Selection history is relative

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ABSTRACT

Visual attention can be tuned to specific features to aid in visual search. The way in which these search strategies are established and maintained is flexible, reflecting goal-directed attentional control, but can exert a persistent effect on selection that remains even when these strategies are no longer advantageous, reflecting an attentional bias driven by selection history. Apart from feature-specific search, recent studies have shown that attention can be tuned to target-nontarget relationships. Here we tested whether a relational search strategy continues to bias attention in a subsequent task, where the relationally better color and former target color both serve as distractors (Experiment 1) or as potential targets (Experiment 2). We demonstrate that a relational bias can persist in a subsequent task in which color serves as a task-irrelevant feature, both impairing and facilitating visual search performance. Our findings extend our understanding of the relational account of attentional control and the nature of selection history effects on attention.

1. Introduction

Attention is necessary for organisms to selectively filter and process information available in a complex visual scene. The filtering process can be bottom-up and stimulus-driven (e.g., Theeuwes, 1992), driven by past experience such as reward history, aversive conditioning and statistical regularities (e.g., Anderson, Laurent, & Yantis, 2011, 2012; Anderson & Britton, in press; Kim & Anderson, in press; Nissens, Failing, & Theeuwes, 2017; Failing, Wang, & Theeuwes, 2019), or modulated by top-down goals (e.g., Folk & Remington, 1998; Wolfe, 1994; Yantis, 1993). These three processes can all induce attentional capture, whereby salient or previously rewarded stimuli impair performance when no longer task-relevant (e.g., Anderson, Laurent, & Yantis, 2011; Anderson & Kim, 2019a, 2019b), or stimuli that share a defining feature with the target of visual search draw attention (Anderson & Folk, 2010; Folk, Remington, & Johnston, 1992; Folk & Remington, 1998). For example, at the luggage carousel we tune our attention to the features that resemble our suitcase but can subsequently become distracted by similar-looking baggage.

However, if we know that our snowboard will be significantly larger than any luggage, we can search for a target based on relational information (e.g., larger size) instead of a specific feature (e.g., red). Becker, Folk, and Remington (2013) used a spatial cuing paradigm to show that selection can be independent of the physical colors of targets and depend more specifically on their relative match. Participants searched for an orange target among yellow non-targets (i.e., yellow

context), yielding a "redder than" target-nontarget relation. This was preceded by a color-singleton cue among context cues that ranged from yellow to red, and they found that participants were more attracted to cues that were redder than the context. The relational account has also been extended to size, shape and conjunctions of size and color (Becker, 2010; Becker, Harris, Venini, & Retell, 2014; Becker, Harris, York, & Choi, 2017).

The capture effects from relationally better distractors have been shown to elicit similar electrophysiological signatures compared to feature-specific distractors (Schonhammer, Grubert, Kerzel, & Becker, 2016). The N2pc is an electroencephalogram (EEG) signature over the lateral occipito-parietal cortex that is a biomarker for covert attentional selection and has been shown to be greater for target-similar (Hickey, McDonald, & Theeuwes, 2006; Kiss, Jolicœur, Dell'Acqua, & Eimer, 2008; Schubö & Müller, 2009), previously reward-associated (Qi, Zeng, Ding, & Li, 2013), and fear-related stimuli (Eimer & Kiss, 2007; Buodo, Sarlo, & Munafò, 2010). Schonhammer et al. (2016) employed a variant of the Becker et al. (2013) paradigm while recording participants' EEG and showed that all relatively matching cues (e.g., "redder than" the context stimuli), but not all physically matching cues (i.e., the same color as the target) elicited a significant N2pc. Their study provided neural evidence for the attentional tuning of perceptual representations in a context-dependent manner.

Schonhammer (2016) also showed that participants adopted a feature-specific attentional bias when the context color varied randomly from trial to trial. Participants searched for a specific shade of orange if

they could not search for the reddest item in the display, suggesting that search strategies are flexible and task-dependent. Becker et al. (2014) demonstrated this further by pretraining a subgroup of participants with a feature-specific search strategy and showed that participants can employ either relational or feature-specific search strategies within the same task. A pop-out search task where the target was always orange among yellow non-targets was used. On some trials, a distractor would appear that varied in color from yellow to red. Participants that were primed to use a feature-specific search strategy were more impaired by orange distractors and participants who did not receive the training were more impaired by the relationally better red distractor. The effect of feature-specific priming remained after two blocks of trials, suggesting that learning or selection history plays a role in the persistence of a search strategy.

