

# Rapid and reflexive feature-based attention

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Performance on a visual task is improved when attention is directed to relevant spatial locations or specific visual features. Spatial attention can be directed either voluntarily (endogenously) or automatically (exogenously). However, feature-based attention has only been shown to operate endogenously. Here, we show that an exogenous cue to a visual feature can lead to improved performance in visual search. Response times were measured as subjects detected or discriminated a target oval among an array of disks, each with a unique color. An uninformative colored cue was flashed at the beginning of each trial that sometimes matched the location and/or color of the target oval. Subjects detected or discriminated the target faster when the color of the cue matched the color of the target, regardless of the cue's location relative to the target. Our results suggest evidence for a previously unknown exogenous cuing mechanism for feature-based attention.

Keywords: attention, spatial vision, search

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## Introduction

Our everyday visual experience is strongly affected by attention. Visual attention can enhance or prioritize the processing of specific stimuli over the overwhelming number of other sensory inputs by selecting spatial locations (Bisley & Goldberg, 2010; Carrasco, 2011; Chun, Golomb, & Turk-Browne, 2011; Desimone & Duncan, 1995; Egeth & Yantis, 1997; Johnston & Dark, 1986; Kinchla, 1992; Logan, 1996; Pashler, Johnston, & Ruthruff, 2001; Posner, 1980; Posner & Rothbart, 2007), features (Boynton, Ciaramitaro, & Arman, 2006; Maunsell & Treue, 2006; McAdams & Maunsell, 2000; Saenz, Buracas, & Boynton, 2002; Serences & Boynton, 2007; Treue & Martínez Trujillo, 1999), objects (Blaser, Pylyshyn, & Holcombe, 2000), and even time (Lin, Pype, Murray, & Boynton, 2010; Nobre, Allison, & McCarthy, 1998; Swallow & Jiang, 2010). In the past, studies have focused on spatial attention and its derivatives—volitional (endogenous) and reflexive (exogenous) allocation of spatial attention. Feature-based attention, however, has typically been studied using paradigms in which participants voluntarily deploy attention toward a particular visual feature. Attending to a feature such as color or motion in this way produces a global facilitation of processing for stimuli containing that feature throughout the visual field (Liu & Mance, 2011; Saenz, Buracas, & Boynton, 2003; White & Carrasco, 2011). Given that numerous studies have shown that exogenous cues can enhance sensitivity to visual input

at a cued location (Bisley & Goldberg, 2010; Carrasco, 2011; Chun et al., 2011; Desimone & Duncan, 1995; Egeth & Yantis, 1997; Johnston & Dark, 1986; Kinchla, 1992; Logan, 1996; Pashler et al., 2001; Posner, 1980; Posner & Rothbart, 2007), we hypothesized that salient features of an exogenous cue might automatically produce feature-based attentional effects that are independent of location-based cuing effects.

To test this hypothesis, we used a visual search paradigm preceded by different combinations of exogenous spatial and feature cues. We found that the color feature on the cue can rapidly and reflexively produce search benefits at multiple locations throughout the visual field as quickly as 260 ms after the onset of the cue. These feature-based search benefits are independent of spatially based search benefits and the two can combine to produce search benefits beyond either alone.

## Methods

### Participants

Twenty-one members of the University of Washington community (10 females and 11 males) received financial compensation or course credit for participating in [Experiment 1](#), 16 participated in [Experiment 2](#) (8 females and 8 males), and 18 participated in [Experiment 3](#) (14 females and 4 males). All reported normal or corrected-to-normal

visual acuity. All subjects gave informed consent to participate in this experiment, which was approved by the University of Washington Human Subjects Institutional Review Board.

## Apparatus, stimuli, and procedure

Displays were generated in Matlab (Mathworks) using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) and presented on a 51-cm (diagonal) Samsung Syncmaster 1100DF CRT monitor at  $1024 \times 768$  resolution, refreshed at 75 Hz. Participants used a chin rest and sat with their eyes 50 cm from the screen. Prior to the start of the experimental trials, participants were asked to discriminate between the 6 colors used in the experiments to ensure adequate color vision. The background of the displays was black ( $0 \text{ cd/m}^2$ ). Display items consisted of disks (1.8 degrees of visual angle) filled with 1 of 6 solid colors.

