search for nonseparable colors in a task modeled on an airport security search. Searching for two different objects of the same color from among other colored distractor objects was just as efficient as searching for a single target type. However, when participants searched for two targets of dissimilar colors, response times were slower and participants made more eye movements to distractors (Menneer et al., 2009; Stroud et al., 2011). Because the targets in this condition were not linearly separable from the distractors, the authors suggested that participants may search for two colors by adopting one general set that incorporates both target colors. This set would also include any intervening distractor colors, and as a result attention would sometimes be allocated to distractors. However, the stimuli often contained conjunctions of target and distractor colors, and it is not clear how individual features guided spatial attention in this task.

Moore and Weissman (2010) tested whether participants could tune their ACSs to two colors while ignoring irrelevant colors. They used a Rapid Serial Visual Presentation (RSVP) task in which participants searched for a target letter in a rapid sequence of colored letters. The target letter was one of two colors (e.g., green or orange) and varied unpredictably, requiring participants to search for both colors. On some trials, a peripheral distractor was presented to the left or right of the central stream, just prior to the target. The distractor was either one of the two target colors or an irrelevant color (e.g., purple). Target-colored distractors (green or orange) captured attention and impaired the identification of subsequent targets, while irrelevantly colored distractors (purple) had no effect on performance.

The results of Moore and Weissman (2010) suggest that interference by distractors is contingent on attentional set for two target colors, consistent with the use of multiple ACSs. However, it is not clear whether these effects reflect shifts of spatial attention. Spatial attention selection can be distinguished from feature-based attentional selection, which is thought to operate across the entire visual field and enhance the processing of items containing a relevant feature without respect to their spatial location (Andersen, Muller, & Hillyard, 2009; Carrasco, 2011; Maunsell & Treue, 2006). Target-colored distractors in Moore and Weissman's task may have attracted nonspatial attention via feature-based selection. This allocation of attentional resources may have produced a temporary attentional blink (Raymond, Shapiro, & Arnell, 1992), impairing the processing of subsequent targets, consistent with findings that distractors matching the top-down attentional set capture nonspatial attention in RSVP tasks and elicit an attentional blink (Barnard, Scott, Taylor, May, & Knightley, 2004; Folk et al., 2008; see also Nieuwenstein, 2006, for nonspatial cueing by multiple target colors in an RSVP task). Thus, target-colored distractors may have interfered with performance without ever capturing spatial attention. Because Moore and Weissman did not manipulate the spatial location of the distractor with regard to the target, it is not possible to determine whether attention actually shifted to the distractor location, and hence whether spatial attention allocation is also contingent on a set for two colors. In addition, Moore and Weissman found that for target-relevant distractors, responses were more accurate when the distractor and target colors matched (e.g., green distractor, green target), than when they did not match (e.g., green distractor, orange target). This suggests that the color congruence of the targets and distractors has some effect on target identification performance. However, it is not clear from the results of Moore and Weissman whether color congruence directly affects the allocation of attention to targets in dual-target search or whether attentional capture by targets and distractors occurs independently of color congruence.

In the present study, we examined whether spatial attention can be guided by attentional control settings for two different colors. To obtain a relatively pure measure of spatial attention shifts, we manipulated spatial validity in a spatial cueing task (Posner, 1980), which has been used in many studies examining ACSs and attentional capture (e.g., Anderson & Folk, 2010; Ansorge & Heumann, 2003; Becker et al., 2010; Belopolsky, Schreij, & Theeuwes, 2010; Jonides, 1981; Folk et al., 1992, 1994; Folk & Remington, 1998, 2008; Lamy et al., 2004). In this task, participants identified a colored target letter appearing at one of four spatial locations. Prior to the target, a spatially nonpredictive colored cue was presented at one of the locations. The spatial cueing task is based on the reasoning that if the cue captures spatial attention, it should affect the time taken to detect the target. If the target happens to appear in the same location as the cue (*valid cue*), response times will be reduced, because spatial attention is already present at the target location. Conversely, if the target appears at a different location (*invalid cue*), response times will be slowed, because attention must shift a second time from the cue location to the target location. A significant difference between valid and invalid trials (the validity effect) is taken as evidence that the cue captured spatial attention. Contingent capture theory predicts that validity effects will only occur for cues that match the ACS (e.g., Folk et al., 1992). In the present study, participants searched for a target that could be one of two colors (e.g., red or green), varied unpredictably. If participants can adopt an attentional set for two distinct colors, validity effects should be present for cues matching these two colors, but not for irrelevantly colored cues. In addition, by manipulating the spatial validity of the cue, we were able to assess the effects of spatial shifts of attention independently from the effects of color congruence. If two ACSs are maintained consistently, and both guide attention in a similar manner, then spatial validity should not interact with the color congruence of the cue and target. That is, the effect of spatial capture should be the same when the cue and target are the same color (e.g., red cue, red target) and when the cue and target are different target colors (e.g., red cue, green target). However, if the cue-target color congruence does affect how attention is allocated to the target, then the size of the validity effect may vary depending on the match between the cue and target color.

## Intertrial Priming

The present study also examined the degree to which ACSs for two colors are influenced by intertrial priming. A number of visual search studies have found that when the target-relevant property varies unpredictably, performance is more efficient if the target feature is repeated across trials than if it is switched (Becker, Ansorge, & Horstmann, 2009; Folk & Remington, 2008; Leonard & Egeth, 2008; Maljkovic & Nakayama, 1994). It has been suggested that intertrial priming may explain contingent capture effects—target-relevant cues only capture attention because they are frequently primed by the target (Belopolsky et al., 2010; Theeuwes & Van der Burg, 2007; Kristjansson, Wang, & Nakayama, 2002). Although intertrial priming could not explain contingent capture effects in search for a single target (Folk & Remington, 2008), it has not been explored in search for multiple targets. If participants must search for two different target colors and cannot maintain both ACSs at once, attentional capture may be primed by the target on the previous trial. For example, if participants are searching for green and red targets, identifying a green target may prime capture by green. A green cue presented on the following trial would capture attention, while a red cue would not. Thus, cues would only capture attention when they match the target on the previous trial.

To directly assess intertrial priming and its effects on spatial attention in dual-target search, we examined whether the color of the target on trial $N$ determined capture by cues on trial $N + 1$. If the presence of attentional capture is primed by the target on the previous trial, then cueing effects should be present only when the cue color matches the target color on the previous trial. On the other hand, if participants can consistently maintain a set for both colors, all target-colored cues should capture attention, regardless of the target on the previous trials. Note that this second prediction does not rule out any effect of bottom-up intertrial priming. It is possible that even though all target-relevant cues capture attention, there is an additional bias toward the previous target color, which may result in a larger degree of capture for cues matching the preceding target. However, if participants can set for two colors at once, intertrial priming should not entirely account for the results.

## Experiment 1

Prior to examining attentional set for multiple individual features, Experiment 1 was conducted as a baseline experiment to show the effects of search for multicolored targets under color singleton mode. Participants searched for a target that could be either green or red. The target color varied randomly, and thus participants could not predict which of the two colors would appear next. A cue was presented just before the target at one of the four locations, colored either red, green, or blue. In the first experiment, the target letter was presented as a color singleton among homogenous white distractor letters. Previous research has shown that when the target is a singleton, participants do not need to search for a specific feature value, but can instead search at the level of color discontinuity (Bacon & Egeth, 1994; Folk & Anderson, 2010; Folk et al., 1994). Under this search mode, any color singletons will capture attention, whether or not they match the target colors. Thus, it was predicted that, in Experiment 1, capture would occur equally for cues that matched one of the two target colors (*relevant cues*, green or red) and cues that did not match either target (*irrelevant cues*, blue). To explore the relationship between attentional capture and color congruence, relevant cues were separated into those that matched the target color (*relevant match*, e.g., red cue, red target) and those that did not (*relevant nonmatch*: e.g., red cue, green target).

In each of the experiments in the present study, intertrial analyses were conducted to assess whether attentional capture by target relevant cues was due solely to intertrial priming. Folk and Remington (2008) showed that in singleton search mode, capture occurs for all singleton cues, regardless of the previous target. However, there is an additional bottom-up bias toward cues that are the same color as the target on the previous trial. Based on this, in Experiment 1, we expected validity effects for all cues, with greater effects when the cue matched the target on the previous trial.

## Method

### Participants

Eighteen undergraduate students were recruited from the Villanova University human participant pool. All subjects reported normal or corrected-to-normal visual acuity and color vision. Undergraduate students were compensated for their time with credit toward fulfillment of a class research requirement.

### Apparatus

A Zenith 386 microcomputer equipped with a Sigma Design, Color 400 graphics board was used to present the stimuli on a Princeton Graphics Ultrasync monitor. Participants viewed the monitor from a distance of 50 cm through lens-less goggles attached to a porthole in the front of a viewing box. The inside of the box was painted black and all but the screen of the monitor was occluded when peering through the goggles.

### Stimuli

Each trial involved three different displays (see Figure 1). The first display—the fixation display—consisted of a fixation square (.34° × .34° visual angle) surrounded by four peripheral boxes (1.15° × 1.15°) placed 4.1° above, below, to the left, and to the right of fixation. The color of the boxes and fixation square was light gray (RGB: 85, 85, 85; CIE: $x$ = .346, $y$ = .358) and the background of the CRT screen was black.