The stimuli Becker et al. (2014) used in Experiment 3 differed only in color. It remains to be seen if relational search can be primed and if it persists when color is no longer task-relevant; that is, whether participants can learn to engage this mode of selection automatically. On one hand, stimuli that previously served as targets can come to involuntarily capture attention when appearing as task-irrelevant distractors in a subsequent task (Anderson & Britton, 2019; Kim & Anderson, 2019b; Kyllingsbaek, Schneider, & Bundesen, 2001; Kyllingsbæk, Van Lommel, Sørensen, & Bundesen, 2014; Qu, Hillyard, & Ding, 2017; Shiffrin & Schneider, 1977; see also Theeuwes, 2004). That is, persistently searching for and finding a feature-defined target can produce a persistent bias to orient to stimuli possessing this diagnostic feature, even when it is no longer useful in localizing the target. Such stimulus-specific biases may be driven by the tuning of feature-specific response in the visual system, as might be predicted from theories of perceptual learning and neurophysiological studies of feature-based attention (e.g., Desimone & Duncan, 1995; Ling, Jehee, & Pestilli, 2015; Martinez-Trujillo & Treue, 2004; Maunsell, 2015; Reynolds & Chelazzi, 2004; Serences, 2008; Itthipuripat, Sprague, & Serences, 2009; Sprague & Serences, 2013). A relational account need not be invoked to explain persistent effects of search history on subsequent information processing.

On the other hand, such effects of selection history on the control of attention could involve the learning of a relational attentional bias rather than a feature-specific orienting response, as the aforementioned studies probing selection history effects are not equipped to test between these two possibilities. Studies investigating the persistence of search modes on the control of attention suggest that the learning of a more abstract or relational attentional template is possible. Leber and Egeth (2006a, 2006b) trained participants to use either feature search or singleton search (see Bacon & Egeth, 1994) to find a shape-defined target. They then tested both groups' ability to search for a singleton shape while ignoring a color singleton, and found that those in the feature search training group did not experience distractor-related performance impairments. This was presumably because they remained in feature search mode, making them better at ignoring the color singleton. If relational search operates similarly to feature search and singleton search mode in that it can be learned from experience and exert a persistent influence on attention after learning has taken place, then the attentional set for relationally better features, like a redder color, should be similarly persistent; such features should continue to capture attention in a subsequent visual search task.

In the present study, we manipulated two components of selection history (see Kim & Anderson, 2019a), namely reward history and search history (former target status), under conditions in which each of two color-defined targets could be identified on the basis of either their specific (e.g., orange) or relative (e.g., redder than the non-targets) color. One target color was associated with high reward and the other with low reward. In a subsequent test phase without reward, we tested whether prior-target feature-matching or relational-matching distractors more robustly captured attention when these stimuli simultaneously competed for attention with a shape-defined target, and

whether any observed bias was modulated by reward history.

2. Experiment 1

In the training phase of Experiment 1, participants received monetary reward for making saccades towards an orange target among yellow non-targets or a cyan target among green non-targets, with one of them yielding high rewards and the other yielding low rewards on average. This yielded a "redder than" and "bluer than" relationship associated with reward, as well as specific feature-reward pairings. In a subsequent test phase, participants made saccades towards a shape-defined target while ignoring non-targets; non-targets could be rendered in a prior target color from training (e.g., orange) or in a color (e.g., red) relationally more distinct from the context colors than the prior target color. If participants remain in relative search mode, then there should be more oculomotor capture for the relationally-matching color (e.g., red), compared to the prior target color (e.g., orange), whereas if consistently orienting to a particular feature during training gives rise to feature-specific perceptual learning and a corresponding perseveration of attentional bias, the opposite pattern should be observed (i.e., more oculomotor capture for orange compared to red). Whichever bias is evident (feature-specific or relational), the magnitude of this bias might vary as a function of reward history.

3. Methods

3.1. Participants

Thirty-one participants (M = 22.35 years of age, SD = 3.44, 19 female) were recruited from the Texas A&M University community. All participants reported normal or corrected-to-normal visual acuity and normal color vision. Participants were compensated with their earnings from the training task. All procedures were approved by the Texas A&M University Institutional Review Board and conformed with the principles outlined in the Declaration of Helsinki. The smallest effect size for the relative vs match comparison in Becker et al. (2013) was d_z = 0.82 (t/sqrt(n)), which indicated power (1-β) > 0.9 for the present study.

3.2. Apparatus

Stimuli were generated using MATLAB 2017 (MathWorks, Natick, MA, USA) with Psychophysics Toolbox extensions (Brainard, 1997) and presented on a Dell P2717H monitor linked to a Dell OptiPlex 7040 (Dell, Round Rock, TX, USA). Participants viewed the monitor from a distance of approximately 70 cm in a dimly-lit room. An EyeLink 1000 Plus desktop-mount eye tracker (SR Research, Ottawa, Ontario, Canada) sampling at 1000 Hz monitored participants' right eye position.