Each trial in the experiments consisted of four stages (see Figure 1 for a schematic illustration). (1) The initial preview display duration was jittered between 250 and 500 ms and consisted of a small fixation marker. (2) This was followed by a colored square cue (0.92 degree of

visual angle), presented for 59 ms at one of the item locations eventually presented in the search display, then a blank screen for 200 ms. (3) The colored cue was followed by a visual search display with 3 or 6 items placed randomly in eight possible locations positioned evenly on a circular array around fixation with a radius of 5.03 deg. This search display remained in view until participants responded or 2000 ms elapsed.

In 50% of search displays, a target oval was created by narrowing a circle by 5.5% (1.8 deg to 1.7 deg) along the horizontal dimension or vertical dimension. Trials varied by (1) *target presence*: whether the target oval was present or absent, (2) *spatial validity*: whether the cue's location coincided with the target oval's location, (3) *feature validity*: whether the color of the cue coincided with the color of the target oval, and (4) *display size*: the size of the search array (either 3 or 6 items). The location and color of the cue were counterbalanced and randomized in every block for every participant. Importantly, counterbalancing was done in such a way that the cue locations and colors were completely uninformative with respect to the eventual location of the target in the search displays. For set size 3 in Experiment 1, this meant that, overall, the cue's location, color, or combination of location and color

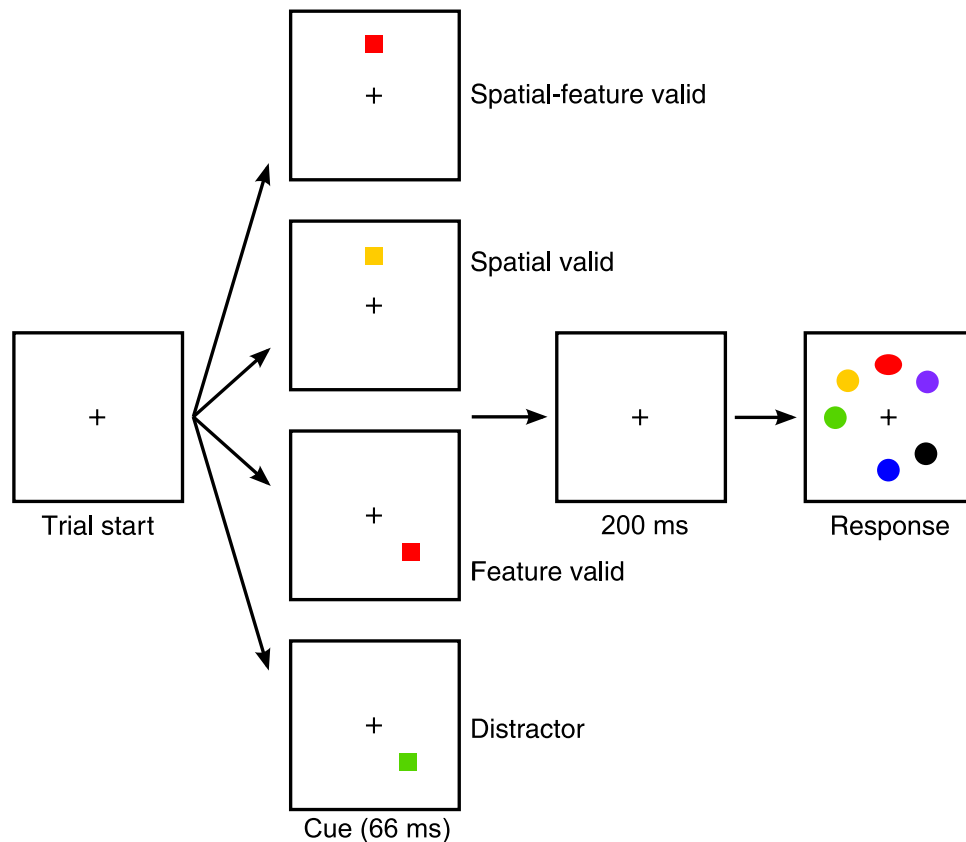


Figure 1. Illustration of a sample visual search sequence in Experiment 1. The displays in each trial consisted of a fixation marker for 250–500 ms, followed by an exogenous cue, then a search display where participants had to locate the presence of an oval among circles. Exogenous cues varied in both spatial and feature validity and were always uninformative relative to the eventual location of the oval target.