The second display—the cue display—consisted of the appearance of four sets of small circles (.23° in diameter) surrounding each of the four peripheral boxes in a diamond configuration. Cues consisted of three sets of white circles (RGB: 255, 255, 255; CIE: $x$ = .346, $y$ = .358) and one set of circles colored either red (RGB: 255, 85, 85; CIE: $x$ = .560, $y$ = .339), green (RGB: 85, 255, 85;

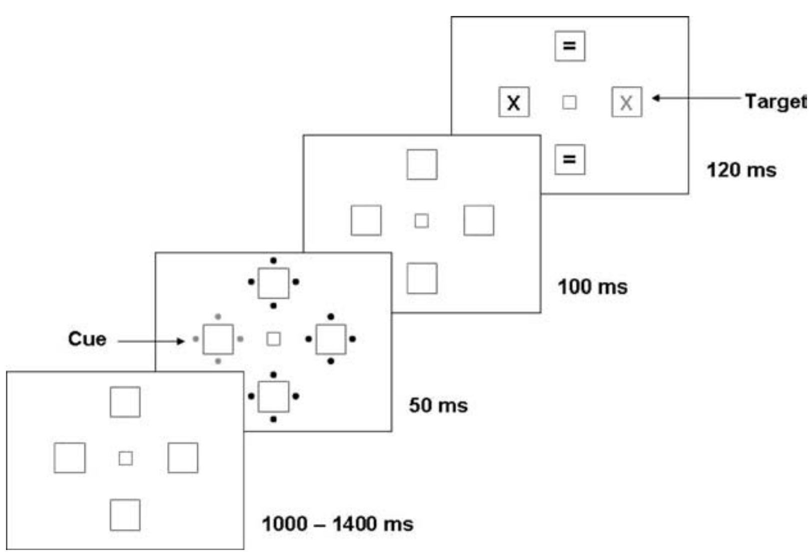


*Figure 1.* Example of a trial sequence in Experiment 1. Black and white have been inversed for illustrative purposes: stimuli are presented on a black background, and the black dots and letters shown here are white. The gray cue and target were either red or green.

CIE: $x = .326$, $y = .553$), or blue (RGB: 85, 85, 255; CIE: $x = .200$, $y = .134$).

The final display—the target display—consisted of the appearance of an “X” or an “=” in each of the peripheral boxes. These characters subtended approximately .57° visual angle in height and width. Three of the characters were white while the other was colored either red or green.

## Design

The experiment consisted of 5 blocks of 48 trials. All possible combinations of cue color or type, target color (red or green), and target identity (X or = ) appeared equally often. Within each of these combinations, the target appeared at the cued location in 25% of the trials and at a nontarget location (chosen randomly on each trial) in 75% of the trials. The identity of the nontarget characters in the target display was chosen randomly on each trial.

Three different cue conditions were possible: relevant match, relevant nonmatch, and irrelevant. In the relevant-match condition, the cue and target on a given trial were the same color (e.g., green cue followed by green target). In the relevant-nonmatch condition, the cue was one of the two target colors, but differed from the target on that trial (i.e., green cue followed by red target, or red cue followed by green target). Thus, although the cue did not match the target on the current trial, it was still relevant to the overall task goals. In the irrelevant condition, the cue was colored blue, and therefore did not match either target color and was irrelevant to the task goals.

## Procedure

Each participant was tested individually over the course of a single experimental session. Participants were instructed to respond as quickly as possible while minimizing errors. Maintaining fixation on the central square was stressed, and participants were told that failing to do so would impair overall performance. Participants were also fully informed about the relationship between cue location and target location, and they told to try to ignore the cue.

Each trial began with a 500-ms long presentation of the fixation display. After this 500-ms period, the fixation square blinked off for 100 ms and then back on for a randomly varying foreperiod of either 1000, 1100, 1200, or 1400 ms. The cue display then appeared for 50 ms, followed by the fixation display for 100 ms. The target appeared for 120 ms, followed again by the fixation display. The next trial sequence was initiated 1000 ms after a response was made or the trial terminated. Phenomenally, the four display boxes and fixation square appeared to remain on the CRT screen for the duration of each trial and intertrial interval.

Participants made a target identification by pressing the “.” key with their right index finger and the “0” key with their left index finger on the numeric keypad for the “X” and “=” targets, respectively. Response time was measured from the onset of the target display until a response was made or 1500 ms had passed. If a response was not made within this 1500-ms period, the trial was terminated. The computer emitted a 500-ms long, 1000-Hz tone to inform the participant when an error was made. Error trials were followed by a “buffer” trial, the parameters of which were randomly drawn from the set for that block. Response times for error or buffer trials were not included in the analysis.

# Results

## Response Time

Response time data were analyzed in a 2 × 3 × 2 (Target Color [red, green] × Cue Condition [relevant match, relevant nonmatch, irrelevant] × Validity [valid, invalid]) within-subjects analysis of variance (ANOVA) with an alpha level of .05. The main effect of cue condition was significant, $F(2, 34) = 11.65$, $p < .001$, $\eta_p^2 = .41$. Reaction times were faster in the relevant-match condition than the relevant-nonmatch, $t(17) = 4.54$, $p < .001$, $d = .26$, and irrelevant conditions, $t(17) = 4.92$, $p < .001$, $d = .23$, which did not differ ($p = .96$). Reaction times were also faster for valid trials than for invalid trials, $F(1, 17) = 129.53$, $p < .001$, $\eta_p^2 = .88$. As predicted, cue condition did not interact with validity ($p = .61$). Validity effects, as shown in Figure 2, were equivalent for relevant match, relevant nonmatch, and irrelevantly colored cues. No other main effects or interactions were significant ($p$s $> .16$).

## Accuracy

Overall accuracy for Experiment 1 was 95.45% (see Table 1 for accuracy rates at each level of validity and cue condition). A 2 × 3 × 2 within-subjects ANOVA revealed that accuracy was higher in the valid condition than in the invalid condition, $F(1, 17) = 11.03$, $p = .004$, $\eta_p^2 = .39$. The interaction between target color and validity approached significance, $F(1, 17) = 4.28$, $p = .05$, $\eta_p^2 = .20$, indicating that the validity effect was slightly greater when the target was green than when the target was red. There were no other significant main effects or interactions between variables ($p$s $> .15$).

## Intertrial Priming

To explore whether validity effects were dependent on intertrial priming, trials with red and green cues were divided into *primed*

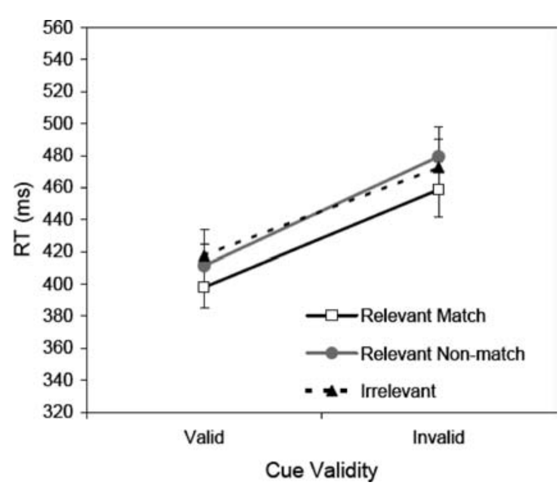


*Figure 2.* Mean response time as a function of cue condition and validity in Experiment 1. Error bars show standard error of the mean. RT = reaction time.

Table 1
*Mean Accuracy (Proportion Correct) as a Function of Cue Condition and Validity in Experiments 1–5*

| | | Cue Condition | | |
|---|---|---|---|---|
| Experiment | Validity | Relevant matching | Relevant nonmatching | Irrelevant |
| Experiment 1 | Valid | .97 | .97 | .97 |
| | Invalid | .94 | .94 | .94 |
| | Validity effect | .03* | .03* | .03* |
| Experiment 2a | Valid | .97 | .95 | .96 |
| | Invalid | .94 | .91 | .94 |
| | Validity effect | .03* | .04* | .02 |
| Experiment 2b | Valid | .94 | .90 | .90 |
| | Invalid | .90 | .84 | .91 |
| | Validity effect | .04* | .06* | −.01 |
| Experiment 3 | Valid | .93 | .90 | .90 |
| | Invalid | .89 | .77 | .88 |
| | Validity effect | .04* | .13* | .02 |
| Experiment 4 | Valid | .95 | .90 | .88 |
| | Invalid | .90 | .80 | .90 |
| | Validity effect | .05* | .10* | −.02 |
| Experiment 5 | Valid | .94 | .94 | .94 |
| | Invalid | .94 | .91 | .94 |
| | Validity effect | .00 | .03 | .00 |

* $p < .05$.

(cue color matched the target on the previous trial) or *unprimed* (cue color did not match the target on the previous trial) trials. Data were then analyzed in a 2 × 2 (Prime Condition [primed, unprimed] × 2 Validity [valid, invalid]) within-subjects ANOVA. Two further analyses were also conducted to assess the effect of color congruence. The first analysis examined whether the measurement of intertrial priming on a given trial was influenced by the cue condition of the current trial (relevant match or relevant nonmatch), by entering it as an additional factor into the ANOVA. In the second analysis, the cue condition of the previous trial (relevant match, relevant nonmatch, or irrelevant) was entered separately into an ANOVA with prime condition and validity, to account for the possibility that the color of the cue on the previous trial interfered with the target's ability to prime the subsequent cue. When the cue and target are different colors (relevant nonmatch or irrelevant), priming of the target color may be weaker than when the cue and target are the same color, and therefore intertrial priming effects may only arise in the relevant-match condition.