3.3. Measurement of eye position

Head position was maintained throughout the experiment using an adjustable chin rest including a bar upon which to rest the forehead (SR Research). Participants were given a short break between different runs of the task, during which they were allowed to reposition their head to maintain comfort. Eye position was calibrated prior to each block of trials using a 9-point calibration (Anderson & Yantis, 2012; Anderson & Kim, 2019a, 2019b; Liao & Anderson, 2020) and was manually drift-corrected by the experimenter as necessary (the next trial could not begin until eye position had been registered within 1.2° visual angle of the center of the fixation cross for 500 ms; see e.g., Kim & Anderson, 2019a, 2019b; Nissens et al., 2017). During the presentation of the search array, the position of the eyes was continuously monitored in real time with respect to the six stimulus positions, such that fixations were coded online (Anderson & Kim, 2019a, 2019b; Le Pelley, Pearson, Griffiths, & Beesley, 2015).
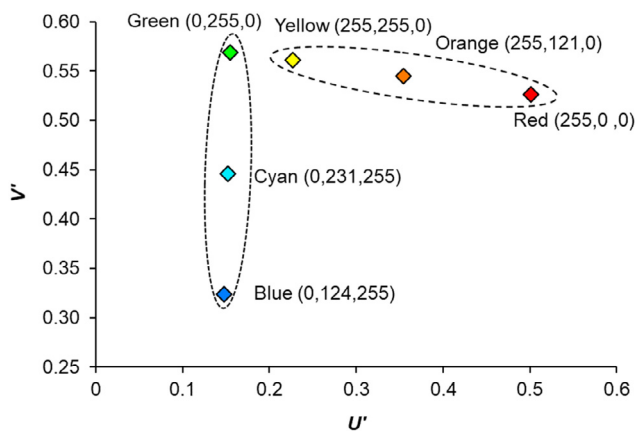
Fig. 1. RGB (red, green, blue) values of the colors used (values in parentheses) and their positions in CIE (Commission International de l'Éclairage) 1976 color space (u'- and v'-coordinates).

3.4. Stimuli

Color values were chosen such that the points corresponding to red (u' = 0.501, v' = 0.526, cd/m^2 = 40.60) and yellow (u' = 0.227, v' = 0.561, cd/m^2 = 207.28) and those corresponding to blue (u' = 0.148, v' = 0.324, cd/m^2 = 56.05) and green (u' = 0.155, v' = 0.569, cd/m^2 = 166.99) were approximately equally spaced with orange u' = (0.354, v' = 0.545, cd/m^2 = 73.51) and cyan (u' = 0.152, v' = 0.447, cd/m^2 = 153.05) halfway between the corresponding pairs of points, respectively, in CIE 1976 color space (Fig. 1). Thus, the two sets of color were yellow-orange-red (the red set), and green-cyan-blue (the blue set).

3.5. Training phase

The experiment consisted of two phases. Participants were instructed to "look directly at the orange or cyan square" to earn money. After a 10-trial practice block, participants completed 240 reward trials. The target was equally-often cyan and orange (counterbalanced by target location). The high-value color (cyan or orange, counterbalanced across participants) yielded 10¢ 80% of the time and 2¢ 20% of the time, and vice versa for the low-value color. Participants were not informed of the value contingencies. Fixations on any other colored square terminated the trial without reward (the target had to be the first stimulus fixated to receive a reward). Oculomotor response time (RT) in ms, the time between stimulus onset and when a fixation on a square was registered, was logged, as were fixations on non-targets.

Each trial began with a fixation cross (1.1° visual angle), which remained on the screen until eye position had been registered within 1.2° of the fixation cross for a continuous period of 500 ms. After a 200 ms blank screen, four squares would appear in the four cardinal directions at 8.3° eccentricity from the center of the screen. The squares (3.1° × 3.1°) remained on the screen until eye position had been registered within 4.3° of the center of the square for a continuous period of 100 ms. One of the squares was either cyan among greens or orange among yellows. After participants fixated any of the four squares, a 200 ms blank screen was followed by a 1500 ms feedback display indicating current and total earnings (Fig. 2A). The feedback display was followed by a blank 200 ms inter-trial-interval (ITI).

3.6. Test phase

Each trial consisted of a fixation display (until fixation was acquired for a continuous period of 500 ms), a 200 ms blank, a search array for 1500 ms or until the target was found, a 1500 ms feedback screen ("Too Slow!") if participants failed to fixate the target within the timeout

limit, and a blank 200 ms ITI (see Fig. 2B). The search array consisted of four shapes in the four cardinal directions at 8.0° eccentricity, one of them being a shape singleton (a circle [1.7° radius] among diamonds [2.5° x 2.5°] or vice versa). Fixations for a continuous 100 ms within 0.2° around the target were accepted. On distractor-absent trials, all four shapes were the training phase's context colors (yellow or green). On distractor-present trials, the target and one non-target were the context colors, one non-target was the previous target-singleton color (orange or cyan), and the last non-target color was red or blue.