coincided with the target oval by chance on 33.3% of the trials. For set size 6 in [Experiments 1](#) and [3](#), specific breakdowns of trials were generated such that 16.7% of the trials in set size 6 were spatial valid trials and 16.7% of the trials were feature valid trials. Consequently, in set size 6, the cue's location and color both coincided with the target oval by chance on 2.78% of trials.

In [Experiments 1](#) and [2](#), participants were instructed to search for a target oval (while maintaining fixation at the center fixation point) and to press a key as quickly as possible if the target oval was present. If the oval was not present, participants had to wait until the trial timer elapsed, withholding any response. A small plus sign (correct), minus sign (incorrect), or circle (no response) provided feedback after each trial and was replaced by a fixation marker to serve as the fixation for the following trial and signal the start of the next set of displays. Participants were explicitly informed that target ovals would be present in 50% of the displays and search displays would be preceded by colored cues that were not predictive of the eventual location of the target oval. Participants were instructed to respond as quickly as possible while maintaining an overall accuracy of at least 80%. Each participant was tested for a total of 540 trials, in 9 blocks of 60 trials. Blocks were separated by brief breaks, with a longer break at the halfway point.

In [Experiment 2](#), displays were identical to [Experiment 1](#) except for two critical differences. A set size of 5 was used instead of 3 and 6 in [Experiment 1](#), and the exogenous cues were only presented at fixation, at the location of the fixation marker. Each participant was tested for a total of 1200 trials, in 20 blocks of 60 trials. In both experiments,

participants completed 40 practice trials prior to the test trials.

In [Experiment 3](#), displays were identical to [Experiment 1](#); however, the task was changed to a discrimination task and only set size 6 was used. Target ovals were oriented either vertically or horizontally and subjects responded on each trial by pressing “V” or “H” on the keyboard, respectively. Participants were explicitly informed that target ovals would be present in 100% of the displays. Each participant was tested for a total of 1296 trials in 16 blocks of 81 trials. Participants completed 40 practice trials prior to the test trials.

## Experiment 1

The aim of [Experiment 1](#) was to measure the effects of uninformative exogenous feature and spatial cues on response times (RTs) when detecting a target across four conditions in a  $2 \times 2$  design (spatial validity  $\times$  feature validity).

[Figure 2A](#) shows mean response times for trials where observers correctly detected target ovals in set size 6. Subjects detected targets fastest in the spatial–feature valid condition (mean = 765 ms,  $SD = 171$  ms), followed by the spatial valid (mean = 818 ms,  $SD = 176$  ms), feature valid (mean = 876 ms,  $SD = 174$  ms), and spatial and feature invalid conditions (mean = 912 ms,  $SD = 174$  ms). A repeated-measures 2 (spatial validity)  $\times$  2 (feature validity) ANOVA shows the expected main effect for