Experiment 1 found no evidence of intertrial priming. There was no main effect of prime condition ($p = .34$) and no interaction between prime condition and validity in the reaction time data ($p = .50$), indicating that validity effects were the same for primed and unprimed trials (see Table 2 for means and a comparison of validity effects). Further analyses showed that the relationship between prime condition and validity did not differ by cue condition of the current trial ($p = .11$) or the previous trial ($p = .68$). Similarly, there was no main effect of prime condition ($p = .97$) or interaction with validity in the accuracy data ($p = .49$), nor did these effects interact with current ($p = .95$) or previous trial cue condition ($p = .74$).

## Discussion

Consistent with previous studies (Bacon & Egeth, 1994; Folk & Anderson, 2010; Folk & Remington, 2008; Folk et al., 1994), Experiment 1 showed that when participants searched for a color singleton target, all color singleton cues captured attention. This occurred for cues that matched one of the two target colors (red or

Table 2
*Mean Reaction Time and Accuracy (Proportion Correct) as a Function of Prime Condition and Validity in Experiments 1–5*

| | | Prime condition | | | | | |
|---|---|---|---|---|---|---|---|
| | | Primed | | Unprimed | | Primed minus unprimed | |
| Experiment | Validity | $M_{RT}$ | Accuracy | $M_{RT}$ | Accuracy | $M_{RT}$ | Accuracy |
| Experiment 1 | Valid | 403.68 | .97 | 405.11 | .96 | | |
| | Invalid | 464.28 | .94 | 473.52 | .94 | | |
| | Validity effect | 60.60* | .03* | 68.40* | .02* | −7.80 | .01 |
| Experiment 2a | Valid | 742.37 | .95 | 746.96 | .97 | | |
| | Invalid | 798.83 | .92 | 789.07 | .94 | | |
| | Validity effect | 56.46* | .03* | 42.11* | .03* | 14.35 | .00 |
| Experiment 2b | Valid | 731.79 | .92 | 742.06 | .92 | | |
| | Invalid | 802.11 | .88 | 791.20 | .87 | | |
| | Validity effect | 70.32* | .04* | 49.14* | .05* | 21.18 | −.01 |
| Experiment 3 | Valid | 739.90 | .92 | 722.47 | .91 | | |
| | Invalid | 796.20 | .82 | 792.65 | .84 | | |
| | Validity effect | 56.30* | .10* | 70.18* | .07* | −13.88 | .03 |
| Experiment 4 | Valid | 685.64 | .92 | 710.15 | .93 | | |
| | Invalid | 770.53 | .85 | 771.47 | .86 | | |
| | Validity effect | 84.90* | .07* | 61.33* | .07* | 23.57 | .00 |
| Experiment 5 | Valid | 562.81 | .93 | 561.06 | .95 | | |
| | Invalid | 602.94 | .93 | 600.51 | .92 | | |
| | Validity effect | 40.13* | .00 | 39.45* | .03* | 0.68 | −.03* |

*Note.* RT = reaction time.
* $p < .05$.

green cues) and cues that did not match either target color (blue cues). The results point to the use of an ACS for color singletons, which directs spatial attention toward any color discontinuity in the display. The results also showed an effect of color congruence, because reaction times to relevant-match trials were significantly faster than trials with irrelevant or relevant-nonmatch trials. However, color congruence did not interact with spatial cueing.

As expected, all cues captured attention irrespective of the color of the previous target. However, there was no significant effect of intertrial priming whatsoever, which is somewhat inconsistent with Folk and Remington (2008), who found that the size of the validity effect was greater for cues that matched the target on the previous trial. However, bottom-up priming effects are not always present in singleton search. Eimer and Kiss (2010) used a very similar design to the present experiment, with red and green singleton targets and red, green, and blue cues, and found no effects of intertrial priming. It may be that the presence of a third colored cue interferes with or dilutes the effect of the priming.

## Experiment 2

Experiment 2 examined the effects of tuning ACSs to two colors on spatial attention. As with Experiment 1, participants searched for a target that could be one of two colors, preceded by a cue that either matched one of the two target colors or was an irrelevant color. In Experiment 2a, the target colors were red and green, and the irrelevant color was blue. In Experiment 2b, the target colors were blue and green, and the irrelevant color was red. To make singleton search mode inefficient, and to encourage search for specific features, the target was no longer presented as the sole colored item in the display. Targets were accompanied by two white letters and one irrelevantly colored letter (the distractor). For example, if participants were searching for red and green targets, the target was always presented with a blue distractor. Thus, to rapidly identify the target, participants were forced to search specifically for the target colors and to ignore the distractor color. If spatial attention can be tuned toward two distinct features, a validity effect should be present for target colored cues but not for irrelevantly colored cues.

### Method

#### Participants

Forty-three, first-year psychology students from the University of Queensland participated in Experiment 2, divided between Experiment 2a (21 participants, 18 women and 3 men; $M_{age} = 18.90$ years) and Experiment 2b (22 participants, 12 women and 10 men; $M_{age} = 21.81$ years), in return for course credit.

#### Stimuli and Apparatus

Experiment 2 was conducted in a different laboratory than Experiment 1, and Experiment 2 used a slightly differently methodology. Participants were tested individually or in groups of two or three, each seated at an individual testing booth approximately 57 cm away from an Optiplex 7800 computer with BenQ CRT monitor. The fixation display was identical to Experiment 1, except that a small plus-sign (.70° × .70°) was used as a fixation point, rather than a small square (see Figure 3). In the cue frame, dots appeared around each of the placeholders, and one of these dot configurations (the cue) was colored either red (RGB: 255, 0, 0; CIE: $x = .648$, $y = .331$), green (RGB: 0, 255, 0; CIE: $x = .321$, $y = .598$), or blue (RGB: 0, 0, 255; CIE: $x = .156$, $y = .066$). The target frame consisted of four characters (X or = ) presented in size 24 Arial bold font. Two of these characters were white and two were colored (the target and the distractor letter). In Experiment 2a, the target letter was either green or red, and the distractor letter was blue. In Experiment 2b, the target could be either green or blue, and the distractor was red.

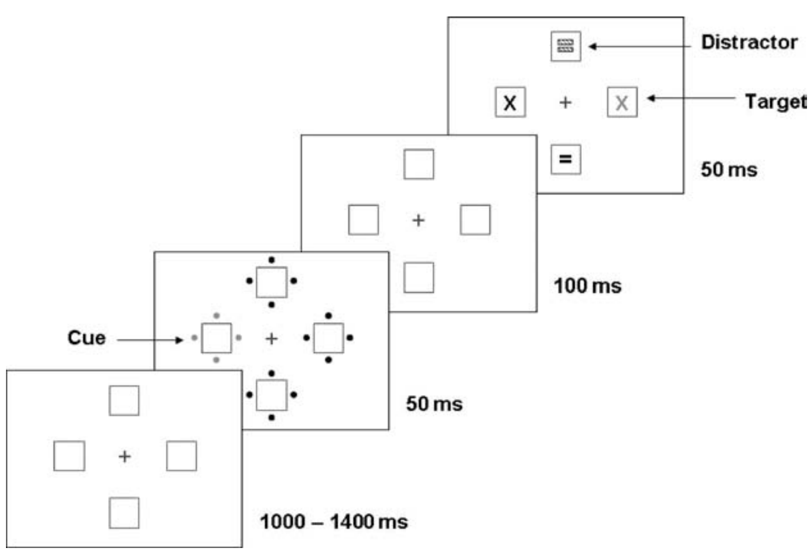


*Figure 3.* Example of a trial sequence in Experiment 2. In Experiment 2a, the gray target was red or green and the striped distractor letter was blue. In Experiment 2b, the gray target was blue or green and the striped distractor letter was red.

## Procedure

The trial sequence was the same as in Experiment 1, with the exception that the target was present for 50 ms rather than 120 ms. After presentation of the target, the fixation display remained on the display until a response was made. Participants responded by pressing the comma (,) key with the left index finger if the target was "X", and the full stop (.) key with the right index finger if the target was "=". If participants made an incorrect response, a 200-ms tone was played over headphones. Buffer trials were not presented after an incorrect response. After a response, the fixation display remained on the screen for 500 ms before the next trial began.

Once again, cues could either be relevant match (the same color as the target), relevant nonmatch (one of the target colors but not matching the target on the present trial), or irrelevant (the distractor color). Participants completed 64 trials for each combination of target and cue color. Of these, 16 were valid and 48 were invalid. This amounted to 384 experimental trials, presented in 4 mixed blocks of 96 trials, preceded by 12 practice trials.

## Results

Two participants from Experiment 2a and one from Experiment 2b with accuracy rates of 49, 51, and 51%, respectively, appeared not to understand the task instructions, and their data were removed from analyses. Trials with reaction times less than 200 ms or greater than 1500 ms (6.55% of Experiment 2a trials; 7.11% of Experiment 2b trials) and incorrect trials were removed from the data for the reaction time analyses.

## Response Time

The reaction time data were consistent with contingent attentional capture by target-relevant cues. Data for the two experiments were analyzed in separate 2 × 3 × 2 (Target Color [red, green] × Cue Condition [relevant match, relevant nonmatch, irrelevant] × Validity [valid, invalid]) within-subjects ANOVAs. Both experiments revealed a significant main effect of validity—Experiment 2a, $F(1, 18) = 26.66$, $p < .001$, $\eta_p^2 = .60$; Experiment 2b, $F(1, 20) = 28.91$, $p < .001$, $\eta_p^2 = .59$—with faster reaction times for valid than for invalid trials. The main effect of cue condition was also significant—Experiment 2a, $F(2, 36) = 24.03$, $p < .001$, $\eta_p^2 = .57$; Experiment 2b, $F(1, 20) = 28.91$, $p < .001$, $\eta_p^2 = .59$. Reaction times on relevant-match trials were faster than both relevant-nonmatch—Experiment 2a, $t(18) = 5.89$, $p < .001$, $d = .57$; Experiment 2b, $t(20) = 5.63$, $p < .001$, $d = .67$—and irrelevant trials—Experiment 2a, $t(18) = 3.61$, $p = .002$, $d = .21$; Experiment 2b, $t(20) = 3.94$, $p < .001$, $d = .19$—while relevant-nonmatch trials were slower than irrelevant trials—Experiment 2a, $t(18) = 4.02$, $p < .001$, $d = .37$; Experiment 2b, $(20) = 4.56$, $p < .001$, $d = .48$. In Experiment 2a, responses to green targets ($M = 745.50$) were significantly faster than to red targets ($M = 789.75$), $F(1, 18) = 6.91$, $p = .02$, $\eta_p^2 = .28$, but there was no main effect of target color in Experiment 2b ($p = .81$).