Prior to the 192-trial test phase, participants completed a 20-trial practice block and were told to "look directly at the different shape" and to respond "as quickly and accurately as you can." There were 48 distractor-absent trials and 144 distractor-present trials. The shape singleton target's location was counterbalanced against target color and (on distractor-present trials) both distractor locations. Again, RT in ms was logged, as were fixations on non-targets > 50 ms.

3.7. Data analysis

For the training phase, RT to fixate the target was trimmed by 2.5 standard deviations from the condition mean (computed separately for each participant), resulting in 0.67% of responses being removed. Proportion of correct responses and RT were compared using pairwise t tests. For the test phase, on distractor-present trials we recorded the first stimulus participants fixated for > 50 ms (as in, e.g., Anderson & Kim, 2019b). If the first fixation was a distractor, we labeled it as either relative (blue or red) or trained (cyan or orange). The proportion of oculomotor capture was analyzed with two 2 × 2 ANOVAs, one focusing on distractor condition (relative vs trained color) as a function of the reward history of the colors (high vs low), and another focusing on distractor condition as a function of the physical colors used (cyan vs orange). The first ANOVA was designed to test our main hypotheses, and the second to probe whether performance differed by the counterbalanced factor of color. The effect sizes η_p^2 and d for both training and test phases were also computed, but the data were not otherwise transformed. Data were analyzed using SPSS and MATLAB.

4. Results

4.1. Training phase

Accuracy did not differ across high- and low-value targets, t (30) = 1.38, p = 0.178 (Fig. 3). Participants were marginally more accurate for a cyan target among green non-targets compared to an orange target among yellow non-targets, t(30) = 1.94, p = 0.062, d = 0.35. RT to fixate the targets did not differ across high- and low-value targets, t(30) = 0.86, p = 0.395. Regardless of reward association, participants were faster to fixate on cyan compared to orange targets, t(30) = 4.33, p < 0.001, d = 0.78.

4.2. Test phase

A 2 × 2 ANOVA with distractor condition (relative vs trained color) and value (high- vs low-value context) as factors revealed a main effect of distractor condition on oculomotor capture, $F(1,30)$ = 14.65, p = 0.001, η_p^2 = 0.328, with participants looking at the relative distractor more often than the trained distractor (Fig. 4). There was no main effect of reward, $F(1,30)$ = 0.44, p = 0.510, nor an interaction between reward and distractor type, $F(1,30)$ = 0.10, p = 0.751.