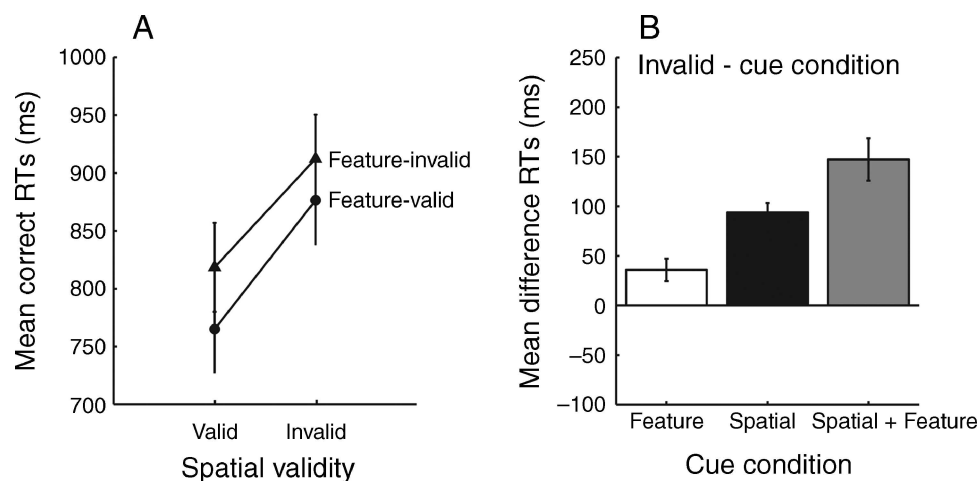


Figure 2. (A) Mean correct response times (RTs) for [Experiment 1](#). Mean correct reaction times suggested that response times to spatial and feature valid cues were faster than response times to spatial and feature invalid cues. Interestingly, there was no significant interaction between spatial and feature validity, indicating that the spatial and feature validity benefits did not interact to produce a multiplicative reduction in reaction times. Error bars represent 1 *SEM*. (B) Mean correct difference reaction times (RTs) for [Experiment 1](#). Cue benefits represent the difference between RTs from both spatially and featurally invalid trials and the three valid cue types (spatially valid, featurally valid, and both spatially and featurally valid). Bonferroni–Holm corrected paired-samples *t*-tests suggested that cues that were both spatially and featurally valid produced significant cue benefits above and beyond cues that were just spatially valid. Error bars represent 1 *SEM*.

spatial validity,  $F(1,20) = 56.70$ ,  $p < 0.01$ , partial  $\eta^2 = 0.74$ , but also a significant main effect for feature validity,  $F(1,20) = 14.20$ ,  $p < 0.01$ , partial  $\eta^2 = 0.42$ . There was no significant interaction between spatial and feature validity,  $F(1,20) = 0.64$ ,  $p = 0.43$ , partial  $\eta^2 = 0.03$ .

Figure 2B shows mean correct difference RTs for Experiment 1. Cue benefits represent the difference (in ms) between RTs from each of the three valid conditions (spatially valid, featurally valid, and both spatially and featurally valid) and the spatially and featurally invalid condition. Five post-hoc paired  $t$ -tests were conducted to more precisely determine the relationships between the different cue conditions, with the familywise type I error rate held at 0.05 via Bonferroni–Holm  $p$ -value correction. As expected, each of the valid cue conditions resulted in faster reaction times than the spatial and feature invalid condition (*spatial valid vs. spatial and feature invalid*:  $t(20) = 9.78$ , corrected  $p < 0.001$ ; *feature valid vs. spatial and feature invalid*:  $t(20) = 3.17$ , corrected  $p < 0.01$ ; *spatial–feature valid vs. spatial and feature invalid*:  $t(20) = 6.88$ , corrected  $p < 0.001$ ). Furthermore, while a spatially valid cue produced a larger RT benefit than a featurally valid cue ( $t(20) = 4.17$ , corrected  $p = 0.001$ ), RTs for spatial–feature valid cues were significantly faster than just spatial valid alone ( $t(20) = 2.70$ , corrected  $p = 0.014$ ), indicating that the addition of feature validity further facilitated reaction times to targets even when the spatial cue already matched the location of the target. These tests together demonstrate that the main effect of feature validity was driven by feature-based benefits in both spatially valid and spatially invalid trials, not just in one or the other.

Analysis of accuracies indicated no evidence of a speed–accuracy trade-off in set size 6. Average accuracy rates were very high (spatial and feature invalid = 94.55%,  $SEM = 1.18\%$ ; spatial valid = 94.64%,  $SEM = 1.18\%$ ; feature valid = 94.71%,  $SEM = 1.38\%$ ; spatial and feature valid = 96.66%,  $SEM = 1.80\%$ ). A one-way ANOVA revealed that accuracy did not vary significantly across the four conditions,  $F(3,60) = 1.090$ ,  $p = 0.36$ , as expected. These results replicate previous findings that search items that coincide with the location of a preceding exogenous cue receive prioritized processing in the visual search that follows (Giordano, McElree, & Carrasco, 2009; Posner, 1980; Posner & Petersen, 1990; Schreij, Owens, & Theeuwes, 2008; Schreij, Theeuwes, & Olivers, 2010; Yantis, 1993; Yantis & Egeth, 1999; Yantis & Jonides, 1984, 1990). However, these results also reveal a novel search benefit when the target and the cue share a feature (color), regardless of the relative location of the two items. This would appear to be the result of the exogenous cue producing a global spread of feature-based attention that operates alongside normal spatial cuing mechanisms. Furthermore, the lack of a significant interaction effect between spatial and feature validity suggests that validity in both cue dimensions results in the reaction time benefit that would be expected by summing the individual