Crucially, the interaction between cue condition and validity was significant in both Experiment 2a, $F(2, 36) = 3.41$, $p = .04$, $\eta_p^2 = .16$, and Experiment 2b, $F(2, 40) = 14.92$, $p < .001$, $\eta_p^2 = .43$. Simple effects of validity were conducted at each level of cue condition (see Figure 4). The results indicated that attentional capture occurred only for target-colored cues: Reaction times were significantly faster in the valid than in the invalid condition for both relevant-match trials—Experiment 2a, $t(18) = 4.06$, $p = .001$, $d = .43$; Experiment 2b, $t(20) = 6.07$, $p < .001$, $d = .63$—and relevant-nonmatch trials—Experiment 2a, $t(18) = 4.61$, $p < .001$, $d = .41$; Experiment 2b, $t(20) = 3.85$, $p = .001$, $d = .37$. In Experiment 2a, the magnitude of the validity effect was the same across both conditions ($p = .91$). However, in Experiment 2b, the validity effect was greater in the relevant-match condition (77.03 ms) than in the relevant-nonmatch condition (43.33 ms), $t(20) = 2.12$, $p = .04$, $d = .61$. What is most important is that there was no significant validity effect, and therefore no evidence of attention capture, for irrelevant cues in either experiment ($p$s > .16). No other effects were significant ($p$s > .09).

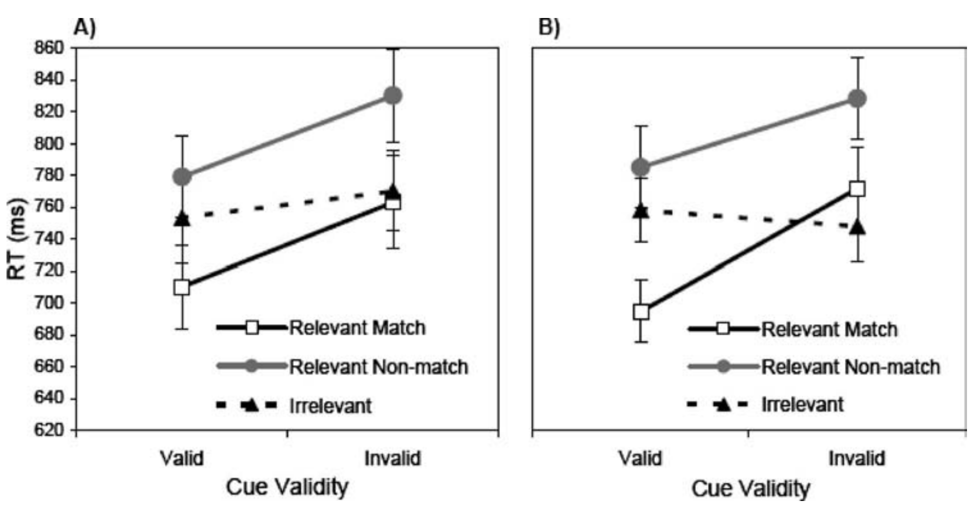


*Figure 4.* Mean response time as a function of cue condition and validity in Experiment 2a (A) and Experiment 2b (B). Error bars show standard error of the mean. RT = reaction time.

## Accuracy

Total mean accuracy was 94.00% in Experiment 2a and 90.08% in Experiment 2b. In general, the accuracy data was consistent with the reaction time data. Both experiments showed a significant main effect of cue condition—Experiment 2a, $F(2, 36) = 5.63$, $p = .007$, $\eta_p^2 = .24$; Experiment 2b, $F(2, 40) = 11.56$, $p < .001$, $\eta_p^2 = .37$. Accuracy was higher in relevant-match than relevant-nonmatch trials in both experiments—Experiment 2a, $t(18) = 2.98$, $p = .008$, $d = .55$; Experiment 2b, $t(20) = 4.30$, $p < .001$, $d = .58$—and in Experiment 2b, relevant-nonmatch accuracy was also lower than irrelevant accuracy, $t(20) = 3.21$, $p = .004$, $d = .44$. Valid trials were more accurate than invalid trials—Experiment 2a, $F(1, 18) = 9.36$, $p = .007$, $\eta_p^2 = .34$; Experiment 2b, $F(1, 20) = 13.19$, $p = .002$, $\eta_p^2 = .40$.

In Experiment 2b, validity interacted significantly with cue condition, $F(2, 40) = 5.73$, $p = .006$, $\eta_p^2 = .22$. Planned comparisons revealed significantly higher accuracy in the valid compared with the invalid condition for the relevant-match cue, $t(20) = 3.00$, $p = .007$, $d = .51$, and for the relevant-nonmatch cue, $t(20) = 3.18$, $p = .005$, $d = .60$, and the size of the validity effects did not differ ($p = .38$). There was no difference between valid and invalid trials in the irrelevant condition ($p = .33$). No other main effects or interactions were significant ($p$s $> .25$).

## Intertrial Priming

As with Experiment 1, trials with target-colored cues were divided according to whether the current cue was the same as (primed) or different from (unprimed) the target color on the previous trial. A 2 × 2 (Prime × Validity) within-subjects ANOVA of reaction times found no evidence for intertrial priming in either experiment—there was no main effect of priming ($p$s $> .74$), and priming did not interact with validity ($p$s $> .26$). This pattern did not vary across different levels of current cue condition ($p$s $> .27$) or previous cue condition ($p$s $> .16$). In the accuracy data, unprimed trials had higher accuracy than primed trials in Experiment 2a, $F(1, 18) = 6.08$, $p = .02$, $\eta_p^2 = .25$, but not in Experiment 2b ($p = .85$). What is most important is that the interaction between validity and prime condition was not significant in either experiment ($p$s $> .43$). This pattern did not vary across current trial cue conditions ($p$s $> .63$), however, in Experiment 2b, intertrial effects were dependent on the cue condition of the previous trial, $F(2, 40) = 3.25$, $p = .05$, $\eta_p^2 = .14$. When the previous trial was relevant nonmatch, validity effects were greater in unprimed trials than in primed trials, $t(20) = 2.91$, $p = .009$, $d = .63$. The interaction with previous cue condition was not significant in Experiment 2a ($p = .09$).

## Discussion

The results of Experiment 2 are consistent with the maintenance of ACSs for two separate colors. When participants were searching for one of two colored letters (e.g., red or green) presented with an irrelevant distractor (e.g., blue), both target colored cues captured attention, while irrelevant cues did not. Furthermore, these results cannot be explained by intertrial priming. Cues that were a different target color from the target on the previous trial captured attention to a similar degree as those that matched the target on the previous trial. Combined, these results suggest that participants were setting for two colors simultaneously. The fact that the irrelevant color produced no evidence of capture indicates that participants were not applying a broad set for color singletons, but instead were searching specifically for the target colors.

The results also showed a significant effect of color congruence—response times were significantly faster in the relevant-match condition than the other two conditions, and slowest in the relevant-nonmatch condition. The relationship with spatial validity is less clear: Even though the two effects were independent in Experiment 2a, they interacted significantly in Experiment 2b. Thus, at this point, we cannot judge whether color congruence effects are independent of shifts of attention (we return to this issue in the General Discussion).

# Experiment 3

Although Experiment 2 showed that spatial attention can be guided by a set for two target colors, at present it is unclear whether these results are limited to situations in which the target colors are linearly separable from the irrelevant distractor color. The target and distractors colors in both Experiment 2a and 2b were linearly separable—red and green are separable from blue, and blue and green from red. Menneer et al. (2009, 2010) and Stroud et al. (2011) found that search for two targets was more efficient when the targets were linearly separable from distractors, and suggested that participants search for two target colors by adopting a single general set that includes both of the target colors as well as any intervening colors. For example, if participants set for red and green targets, they might construct a broad attentional set that includes red, green, and intervening colors (e.g., yellow, orange), but excludes all outside colors (e.g., blue, purple). Thus, it is possible that participants in the present study adopted a single set that encompassed both linearly separable target colors and excluded the distractor color, rather than two distinct attentional sets.

The effect of linear separability on spatial capture was explored in Experiment 3. The method was identical to Experiment 2a, with participants searching for red and green targets. Rather than using blue as the distractor color, the distractor and irrelevant cue in Experiment 3 were yellow-orange (amber). Amber falls directly in between green and red in color space, and therefore the target colors cannot be linearly separated from the distractor color. If participants are capable of setting spatial attention for two non-separable target colors, cueing effects should be observed for both green and red but not for amber cues. If, however, amber cues produce evidence of spatial capture, it would suggest that the pattern in Experiment 2 reflects a top-down ACS for linearly separable regions of color space.

## Method

### Participants

Twenty, first-year psychology students at the University of Queensland (15 women and 5 men) with a mean age of 18.95 years participated in return for course credit.