We then averaged across the reward manipulation and ran a 2 (relative vs trained color) × 2 (red color set vs blue color set) ANOVA. There was a main effect of color set, $F(1,30)$ = 12.58, p = 0.001, η_p^2 = 0.295, and an interaction between distractor condition and color set, $F(1,30)$ = 32.34, p < 0.001, η_p^2 = 0.519. Pairwise comparisons probing the nature of this interaction revealed that relative distractors
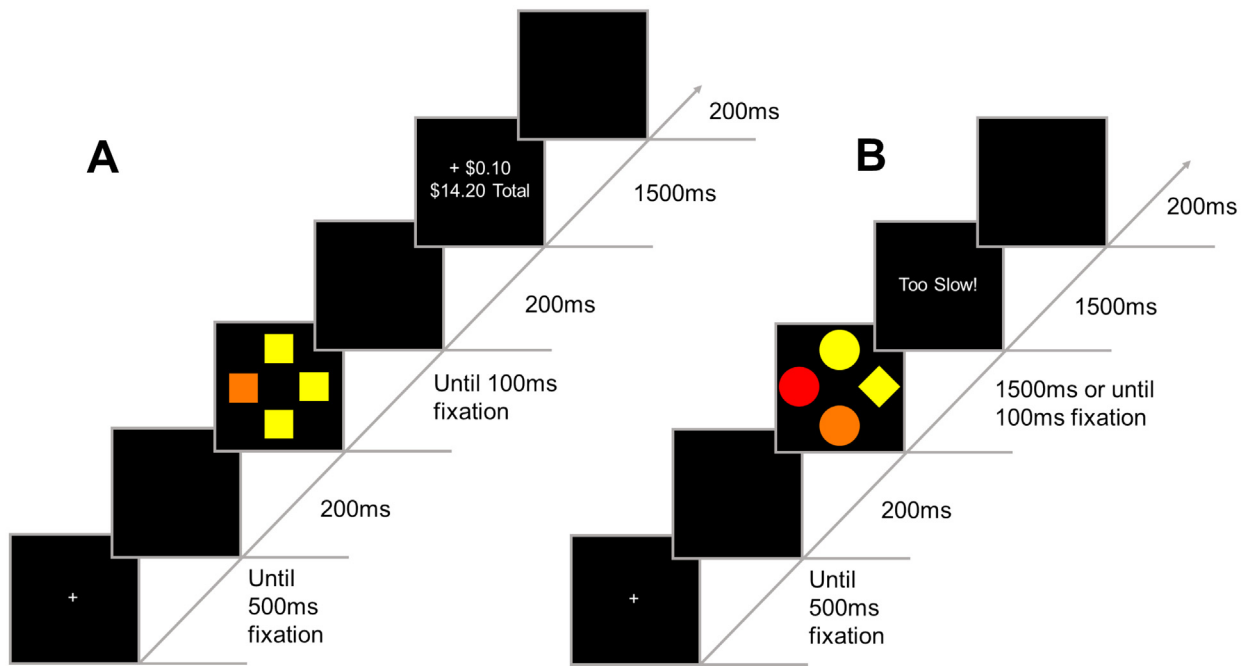
Fig. 2. Time course of trial events during the training and test phase of Experiment 1. Trials in both phases were preceded by a fixation cross; after fixation on the cross was registered, the task began. In the training phase (A), participants were instructed to fixate the uniquely-colored stimulus and received rewards depending on the set of colors. In the test phase (B), participants were instructed to make a speeded saccade towards the singleton shape while ignoring the colors. There was no feedback for correct responses, but the words "Too Slow!" would appear if the target shape was not fixated before the timeout limit.
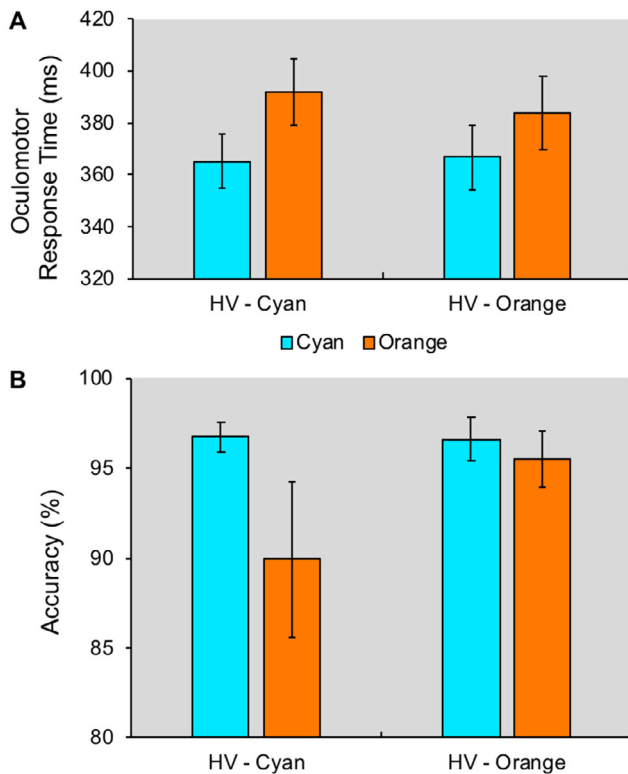

Fig. 3. Mean performance for the training phase. (A) RT and (b) accuracy between the different High Value (HV) conditions for the two sets of colors. Error bars represent the standard error of the mean.

Fig. 4. Proportion of oculomotor capture from the test phase for (A) the group with cyan as the high-value target and (B) the group with orange as the high-value target. Error bars represent standard error of the means.