benefits of both spatially valid and featurally valid cues. In other words, the spatial- and feature-based cuing benefits appear to originate independently of each other.

In contrast to set size 6, results from set size 3 yielded relatively small and inconclusive effects. Here, targets were detected fastest in the spatial valid condition (mean = 701 ms,  $SD = 132$  ms), followed by the spatial–feature valid (mean = 719 ms,  $SD = 126$  ms), feature valid (mean = 731 ms,  $SD = 122$  ms), and spatial and feature invalid conditions (mean = 758 ms,  $SD = 132$  ms). A repeated-measures  $2$  (spatial validity)  $\times$   $2$  (feature validity) ANOVA was conducted, showing trends consistent with the set size 6 data but no significance at the  $\alpha = 0.05$  criterion. There was no statistically significant main effect of spatial validity,  $F(1,20) = 3.90$ ,  $p = 0.06$ , partial  $\eta^2 = 0.16$ , or feature validity,  $F(1,20) = 0.10$ ,  $p = 0.75$ , partial  $\eta^2 = 0.01$ , nor was there a significant interaction between the two,  $F(1,20) = 1.74$ ,  $p = 0.20$ , partial  $\eta^2 = 0.08$ . In order to discern any differences between the conditions, all possible post-hoc paired  $t$ -tests were conducted on RTs from the four cue types, with familywise type I error rate held at 0.05 via Bonferroni–Holm  $p$ -value correction. As might be expected from the lack of any effects in the ANOVA, none of the  $t$ -tests revealed significant differences between the different cue types (smallest corrected  $p = 0.24$ ). Analysis of accuracies indicated no evidence of a speed–accuracy trade-off in set size 3. Average accuracy rates were very high (spatial and feature invalid = 96.00%,  $SEM = 1.00\%$ ; spatial valid = 96.00%,  $SEM = 1.50\%$ ; feature valid = 94.40%,  $SEM = 1.70\%$ ; spatial and feature valid = 96.00%,  $SEM = 1.70\%$ ). A one-way ANOVA revealed that accuracy did not vary significantly across the four conditions,  $F(3,60) = 0.311$ ,  $p = 0.82$ , as expected.

These results for a set size of 3 might be considered a concern for the hypothesis that exogenous cues in our paradigm produced a rapid and reflexive spread of feature-based attention since we observed no discernable RT benefit in response to cues that matched the target color. However, our choice of a three-item search display might not have allowed any possible benefit from a reflexive spread of feature-based attention to manifest even if it existed. In particular, the aspect ratios of our oval targets may have “popped out” of the search array when present in our set size 3 displays, negating any potential cue benefits. There is some evidence for this hypothesis, as we found no significant differences in mean RTs between any of our four cuing conditions. Indeed, we did not achieve statistical significance for the highly studied effect of exogenous spatial cuing (Posner, 1980; Yantis & Jonides, 1984).

## Experiment 2

Our results thus far have suggested the existence of an exogenous feature-based cuing benefit that is spatially independent. However, the cues that produced these