## Stimuli and Procedure

The stimuli and procedure in Experiment 3 were identical to those of Experiment 2a, except that the distractor presented with the target was amber in color (RGB: 255, 170, 0; CIE: $x = .512$, $y = .442$). Cues were either red, green, or amber and were divided into three conditions—relevant match, relevant nonmatch, or irrelevant (amber).

# Results

Data from one participant who scored 63% in accuracy was removed from further analyses. Trials with reaction times less than 200 ms or greater than 1500 ms (6.21% of trials) were removed from the reaction time data.

## Response Time

The reaction time data in Experiment 3 was again consistent with attentional capture by target-colored cues only. A 2 × 2 × 2 within-subjects ANOVA revealed a significant main effect of validity, $F(1, 18) = 25.75$, $p < .001$, $\eta_p^2 = .59$, and cue condition, $F(2, 36) = 27.19$, $p < .001$, $\eta_p^2 = .60$, with the same pattern of results as in Experiment 2. It is important to note that validity interacted significantly with cue condition, $F(2, 36) = 10.00$, $p < .001$, $\eta_p^2 = .36$ (see Figure 5). Planned simple effects showed that valid trials were significantly faster than invalid trials for relevant-match, $t(18) = 5.37$, $p < .001$, $d = .50$, and relevant-nonmatch cues, $t(18) = 4.63$, $p < .001$, $d = .40$, and the magnitude of these validity effects did not differ ($p = .91$). In contrast, there was no significant difference between valid and invalid in the irrelevant condition ($p = .43$). No other main effects or interactions were significant ($p$s $> .33$).

## Accuracy

A 2 × 3 × 2 within-subjects ANOVA revealed significant main effects of validity, $F(1, 18) = 32.53$, $p < .001$, $\eta_p^2 = .64$, and cue condition, $F(2, 36) = 14.12$, $p < .001$, $\eta_p^2 = .44$, in the same pattern as that of Experiment 2b. As with the reaction time data, the interaction between validity and cue condition was also significant, $F(2, 36) = 12.35$, $p < .001$, $\eta_p^2 = .41$. Accuracy was higher in the valid condition than in the invalid condition for relevant-match cues, $t(18) = 2.81$, $p = .01$, $d = .74$, and relevant-nonmatch cues, $t(18) = 7.39$, $p < .001$, $d = 1.50$, but not for irrelevant cues ($p = .34$). The magnitude of the validity effect was significantly greater in the relevant-nonmatch condition than in the relevant-match condition, $t(18) = 4.56$, $p < .001$, $d = 1.28$ (see Table 1). No other effects were significant ($p$s $> 15$).

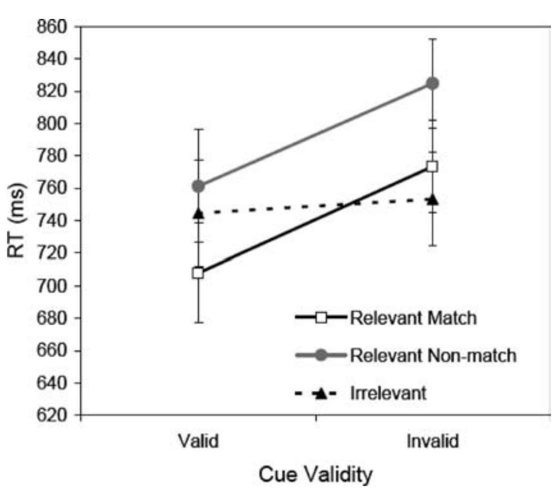


*Figure 5.* Mean response time as a function of cue condition and validity in Experiment 3. Error bars show standard error of the mean. RT = reaction time.

## Intertrial Priming

Experiment 3 found no evidence for intertrial priming. A 2 × 2 within-subject ANOVA on reaction time data revealed no main effect of prime condition ($p = .12$), and prime condition did not interact with validity ($p = .34$). These results did not vary with current trial cue condition ($p = .63$) or previous trial cue condition ($p = .53$). The same was true in the accuracy data—there was no difference between the primed and unprimed conditions ($p = .86$), and prime condition did not interact with validity ($p = .20$). There was no interaction with current ($p = .12$) or previous ($p = .85$) cue condition.

# Discussion

The results of Experiment 3 indicate that attention was captured by both the green and red cues, while irrelevant amber cues were ignored. These findings are particularly significant because the to-be-ignored color appeared directly in between the target colors in color space. The pattern of response times in Experiment 3 was very similar to that of Experiment 2a, which suggests that participants used the same strategy to set for two linearly separable colors (Experiment 2) as two nonseparable colors (Experiment 3).

The reaction time data of Experiment 3 are consistent with independent effects of spatial attentional allocation and color congruence, given that the validity effects were almost identical in the relevant-match and relevant-nonmatch conditions. However, this was not the case in the accuracy data. The validity effect was more pronounced in the relevant-nonmatch condition than the relevant-match condition, and this interaction appeared to stem from particularly poor performance on invalid relevant-nonmatch trials. Such a result may have arisen from a speed–accuracy trade-off, in which participants sacrificed accuracy for response speed in the invalid relevant-nonmatch condition, masking an interaction in the reaction time data. However, a closer inspection of the data did not support this hypothesis. Accuracy in the relevant-nonmatch condition did not correlate with reaction times ($r = -.08$, $p = .76$), and participants who showed only a small interaction in accuracy, or none at all, did not show any indication of the expected interaction in reaction time data ($p = .42$). Additionally, when the data were median-split into fast and slow trials, the interaction between spatial validity and color congruence in accuracy did not vary between fast and slow trials ($p = .27$). Combined, these results suggest that the reaction time data was not contaminated by a speed–accuracy trade-off.

## Experiment 4

One alternative account for the present results is that, rather than setting for the two target colors, participants have simply inhibited the irrelevant distractor color. In addition to facilitating the selection of relevant items, top-down control can also act to suppress shifts of spatial attention to irrelevant features, through the maintenance of an *inhibitory set* (Lamy & Egeth, 2003; Lamy et al., 2004; Theeuwes & Burger, 1998; Olivers & Humphreys, 2003). Because the irrelevant color in the previous experiments was constant, participants may develop an inhibitory set for that color, and then attend to any color singleton that does not match. In this way, participants need only maintain a single inhibitory set, rather than multiple facilitative sets.

The aim of Experiment 4 was to rule out this possibility. In previous experiments, participants could detect the target by ignoring a single distractor color. Therefore in Experiment 4, the target was presented with three distractor colors rather than one. The target frame consisted of four different colored letters: the target (green or red) and three distractors (amber, aqua, and purple). The distractors colors were such that they could not be linearly separated from the targets—aqua (blue-green) and purple (blue-red) fall on either side of the target colors, with amber (green-red) in the middle. This acted to reduce the possibility that participants could avoid all the distractors with one inhibitory set, or attend to all the targets with one ACS. If the results so far have been due to ACSs for two target colors, then capture should occur only for green and red, and not for amber, aqua, or purple.

### Method

#### Participants

Twenty-two, first-year psychology students from the University of Queensland (13 women, 9 men) with a mean age of 18.86 years participated in return for course credit.

#### Stimuli and Procedure

The task was identical to the task in Experiments 2 and 3. However, in Experiment 4, the target display consisted of four colored letters. One target letter was present and could be either red or green. The three remaining letters were amber, aqua (RGB: 0, 255, 255; CIE: $x = .249$, $y = .367$), and purple (RGB: 255, 0, 255; CIE: $x = .364$, $y = .178$). The location of the target and three distractor letters varied randomly on each trial. Cue frames consisted of colored dots around one box (the cue) and white dots around the remaining boxes. The cues could be green, red, amber, aqua, or purple. Cue color and location also varied randomly. Participants completed 192 trials with a green or a red cue (96 relevant-match cue and 96 relevant-nonmatch cue) and 192 trials with an amber, aqua, or purple cue (irrelevant cue), resulting in a total of 384 trials.

### Results

Reaction times less than 200 ms and greater than 1500 ms (5.54% of total trials) were removed from the data for reaction time analyses. Trials in the irrelevant cue condition were initially divided by cue color, to detect any differences in the pattern of responses across the three different distractor colors. A 2 × 3 × 2 (Target Color × Distractor Color × Validity) within-subjects ANOVA revealed no overall difference in reaction times following amber, aqua, or purple cues ($p = .80$), and distractor color did not interact with any other variables ($ps > .37$). There were also no significant effects of distractor color in the accuracy data ($ps > .40$). Because the effect of validity did not differ between the different distractor cue colors, data from all three irrelevant cue colors were combined under the irrelevant condition.

#### Response Time

The reaction time data once again supported attentional capture by target-colored cues only. A 2 × 3 × 2 within-subjects ANOVA revealed the same main effects of validity, $F(1, 21) = 25.45$, $p < .001$, $\eta_p^2 = .55$, and cue condition, $F(2, 42) = 45.54$, $p < .001$, $\eta_p^2 = .68$, as the previous two experiments. Of note is that validity interacted significantly with cue condition, $F(2, 42) = 24.62$, $p < .001$, $\eta_p^2 = .54$ (see Figure 6). Valid trials were significantly faster than invalid trials for relevant-match cues, $t(21) = 6.60$, $p < .001$, $d = .63$, and relevant-nonmatch cues, $t(21) = 4.35$, $p < .001$, $d = .47$, and the magnitude of the validity effect did not vary between these two conditions ($p = .81$). In the irrelevant condition, the reverse was true, and reaction times were actually faster in the invalid condition than in the valid condition, $t(21) = 3.80$, $p = .002$, $d = 23$.