in the red set produced more capture than all other distractor conditions, $ts > 4.65$, $ps < 0.001$, $ds > 0.83$. In addition, the trained distractor in the blue set (cyan) produced more capture than the trained distractor in the red set (orange), $t(30) = 2.58$, $p = 0.015$, $d = 0.46$.
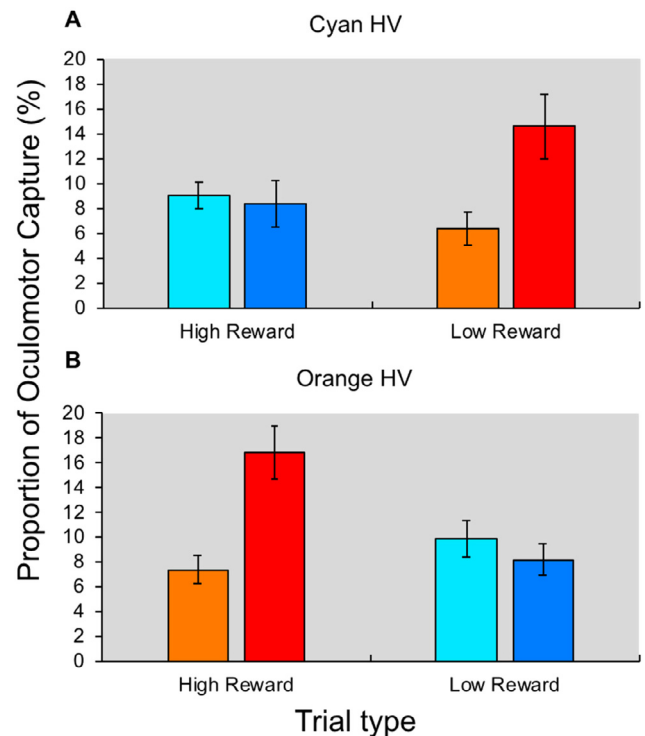
5. Discussion

Previous studies have investigated the deployment of a relational search strategy within the eliciting context (Becker, 2010; Becker et al., 2010, 2013) and how the adoption of a feature-specific search strategy

impairs relational search (Becker et al., 2014). In Experiment 1, we studied the effect of search history and reward history on the persistence of relational versus feature-specific attentional bias when color was no longer task-relevant. In the training phase, participants repeatedly made saccades towards the unique color (orange among yellow or cyan among green), encouraging relational search for the reddest or bluest item. Despite the irrelevance of the strategy going into the test phase, participants were biased to make errant saccades towards the relationally better color rather than the color that previously served as the target color, suggesting that target history effects on attentional bias involve the persistence of relative rather than feature-specific attentional templates. This selection history bias was not modulated by the rewards associated with each of two relative attentional templates.

Our findings support and extend the relational account of attentional control (Becker, Folk, & Remington, 2010), demonstrating a bias to persist in relation-based attentional orienting even when the color of stimuli is no longer task-relevant. Consistent with Leber and Egeth (2006a, 2006b; see also Leber, Kawahara, & Gabari, 2009), our findings suggest that observers can perseverate in attentional strategies, extending this phenomenon to a relational strategy and to a situation in which this perseveration actually misguides attention (results in increased distraction), consistent with an involuntary bias. Unlike with feature-based attentional orienting (Anderson, 2016; Failing & Theeuwes, 2018), we do not see evidence that reward history modulates this bias, suggesting a potential difference between attentional capture driven by associative reward learning and attentional capture driven by a perseveration of strategy (which appears less subject to reward history effects).

6. Experiment 2

Experiment 1 supports the idea that a relational attentional set can persist involuntarily into a subsequent task as a result of selection history. However, the evidence in favor of a relational attentional set was particular to red in a yellow context, with blue in a green context producing evidence for neither a relational nor a feature-specific bias. Therefore, it is unclear whether the pattern of results we observed reflects a relative feature bias or whether it reflects a bias particular to the color red (e.g., Elliot & Maier, 2007; Elliot, Maier, Moller, Friedman, & Meinhardt, 2007), which we sought to clarify in Experiment 2.

Although we controlled for the two sets of colors in CIE color space in Experiment 1, it may be the case that participants were more sensitive to the categorical differences between yellow, orange and red compared to green, cyan and blue. CIE is a mathematical generalization of human color vision (Robertson, 1977) that does not represent how people actually perceive colors (Moreland, 2009). It is quite possible that participants were conceptualizing cyan as light blue rather than its own color, and that this differed somewhat from prior studies using a blue-green color space (e.g., Becker et al., 2017; Martin & Becker, 2018). Experiment 1 also differs from prior demonstrations of relational attentional bias (e.g., Becker, 2010; Becker et al., 2010, 2013) in that participants were asked to adopt two different relational strategies particular to two different contexts. It is possible that participants are only capable of adopting one relational attentional template at a time, regardless of context, and defaulted to adopting the yellow–red color space.

To resolve this ambiguity, we conducted a second experiment using a different color set. Rather than using the blue-green color space again with modification, we opted to run a mirror of the orange target color space to produce a bias in another direction (red context to produce a yellower bias), which prior research demonstrates is similarly subject to relational processing (Becker et al., 2013, 2014). Specifically, half of the participants searched for an orange target among red non-targets during training (target is yellower than the non-targets), and the other half searched for an orange target among yellow non-targets (target is

redder than the non-targets), and during the test phase we compared the attentional priority for red, yellow, and orange stimuli. Since we have already demonstrated that oculomotor capture is greater for the relative color, we wanted to see whether this bias also extended to target processing with manual responses. Given that reward was found not to modulate the strength of the relative feature bias that developed as a result of selection history, we did not include a reward manipulation in Experiment 2 and focused exclusively on the role of search history.