benefits always occurred at potential target locations (i.e., confined to the ring of possible circle/oval locations). It is possible, therefore, that featurally valid cues occurring at locations where a target never appears may produce minimal or no benefits. To test this, we conducted a second experiment that was identical to the first except that the set size was fixed at 5 objects and the cues always appeared at fixation rather than at one of the object locations in the search display. A paired  $t$ -test revealed no significant difference in RTs between trials where the cue was featurally valid (mean = 650 ms,  $SD = 76$  ms) relative to trials where the cue was featurally invalid (mean = 647 ms,  $SD = 63$  ms),  $t(14) = 0.32$ ,  $p = 0.74$ , indicating that there may be no discernable feature-based cuing effect when cues are presented at fixation. Average accuracy rates were very high and suggested no speed–accuracy trade-offs (feature invalid = 97.11%,  $SEM = 0.99\%$ ; feature valid = 95.67%,  $SEM = 0.55\%$ ). A paired  $t$ -test revealed that accuracy did not vary significantly across the two conditions,  $t(14) = 1.78$ ,  $p = 0.10$ , as expected. These results suggest that while the benefits of a valid exogenous feature cue are spatially independent, the cue itself may have to be in a target-relevant location to achieve this benefit.

## Experiment 3

If the effects observed in [Experiment 1](#) are due to the reflexive orienting of feature-based attention to an object exhibiting a matching feature of an exogenous cue, then

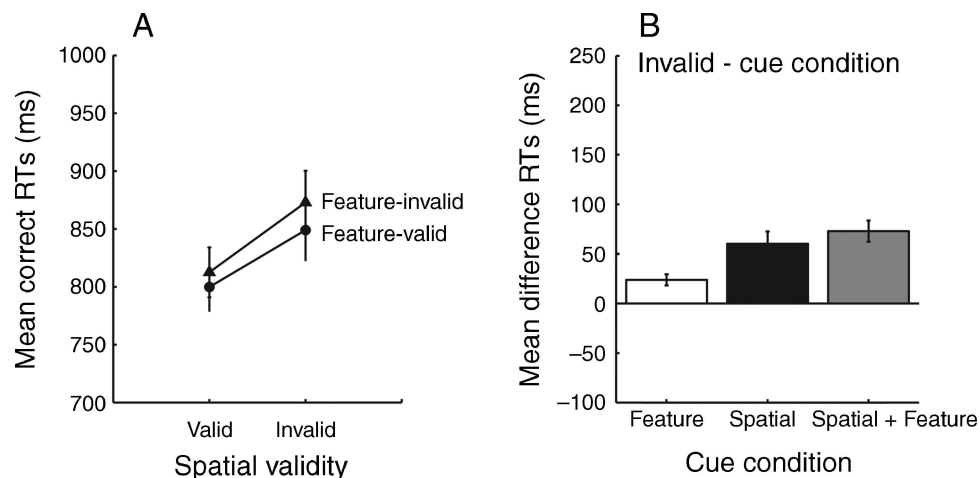


Figure 3. (A) Mean correct response times (RTs) for [Experiment 3](#). [Experiment 3](#) replicates the results of [Experiment 2](#) using identical displays but changing the task from a detection task to a discrimination task. Mean correct reaction times suggested that response times to spatial and feature valid cues were faster than response times to spatial and feature invalid cues. Interestingly, there was no significant interaction between spatial and feature validity, indicating that the spatial and feature validity benefits did not interact to produce a multiplicative reduction in reaction times. Error bars represent 1  $SEM$ . (B) Mean correct difference reaction times (RTs) for [Experiment 3](#). Cue benefits represent the difference between RTs from both spatially and featurally invalid trials and the three valid cue types (spatially valid, featurally valid, and both spatially and featurally valid). Error bars represent 1  $SEM$ .

the effects should generalize across different tasks. The aim of [Experiment 3](#) was to test for effects of reflexive feature-based attention on visual search in a discrimination task where attention must be focused on the target stimulus to complete the task. The stimulus configurations were identical to [Experiment 1](#) except that only a set size of 6 was presented.

[Figure 3A](#) shows mean response times (RTs) for trials where observers correctly discriminated oval orientations. Similarly to [Experiment 1](#), subjects chose the correct orientation fastest in the spatial–feature valid condition (mean = 800 ms,  $SD = 87$  ms), followed by spatial valid (mean = 813 ms,  $SD = 91$  ms), feature valid (mean = 849 ms,  $SD = 110$  ms), and spatial and feature invalid conditions (mean = 873 ms,  $SD = 116$  ms).