A main effect of target color indicated that reaction times were significantly faster to red ($M = 709.38$) than to green ($M = 758.12$) targets, $F(1, 21) = 8.40$, $p = .009$, $\eta_p^2 = .29$. However, this was qualified by a significant interaction with cue condition, $F(2, 42) = 4.21$, $p = .02$, $\eta_p^2 = .17$. Reaction times were faster for red than green targets in both the relevant-match, $t(21) = 3.09$, $p = .005$, $d = .29$ and relevant-nonmatch, $t(21) = 3.30$, $p = .003$, $d = .36$, conditions, but not in the irrelevant condition ($p = .16$). Target color did not interact significantly with validity in either the two-way or three-way interaction ($ps > .40$).

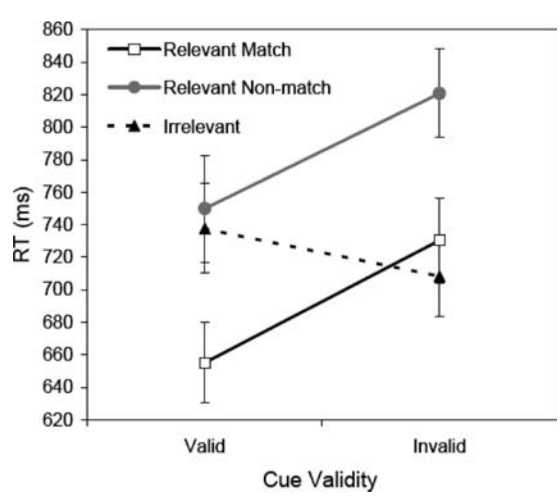


*Figure 6.* Mean response time as a function of cue condition and validity in Experiment 4. Error bars show standard error of the mean. RT = reaction time.

### Accuracy

Mean accuracy was 88.76%. Consistent with previous experiments, the main effect of validity was significant, $F(1, 21) = 23.94$, $p = .001$, $\eta_p^2 = .53$, as was the main effect of cue condition, $F(2, 42) = 20.66$, $p < .001$, $\eta_p^2 = .50$. Validity interacted significantly with cue condition, $F(2, 42) = 12.47$, $p < .001$, $\eta_p^2 = .37$. Accuracy was higher in the valid than in the invalid condition for relevant-match cues, $t(21) = 3.24$, $p = .004$, $d = .68$, and relevant-nonmatch cues, $t(21) = 4.71$, $p < .001$, $d = 1.05$. As was the case in Experiment 3, the magnitude of the validity effect was greater in the relevant-nonmatch than in the relevant-match condition, $t(21) = 2.11$, $p = .05$, $d = .54$. There was no significant validity effect in the irrelevant condition ($p = .08$), although there was a trend toward a negative validity effect, with accuracy lower in valid than in invalid conditions. No other main effects or interactions were significant ($p$s $> .13$).

### Intertrial Priming

There was no evidence of intertrial priming in Experiment 4. In the reaction time data, the main effect of prime condition just reached significance, $F(1, 21) = 4.32$, $p = .05$, $\eta_p^2 = .17$. Reaction times were faster when the cue matched the color of the target on the previous trial ($M = 728.09$) than when it did not match ($M = 740.81$). However, the size of the validity effects did not differ significantly across primed and unprimed trials ($p = .12$), and this effect did not vary across the current ($p = .96$) or the previous ($p = .27$) cue condition. In the accuracy data, there was no effect of prime type ($p = .43$), no interaction between prime type and validity ($p = .76$), and no interaction with the current ($p = .78$) or the previous ($p = .33$) cue condition.

## Discussion

In Experiment 4, as with the previous three experiments, evidence for attentional capture emerged only for cues that matched the target colors. It is difficult to explain this finding by appealing to a single inhibitory set. Because the target colors cannot be linearly separated from the distractor colors, it is unlikely that participants could effectively inhibit all three distractors with only one inhibitory set. Similarly, it is equally unlikely that a single ACS could be tuned to both of the target colors and not to the distractor colors. Because distractor colors fall in between and on either side of the target colors, the present results provide further support for multiple distinct ACSs.

As with Experiment 3, although there was no interaction between validity and color congruence in the reaction time data, validity effects were greater for relevant-nonmatch cues than relevant-match cues in the accuracy data. Once again, there was no evidence that this was due to a speed–accuracy trade-off. There was no correlation between accuracy and reaction time in the invalid relevant-nonmatch condition ($r = -.01$, $p = .95$), and participants who showed only a small interaction in accuracy, or one in the opposite direction, did not show an interaction in reaction time ($p = .99$). When the data was median-split into fast and slow trials, the interaction between spatial validity and color congruence did not vary between fast and slow trials ($p = .77$).

It may be argued that the negative cueing effect for irrelevant cues is evidence for attentional capture. Belopolsky et al. (2010) suggested that negative cueing effects occur because attention is initially captured by a cue, but when the cue is deemed to be irrelevant, attention is rapidly disengaged from the cued location and inhibited from returning. Thus, response times for targets appearing at the valid location are slowed. However, other studies argue that negative cueing effects arise from inhibition occurring independently of attentional capture (Anderson & Folk, 2011; Berlucchi, Chelazzi, & Tassinari, 2000; Lamy et al., 2004; Tassinari & Berlucchi, 1993). Anderson and Folk (2011), for example, showed that the effects of capture and inhibition at a cued location were dissociable, and inhibition could not be taken as evidence that attention had been captured and disengaged from a location. Lamy et al. (2004) suggested that location-specific inhibition may be due to inhibitory sets for known irrelevant features of distractor stimuli.

Although there has as yet been little exploration of the conditions under which negative cueing effects occur, it is possible to speculate that they may be more likely when the task is more difficult, and strong top-down control is required to discriminate targets from irrelevant items. Many of the discrimination tasks reporting negative cueing effects are either those in which the cue matches a no-go item for which a response must be withheld (e.g., Anderson & Folk, 2011; Belopolsky et al., 2010; Folk & Remington, 2008), or, more similar to the present study, when a target is presented in a heterogeneous display containing a number of different distractors (e.g., Lamy & Egeth, 2003; Lamy et al., 2004; Eimer & Kiss, 2008; Eimer, Kiss, Press, & Sauter, 2009). The increased heterogeneity of the target display may explain why the negative cueing effect was present in Experiment 4, but not in the previous experiments—distinguishing the target from among three colored distractors, rather than one colored distractor, may have necessitated stronger top-down control and the additional suppression of irrelevant information. On one hand, the negative cueing effects may have been due to *multiple* inhibitory sets actively suppressing distractor colors. On the other hand, suppression of irrelevant features may have occurred as a byproduct of facilitative ACSs. That is, in addition to biasing attention toward the specified target-relevant features, features that did not match the ACSs may have been suppressed. This issue is addressed in Experiment 5.

## Experiment 5

Experiment 5 further explored the effects of distractor inhibition by using an irrelevant cue color that differed from both target and distractor colors. Participants searched for a red or green target accompanied by a purple or yellow distractor letter, and preceded by either a relevant (red or green) or an irrelevant (blue) cue. Because blue never appears as a distractor with the target, there is little motivation to adopt an inhibitory set for blue. Therefore, if the results of previous experiments are due to inhibitory sets for distractor colors, blue cues should capture attention. On the other hand, if participants are actively setting attention to select target colors, blue cues will not capture attention. In addition, the color of the distractor accompanying the target varied unpredictably in Experiment 5. In previous experiments, the same distractors were present in every trial, and this may have encouraged the use of inhibitory sets. Removing this predictability from Experiment 5 may make it more difficult for participants to actively inhibit distractor colors. However, if participants are adopting facilitative ACSs for target colors, then varying the colors of the distractors should have no effect on the pattern of results.

## Method

### Participants

Eighteen undergraduate students from the Villanova University human participant pool participated in Experiment 5 in exchange for credit toward a course research requirement.

### Stimuli and Procedure

The stimuli and procedure in Experiment 5 were identical to those of Experiment 1, with the following exception. In the target frame, the target letter was either red or green, and was accompanied by two white letters and one distractor letter. The distractor could be either purple (RGB: 255, 85, 255; CIE: $x = .361$, $y = .205$) or yellow (RGB: 255, 255, 85; CIE: $x = .427$, $y = .483$). As in Experiment 1, the cue was either red, green, or blue, and the target was present for 120 ms. Response times longer than 1500 ms were not recorded. Participants completed 5 blocks of 48 trials.

## Results

### Response Time

The reaction time data for Experiment 5 were consistent with the maintenance of facilitative ACS for target colors. Because the color of the distractor in Experiment 5 varied between purple and yellow, distractor color was entered into the analyses as an additional variable. A 2 × 3 × 2 × 2 (Distractor Color × Target Color × Cue Condition × Validity) within-subjects ANOVA revealed significant main effects of validity, $F(1, 17) = 11.95$, $p = .003$, $\eta_p^2 = .41$, and cue condition, $F(2, 34) = 9.47$, $p = .001$, $\eta_p^2 = .36$, in the same direction as previous experiments. The main effect of distractor color was also significant, $F(1, 17) = 21.52$, $p < .001$, $\eta_p^2 = .56$, with faster reaction times when the target was accompanied by a yellow distractor ($M = 556.44$) than by a purple distractor ($M = 612.74$).

As expected, the interaction between validity and cue condition was significant, $F(2, 34) = 6.45$, $p = .004$, $\eta_p^2 = .28$ (see Figure 7). Consistent with hypotheses, reaction times were faster in the valid than in the invalid condition for relevant-match cues, $t(17) = 2.67$, $p = .02$, $d = .25$, and relevant-nonmatch cues, $t(17) = 4.84$, $p < .001$, $d = .33$, but not for irrelevant cues ($p = .83$). The magnitude of the validity effect for relevant-match and relevant-nonmatch cues did not differ ($p = .33$).