7. Methods

7.1. Participants

Sixty new participants (M = 19.52 years of age, SD = 2.09, 31 female) were recruited from the Texas A&M University community, thirty in each of two color conditions (manipulated between-subjects). All participants reported normal or corrected-to-normal visual acuity and normal color vision. Participants were compensated with either 10 dollars or course credit. All procedures were approved by the Texas A&M University Institutional Review Board and conformed with the principles outlined in the Declaration of Helsinki. The data for the training phase for one participant from the relative-red group was lost due to experimenter error.

7.2. Apparatus and stimuli

The apparatus was identical to that of Experiment 1 but without eye-tracking. Manual responses were entered using a standard Dell US-layout keyboard. The stimuli were nearly identical to those used in Experiment 1, with minor adjustments for a non-eye tracking experiment. All shapes (squares, circles, and diamonds) had a 0.3° x 0.3° black square 1.3° from the center on either the left or right side (Gaspelin, Leonard, & Luck, 2015; Gaspelin & Luck, 2018). Participants had to indicate which side the square was on for the target. Only the red color set from Experiment 1 was used in this experiment.

7.3. Training phase

Participants were instructed to "indicate where the dot is on the uniquely colored shape" using the z and m key on the keyboard with their left and right index finger. Participants were given 4 untimed followed by 10 timed trials of practice, in which they were urged to "respond as quickly as possible while still being accurate." There were 640 trials in total with a mandatory 30 s break every 80 trials (7 breaks in total).

Each trial began with a fixation cross (1.1°) for 400 to 600 ms (in increments of 50 ms). After a fixation was registered on the cross, four squares appeared for 800 ms. The squares were of the same size and in the same positions as Experiment 1; however, each now contained a small black dot (Fig. 5A). If participants correctly identified the location of the dot on the uniquely-colored shape, a 1000 ms blank screen appeared; incorrect answers or time-outs were followed by the words "Incorrect" or "Too Slow," respectively, and a 500 ms blank ITI. Monetary feedback was not used in this experiment. The target color was always orange, and the context color was manipulated between-subjects: it was yellow for half of the participants and red for the other half, yielding a redder-than and yellower-than target-nontarget relationship, respectively.

7.4. Test phase

Prior to the 256-trial test phase, participants completed 4 untimed and 10 timed trials and were told to "indicate where the dot is on the unique shape." As in Experiment 1, one shape was now a shape singleton. The circles and diamonds were sized and positioned as in
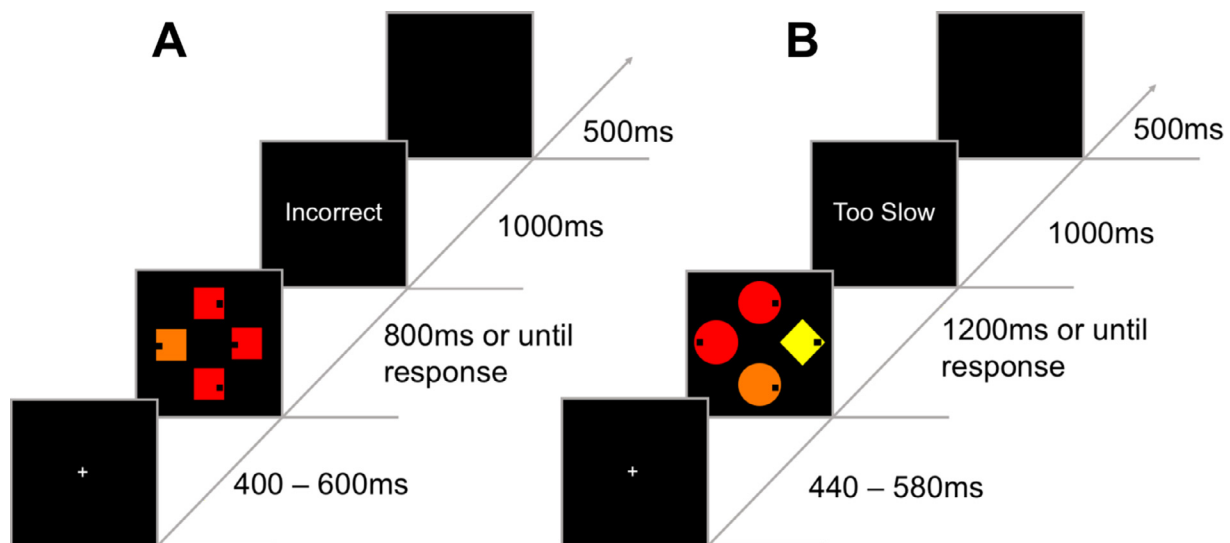
Fig. 5. Sequence of events for Experiment 2. In the training phase (A), each trial began with a fixation cross for a random duration between 400 and 600 ms, followed by four squares for 800 ms, or until response. "Incorrect" was displayed in response to an incorrect response, and "Too Slow" was displayed if a response was not registered before the timeout. Both feedback displays were presented for 1000 ms, after which a blank screen appeared for 500 ms. In the test phase (B), each trial began with a fixation cross for a random duration between 440 and 580 ms, followed by either a diamond among three circles or a circle among three diamonds. The feedback and blank displays were the same as in the training phase.