A repeated-measures 2 (*spatial validity*)  $\times$  2 (*feature validity*) ANOVA revealed the expected main effect for spatial validity,  $F(1,17) = 29.68$ ,  $p < 0.001$ , partial  $\eta^2 = 0.64$ , and also the same significant main effect for feature validity found in [Experiment 1](#),  $F(1,17) = 12.04$ ,  $p < 0.003$ , partial  $\eta^2 = 0.42$ . Further replicating the results from [Experiment 1](#), there was no significant interaction between spatial and feature validity,  $F(1,17) = 1.23$ ,  $p = 0.28$ , partial  $\eta^2 = 0.07$ .

[Figure 3B](#) shows mean correct difference RTs for [Experiment 3](#). Cue benefits represent the difference (in ms) between RTs from each of the three valid conditions (spatially valid, featurally valid, and both spatially and featurally valid) and the spatially and featurally invalid condition. Five post-hoc paired  $t$ -tests were conducted to more precisely determine the relationships between the different cue conditions, with the familywise type I error rate held at 0.05 via Bonferroni–Holm  $p$ -value correction.

Again and as expected from [Experiment 1](#), each of the valid cue conditions resulted in faster reaction times than the spatial and feature invalid condition (*spatial valid vs. spatial and feature invalid*:  $t(17) = 4.86$ , corrected  $p < 0.001$ ; *feature valid vs. spatial and feature invalid*:  $t(17) = 4.22$ , corrected  $p < 0.01$ ; *spatial–feature valid vs. spatial and feature invalid*:  $t(17) = 6.80$ , corrected  $p < 0.001$ ). Furthermore, while a spatially valid cue produced a larger RT benefit than a featurally valid cue ( $t(17) = 3.06$ , corrected  $p = 0.014$ ) and although there were no significant interactions found in the repeated-measures ANOVA, RTs for spatial–feature valid cues were no longer significantly faster than RTs for spatial valid alone ( $t(17) = 1.48$ , corrected  $p = 0.16$ ) in [Experiment 3](#).

Analysis of accuracies indicated no evidence of a speed–accuracy trade-off in this experiment. Average accuracy rates were lower than in [Experiment 1](#)'s detection task but still very high (spatial and feature invalid = 87.71%,  $SEM = 5.15\%$ ; spatial valid = 89.76%,  $SEM = 5.51\%$ ; feature valid = 88.78%,  $SEM = 4.76\%$ ; spatial and feature valid = 89.00%,  $SEM = 7.28\%$ ). A one-way ANOVA revealed that accuracy did not vary significantly across the four conditions,  $F(3,51) = 1.28$ ,  $p = 0.29$ , just as in [Experiment 1](#).

## General discussion

In [Experiment 1](#), we found that uninformative and task-irrelevant exogenous cues that precede a visual search array can produce reaction time benefits for targets that share a color with the cue, even if the cue and the target appear at remote spatial locations. Since the cues are completely non-predictive about the location of the target in the subsequent search task, we hypothesized that the search benefit was produced by a rapid and reflexive spread of feature-based attention that resulted in enhanced processing for items that shared a color with the exogenous cue. Interestingly, though the effect seemed to be independent of more well-known mechanisms of spatial exogenous cuing, it did not reliably appear when search arrays of only three items were used rather than six. Furthermore, in [Experiment 2](#), we found that cues presented at fixation rather than at target locations did not produce any discernable feature-based benefit, suggesting that the exogenous cues needed to capture attention in order for the effect to manifest. Finally, in [Experiment 3](#), we found that the effect appears not only in detection judgments but also when subjects have to discriminate some characteristic of the target oval, leading us to conclude that our results constitute evidence for a previously unreported and unknown type of visual attention: reflexive feature-based attention.

To date, several studies have examined how color features can influence contingent attentional capture by drawing attention to color-salient items in the visual field (Folk, Remington, & Johnston, 1992; Folk, Remington, &

Wright, 1994; Theeuwes, 1994; Theeuwes & Burger, 1998). However, in all of these studies, color marked either a highly salient target or was a task-relevant feature in the subsequent visual search. In contrast, in our method, neither the color nor the spatial location of the cue provided any predictive information as to the color or location of the target oval. Furthermore, targets in our search task were defined by an attribute (shape or oval orientation) completely orthogonal to those of the cues. In other words, even if our participants had been able to adjust their search strategy or attentional allocation in response to the color of the cue, they would have gained no reaction time or accuracy benefit in detecting or discriminating the target over the whole course of the experiment. To our knowledge, the current study is the first to demonstrate a reflexive feature-based benefit on visual search times when the color feature is completely irrelevant to the task.