Finally, target color interacted significantly with cue condition, $F(2, 34) = 3.53$, $p = .04$, $\eta_p^2 = .17$. Further analyses indicated that the reaction times were faster to red than to green targets only in the relevant nonmatch-cue condition, $t(17) = 2.53$, $p = .02$, $d = .31$. No other main effects or interactions were significant ($p$s $> .06$).

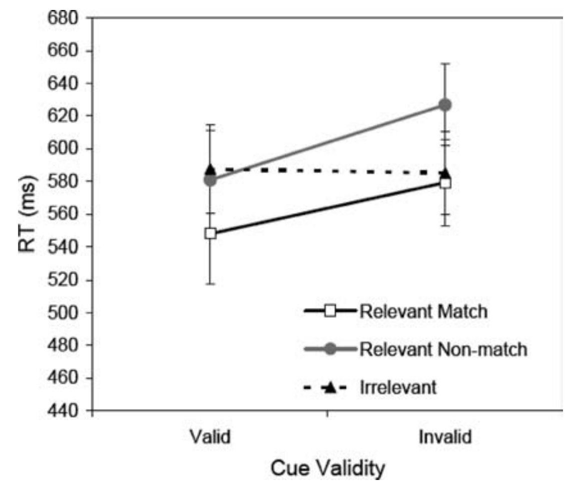


*Figure 7.* Mean response time as a function of cue condition and validity in Experiment 5. Error bars show standard error of the mean. RT = reaction time.

### Accuracy

Mean accuracy for Experiment 5 was 93.62%. A 2 × 2 × 3 × 2 within-subjects ANOVA revealed only a significant main effect of distractor color, $F(1, 17) = 8.21$, $p = .01$, $\eta_p^2 = .33$, indicating that accuracy was higher when the distractor was yellow ($M = 95.16\%$) than when it was purple ($M = 92.09\%$). No other main effects and interactions were significant ($p$s $> .08$).

### Intertrial Priming

A 2 × 2 (Prime Condition × Validity) within-subjects ANOVA found no main effect of prime condition ($p = .80$) or interaction with validity ($p = .97$) in the reaction time data, inconsistent with intertrial priming. The effect did not vary across cue conditions in the current ($p = .76$) or the previous ($p = .41$) trial. Analysis of the accuracy data showed no main effect of prime condition ($p = .68$). However, there was a trend toward a significant interaction between prime condition and validity, $F(1, 17) = 4.29$, $p = .05$, $\eta_p^2 = .20$. Validity effects were greater in the unprimed condition than in the primed condition (see Table 2). This effect did not vary between current ($p = .98$) or previous ($p = .42$) cue conditions.

## Discussion

Experiment 5 provides further evidence that the results reported thus far are not due solely to inhibitory sets. Even when the distractor color varied unpredictably over trials, participants were still able to set for both target colors to the exclusion of the other colors. Furthermore, the irrelevant cue color did not match either of the distractor colors, and yet it still failed to capture attention. Because the irrelevant cue color was never presented as a distractor, it is unlikely that participants adopted an inhibitory set for this color. It may be argued that the irrelevant cue color (blue) was inhibited by virtue of its similarity to one of the distractor colors (purple). If this were the case, capture by the blue cue may depend on the color of the distractor in the previous trial. That is, one may expect to find no cueing effect, or possibly a negative cueing effect, when a blue cue on trial $N$ was preceded by a purple distractor on trial $N - 1$, because the similar color has been inhibited (Becker, 2007; Olivers & Humphreys, 2003). On the other hand, blue cues may be more likely to capture attention and elicit a cueing effect following the yellow distractor. However, the results showed no difference between these two conditions ($p = .79$). Validity effects for blue cues were not significant after a purple distractor (−3 ms) or after a yellow distractor (4 ms). Thus, it seems unlikely that blue cues were inhibited as a result of an inhibitory set for purple distractors. The most likely explanation is that blue cues failed to capture attention because they did not match the attentional ACSs for red and green.

## General Discussion

Attentional control settings were originally regarded as broad, coarse-grained configurations that govern the early allocation of spatial attention (Folk et al., 1992, 1994). However, research continues to reveal that ACSs are considerably more precise, complex, and flexible than originally thought. Here, we have shown that spatial attention can be guided by ACSs for two colors simultaneously, supporting recent studies suggesting that is it possible to maintain multiple attentional sets (Adamo et al., 2008; Adamo, Wozny, et al., 2010; Moore & Weissman, 2010). Although previous work on dual-target search had shown that distractor interference is contingent on top-down control settings (Moore & Weissman, 2010), it was not clear whether these effects reflected shifts of spatial attention. Furthermore, the effects of attentional capture were confounded by the effects of color congruency between the distractor and target. The present study used a spatial cueing study, which enabled us to disentangle the effects of these two processes. The results consistently showed that when participants were setting for two target colors, only cues sharing the target colors captured attention and produced a spatial validity effect.

The present results also allowed us to rule out a number of alternative explanations for our findings. First, these findings were not due to intertrial priming by the targets on the previous trials. If target-colored cues captured attention only because they were primed by previous targets, validity effects would only be expected when the cue was the same color as the target on the previous trial. On the contrary, intertrial analyses revealed that the color of the target did not determine the presence of attentional capture on the subsequent trial. Significant cueing effects emerged both for cues matching the target on the previous trials and for target-colored cues not matching the previous target. Second, the present findings were inconsistent with the view that set for multiple colors is dependent on linear separability (D'Zmura, 1991; Menneer et al., 2009, 2010; Stroud et al., 2011). Spatial attention was captured only by target-colored cues, even when a distractor color fell immediately between the target colors in color space, thereby preventing linear separability (Experiments 3 and 4). Finally, the present findings were not due to a single inhibitory set for distractors, because the results were replicated when there were multiple distractor colors (Experiment 4) and when the distractor color was unpredictable (Experiment 5). Experiment 5 also suggested that participants were using facilitative ACSs for the two target colors, rather than inhibitory sets for distractor colors, because cues that did not match any distractor color also failed to capture attention.

It may be argued that any effect of intertrial priming present in the data was washed out by the long response times found in some of the experiments. Experiments 2–4, which used a relatively short target duration of 50 ms, had longer reaction times (approximately 750 ms) than typically seen in a standard single-set cueing experiment, and it may be that any effects of priming had disappeared by the time participants responded. However, intertrial priming has been demonstrated in visual search studies at reaction times of 800–1000ms (e.g., Becker, 2008; Becker et al., 2009; Meeter & Olivers, 2006; Pinto, Olivers, & Theeuwes, 2005), suggesting that the effects can be sustained longer than it took to respond in the present experiments. Even in Experiment 5, which involved a longer target duration (120 ms) and faster reaction times (approximately 550 ms), intertrial priming effects were not present. Nevertheless, to address the possibility that intertrial priming may have been disguised by long reaction times in Experiments 2–4, we used a median split to select the fastest half of trials in each of the experiments. We then analyzed the effects of intertrial priming using only these faster trials. The interaction between priming condition and validity was not significant in any of the four experiments. Mean validity effects were equivalent for primed and unprimed cues in Experiment 2a (32.45 and 32.22 ms, respectively) and Experiment 2b (29.91 and 30.63 ms, respectively) ($p$s $> .94$). In Experiments 3 and 4, there was a trend toward larger validity effects in the primed than in the unprimed condition (Experiment 3, 35.26 and 26.63 ms, respectively; Experiment 4, 27.63 and 23.34 ms, respectively), but these differences was not significant ($p$s $> .24$). Of note is that the validity effects were always significant for the unprimed cues ($p$s $< .003$), suggesting that capture by relevant cues was not dependent on the target on the previous trial.

Although the interaction between priming condition and spatial validity was not significant in any of the experiments, overall there was a small trend toward greater cueing effects for relevant cues that matched the previous target compared to those that did not. This pattern is similar to the intertrial priming effect in singleton search (Folk & Remington, 2008). Folk and Remington suggested that when the target feature varies unpredictably and cannot be specified in advance, there is a small bottom-up bias in favor of the target feature on the previous trial. Although we can only speculate based on nonsignificant trends, it is possible that when participants are set for two separate target features that vary unpredictably, previously viewed targets produce an additional bottom-up bias that strengthens capture by similarly colored cues on subsequent trials. Nevertheless, it is clear that priming does not account for all the effects of spatial capture by target-relevant cues. Although the *magnitude* of the capture effect by relevant cues may be influenced by intertrial priming, the *presence* of spatial capture is not.

### Color Congruence and ACS Enhancement

Consistent with Moore and Weissman (2010, 2011), we found that target identification was facilitated when the cue matched the target (relevant match, e.g., green cue, green target), and impaired when the cue matched the other target color (relevant nonmatch, e.g., red cue, green target), compared with the irrelevant cue condition. To explain this finding, Moore and Weissman suggested that when participants are set for two target colors (e.g., green and red) and detect a target-relevant distractor (e.g., green), the corresponding ACSs is shifted into the focus of working memory, and the processing of any subsequent items that match this ACS (e.g., green targets) are enhanced over objects matching the other ACS (e.g., orange targets). However, the results of Moore and Weissman did not indicate exactly how the enhancement effect is related to attentional capture. For example, does set enhancement determine how attention is guided to the target or does it affect processes independent of attention? The results of the present study are most consistent with the hypothesis that set enhancement does not affect spatial attention allocation. Except for one experiment, response time validity effects were the same for relevant-match and relevant-nonmatch cues. These results indicate that when participants are setting attention for two target colors, attention is guided to an equal degree by stimuli matching both ACSs.

If the effect of color congruence is not related to attentional guidance, why does it occur? It seems likely that the effect takes place after target selection. In line with the enhancement theory, the cue may trigger a bias in working memory toward similarly colored objects, allowing matching targets to access working memory and be processed more rapidly. If the target does not match the primed color of the cue, access to working memory may be delayed, or it may take longer for the target to be processed. The congruency of the cue and target may also have an effect on the decision-making process in the response selection stage. Although participants do not respond to the color of the target, the presence of incongruent color information (e.g., a red cue and a green target) may nonetheless reduce the certainty of the judgment and slow the time taken to respond.

The conclusion that attention shifts and color congruence are independent is subject to a couple of caveats. First, in one experiment, the validity effect was greater in the relevant-match condition than the relevant-nonmatch condition (Experiment 2b). This was the only experiment that used green and blue targets, rather than green and red targets, and thus it is possible that the relationship between validity and color congruence depends on the target colors. Although we cannot explain why this might be so, Adamo, Pun, and colleagues (2008, 2010) used blue and green cues and targets in a spatial cueing task, and found the same interaction between validity and color congruence. Of note, event-related potential (ERP) evidence suggested that color congruence did not affect early attention allocation and only interacted with spatial validity at later stages of target selection and encoding (Adamo, Pun, et al., 2010). More research is required to assess whether our findings for red and green targets extend to other colors.

Second, it must also be noted that in two experiments, the validity effect in accuracy was greater for relevant-nonmatch than relevant-match cues. These findings did not appear to reflect a speed–accuracy trade-off, and, as such, we do not believe that the additive effects of color congruence and spatial validity in reaction time should be discounted. Rather, the reaction time and accuracy results may reflect different processes. For example, it is possible that when participants are faced with resolving incongruent cue-target colors combined with incongruent cue-target locations, the increased load on working memory begins to impair other processes, such as response mappings, leading to occasional reversals of response mappings and an inordinate increase in errors. Of course, this is mere speculation, and further research is required to highlight how validity and color congruence affect accuracy and reaction time measures differently.

## Implications for Visual Search Theories

The ability to set for multiple colors simultaneously may have implications for how we conceptualize the visual search process. Existing models of visual search tend to only consider top-down settings for a single feature or property. For example, in Guided Search model, Wolfe (1994, 2007) suggested that searching for multiple colors was unlikely to be possible, because participants were unable to search efficiently for a red-green conjunction from among red-blue and green-blue distractors (Wolfe et al., 1990). However, in that example, red and green were present in both the target and the distractors, and thus tuning attention to red and green might result in activating distractor items just as much as target items (Wolfe, 2007). The results of the present study would also predict inefficient search, because a setting for green and red simultaneously would not differentiate the target from the distractors, and all items would be equally capable of capturing attention. Thus, the present findings may still be compatible with a version of Guided Search model in which multiple color channels can be biased simultaneously.

These findings provide support for theories advocating fine-grained visual search for color (e.g., Navalpakkam & Itti, 2006). Participants searched for specific feature values, without being captured by categorically similar colors. For example, participants set for red targets without being captured by other objects containing red, such as purple or amber singleton cues. According to more broad categorical theories (e.g., Wolfe, 1994, 2007), because both purple and amber cues were the reddest objects in the cue display, attention should have been allocated to these objects in a manner similar to red cues. The present finding also conflicts somewhat with spatial cueing studies showing capture by cues of similar color (Anderson & Folk, 2010; Ansorge & Heumann, 2003). For example, Ansorge and Heumann (2003) found that when participants were searching for a green target, cues that were a similar color to the target (blue-green) captured attention, while cues that were dissimilar (yellow-red) did not. Similarly, Anderson and Folk (2010) found that the degree of capture by a colored cue was directly related to the degree of similarity to the target color. However, in both of these studies, the target was usually presented as a color singleton. Thus, participants could have adopted relatively broad color settings that may have encompassed target-similar hues. However, in the present study, the target was often accompanied by color-similar distractors. Differentiating the target from these distractors requires a more finely tuned judgment, and therefore participants may have restricted their ACS to a relatively small region of color space. Thus, participants may be able to tune to both broad and fine areas in colors space, depending on the task goal.

The present study indicates that linear separability is not necessary for a set for multiple target colors. Participants were able to set for two targets without being captured by intervening distractor colors. This suggests that participants are not simply adopting a single set for both target colors, and supports the view that participants were adopting two separate attentional sets. Thus, the finding that dual-target search is less efficient that single-target search (Menneer et al., 2009, 2010; Stroud et al., 2011) may not necessarily be related to linear separability. It may be that the decreased search efficiency in dual-target search is due to the additional load placed on attentional or working memory resources. Consistent with this, we found that reaction times were slower and accuracy was poorer in our dual-target studies, compared with those often see in contingent capture studies. Additionally, as suggested by Menneer et al. (2009), it may be the case that when two ACSs are maintained simultaneously, they compete for attentional resources, which may slow the guidance process or lead to occasional errors.

While linear separability could not explain the present results, it does not discount the validity of the theory itself. Effects of linearly separability appear to be confined to relatively small changes in color. For example, yellow targets pop out from among red and green distractors, despite the fact that yellow falls between red and green in target space (Bauer et al., 1996; D'Zmura, 1991). Given the brief presentation durations in the present study, it was not practical to study small color differences. Future research is needed to examine whether participants can set for two nonlinearly separable targets at smaller color differences.

## The Locus of Attentional Control Settings

The present study, along with other recent studies on complex ACSs, raise questions about the processing stage at which ACSs operate. According to contingent capture theory (Folk et al., 1992), the role of the ACS is to govern the exogenous attentional control system, acting as a filter between preattentive and attentive processing. Items or events found to contain the relevant properties determined by the ACS are given priority access to cognitive processing. This early stage view of ACSs has been supported by a number of studies (Chen & Mordkoff, 2007; Eimer & Kiss, 2008; Folk & Remington, 1998; Kiss, Jolicœur, Dell'Acqua, & Eimer, 2008; Leblanc, Prime, & Jolicœur, 2008; Lien et al., 2010; Lien, Ruthruff, Goodin, & Remington, 2008). For example, ERP studies have examined ACSs while measuring the N2pc component of the evoked response contralateral to the cue hemifield, which is thought to be associated with early spatial shifts of attention (Eimer & Kiss, 2008; Kiss et al., 2008; Leblanc et al., 2008; Lien et al., 2008, 2010). The results show that an N2pc is elicited only by cues matching the task-relevant feature or property of the target.

However, some researchers have suggested that ACSs actually operate at processing stages occurring after spatial attention allocation (Adamo, Pun, et al., 2010; Belopolsky et al., 2010; Pratt & McAuliffe, 2002; Theeuwes, Atchley, & Kramer, 2000; Theeuwes, 2010). For example, Theeuwes et al. (2000) proposed that the capture of attention is initially driven by salience, but ACSs determine the duration attention dwells at a location. Objects that do not match the ACSs are rejected very quickly after selection, such that the attentional shift has no effect on target performance in standard attentional cueing studies. Adamo, Pun, et al. (2010) also suggested that an ACS for color-location conjunctions does not act on early spatial attention. They measured ERPs while participants completed a go/no-go spatial cueing task. Participants searched for color-location conjunctions (e.g., green on the left and blue on the right) while ignoring items that did not match the target conjunctions. They found a significant N2pc for all cues, whether or not they matched the target conjunctions. Instead, the match between the cue and target appeared to modulate ERP components associated with later selection and encoding factors, and it was these factors that produced the expected variation in reaction time. They concluded that ACSs, or at least those employed in their study, act on processes occurring after spatial selection.

The results of Adamo, Pun, et al. (2010) might imply that the present effects must also reflect later processes rather than spatial attention allocation. However, our study can be differentiated from that of Adamo, Pun, et al. in a number of ways. First, the previous study required participants not only to maintain two ACSs, but also to maintain ACSs for conjunctions of features and locations. It may be the case that ACSs for conjunctions cannot operate on spatial attention, but this does not preclude the possibility that ACSs for two features can affect attention allocation. Additionally, the targets and cues in the Adamo, Pun, et al. study were color singletons, which may have encouraged participants to adopt a more broad setting for singletons. If so, capture by all cues would be expected, whether or not they match the color-location conjunction of the target. ACSs may act on early spatial attention if participants are encouraged to adopt feature search mode.

The present study uses a method well established for investigating attentional capture and ACSs (e.g., Anderson & Folk, 2010; Ansorge & Heumann, 2003; Becker et al., 2010; Belopolsky et al., 2010; Jonides, 1981; Folk et al., 1992, 1994; Folk & Remington, 1998, 2008; Lamy et al., 2004; Posner, 1980), and our pattern of results is consistent with those of previous spatial cueing studies showing maintenance of a single ACS. These studies are based on the assumption that the spatial cueing task enables us to access the movements of attention—the response time disparity between valid and invalid conditions is taken as evidence of spatial attention shifts. However, it is still contested whether these results could alternatively be explained by postselection processes (Adamo, Pun, et al., 2010; Chen & Mordkoff, 2007; Folk & Remington, 1998; Pratt & McAuliffe, 2002; Theeuwes et al., 2000), and therefore whether multiple ACSs act on early attention or later processing is still in debate. Future investigations measuring ERPs, and in particular the N2pc component, may shed light on this issue. Because the N2pc is thought to be associated with spatial attention shifts, this may help clarify whether multiple ACSs for color modulate early spatial attention.

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