In [Experiment 2](#), no significant effect was found when the exogenous feature-based cue was presented at fixation. Given that effects were found in [Experiment 1](#) when feature-based cues were inextricably linked with non-foveal spatial cues, but not in [Experiment 2](#), it is possible that attentional capture to the spatial cue is a necessary condition for the exogenous feature-based attention effect. There is conflicting research regarding how the size and shape of the attentional window modulates attentional capture (Belopolsky & Theeuwes, 2010; Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Eriksen & St James, 1986) or whether top-down strategies can override attentional capture (Leber & Egeth, 2006). Other experiments that have looked at attentional capture have shown puzzling results with foveal cues; for example, Folk et al. (1992) presented abrupt onset foveal cues and expected to find significant costs due to the cue on search for a subsequent target compared to a neutral cuing condition, but no costs were found, suggesting that attention was not captured or affected by the foveal cue. Because visual cues must inevitably contain spatial information, Folk et al. also suggested that foveal cues can be extremely problematic given that they always signal a non-target location and thus are conceptually 100% invalid cues. In light of this, presenting our exogenous feature-based cues at the fovea where fixation and attention was presumably already allocated prior to the trial start could have reduced the size of the feature-based effect if attentional capture plays a modulating role in the effects of exogenous feature-based attention.

Is it possible that our results are not due to a reflexive spread of feature-based attention but are instead due to some form of color priming? Research in the past has suggested that repeated color or spatial location priming across trials does modulate performance (Kristjánsson, Ingvarsdóttir, & Teitsdóttir, 2008; Kristjánsson, Vuilleumier, Malhotra, Husain, & Driver, 2005) and color priming on one trial can leave a memory trace lasting between 6 and 17 s that can affect performance on subsequent trials (Goolsby & Suzuki, 2001). However, given the relatively

long time scale such effects are thought to operate over, it seems unlikely that the same mechanism is responsible for the extremely rapid within-trial effects we observe here. Furthermore, in many of these previous studies, the color primes had relative contingencies with the eventual targets such that the color primes were often informative about the eventual target location. In the current paradigm, the color of the cues varied nearly randomly from trial to trial, reducing the effects of any lingering memory traces. Furthermore, the color and spatial features of the cue in our experiments were not predictive of the targets in any way but were completely irrelevant to the task. Taken together, this suggests that the current results were truly reflexive in nature and not the result of cross-trial priming.

Our results have three important implications on models of attention and how different forms of attention interact. First, the results extend previous literature on feature-based attention by showing for the first time that feature-based attentional effects can be produced by a reflexive mechanism that operates on a very short time scale and appears to require no internal guidance. Second, these effects can be elicited by exogenous cues that are irrelevant and uninformative to the task at hand. Third, these results also suggest that exogenous feature-based and spatial attention effects operate independently but can be combined to produce an additive benefit in a search task. Results from the current paper support recent evidence that spatial- and feature-based aspects of the attention control system can be derived independently and interact additively (Hayden & Gallant, 2009; Patzwahl & Treue, 2009). In both [Experiments 1](#) and [3](#), spatial attention effects appeared to be greater than feature-based effects. Recent research has suggested that the speed of feature-based attention is relatively slow compared to endogenous spatial attention (Huang, 2010; Liu, Stevens, & Carrasco, 2007). With this in mind, it may be that in feature valid trials attention is first captured and drawn to the spatial location of the cue. Consequently, feature-based attention spreads throughout the visual field after the processing of the irrelevant color feature on the spatial cue. Because attention is always initially captured to a distractor location in feature valid trials but captured directly to the correct target location in spatial valid trials, this could potentially explain why feature-based effects always appear smaller than spatial-based effects. Future research will have to be conducted to investigate whether attentional capture or the size and shape of the attentional window modulate effects of feature-based attention from exogenous cues.

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