Experiment 1. After the untimed practice trials, participants were instructed to respond "as quickly as possible while still being accurate." Responses slower than 1200 ms were followed by "Too Slow" while incorrect responses were followed by "Incorrect." Both feedback displays were presented for 1000 ms. Correct responses received no feedback. The trial concluded with a 500 ms ITI.

During the practice trials and 64 "filler" trials in the main task, all four shapes were rendered in the context color from the training phase (red or yellow, corresponding to the non-target color experienced during training). On critical trials (Fig. 5B), two shapes were rendered in this context color, one was rendered in the (trained) previous target color, and one was the relationally better color (e.g., yellow, orange and red, respectively, for half of the participants and red, orange, and yellow, respectively, for the other half). On 25% of these trials, the target was the relationally better color while one of the non-targets was the trained color, and vice versa for another 25%; for the remaining 50% of these trials, the target was a context color and the three non-targets were rendered in the three different colors used (i.e., color was non-predictive of target status). The filler trials were not of interest and were included to reduce the frequency of critical colors such that participants were not exposed to them on every trial, consistent with the exposure frequency in Experiment 1. There was a mandatory 30 s break every 64 trials (3 breaks in total).

7.5. Analysis of response times

For both training and test phase, only correct trials were analyzed. RT in the training phase was trimmed by 2.5 standard deviations from the condition mean (computed separately for each participant), resulting in 1.53% and 1.64% of responses being removed in the yellow-context group and red-context group, respectively. RT and accuracy between the two groups were compared using independent-samples t tests. For the test phase, only trials with all three colors were analyzed (192 trials). RT in the test phase was trimmed in the same way as in the training phase, resulting in 1.75% and 2.6% of responses being removed in the yellow-context and red-context group, respectively. RT data was analyzed with a 3 (target color: context vs trained vs relative) × 2 (training context: yellow-context vs red-context) mixed-effects ANOVA, followed by pairwise t tests. If the relationally better color draws attention more than the trained color, participants should

be faster when it serves as the target color (and slower when it serves as the distractor color), whereas the opposite should be true if the trained color competes more effectively for attention.

8. Results

8.1. Training phase

There was no difference in RT between participants in the yellow-context and red-context condition, $t(57) = 0.14$, $p = 0.893$, nor was there any difference in accuracy, $t(57) = 0.94$, $p = 0.353$. The average accuracy was 93.8%.

8.2. Test phase

A 3 × 2 mixed-effects ANOVA with target color (context vs trained vs relative) and training context (yellow-context vs red-context) as factors revealed a main effect of target color, $F(2,116) = 16.36$, $p < 0.001$, $\eta_p^2 = 0.220$, with trained targets being marginally faster than context targets, $t(59) = 1.89$, $p = 0.064$, $d = 0.24$, and relative targets being faster than both context targets, $t(59) = 5.28$, $p < 0.001$, $d = 0.68$, and trained targets, $t(59) = 3.58$, $p = 0.001$, $d = 0.46$ (Fig. 6). There was no main effect of training context, $F(1,58) = 0.05$, $p = 0.821$, but there was an interaction between target color and training context, $F(2,116) = 5.18$, $p = 0.007$, $\eta_p^2 = 0.082$. For the yellow-context training group, relative-color targets were reported faster than context-color targets, $t(29) = 2.39$, $p = 0.024$, $d = 0.44$. For the red-context training group, relative-color targets were reported faster than trained-color targets, $t(29) = 3.50$, $p = 0.002$, $d = 0.64$, and context-color targets, $t(29) = 5.19$, $p < 0.001$, $d = 0.95$, while trained-color targets were reported faster than context-colored targets, $t(29) = 2.38$, $p = 0.024$, $d = 0.43$. No other comparisons were significant.

9. Discussion

In Experiment 2, we replicate the generalized attentional bias for relationally better colors seen in Experiment 1, in this case measured from manual response time. This relational bias was evident following training without reward incentives, demonstrating that it reflects a
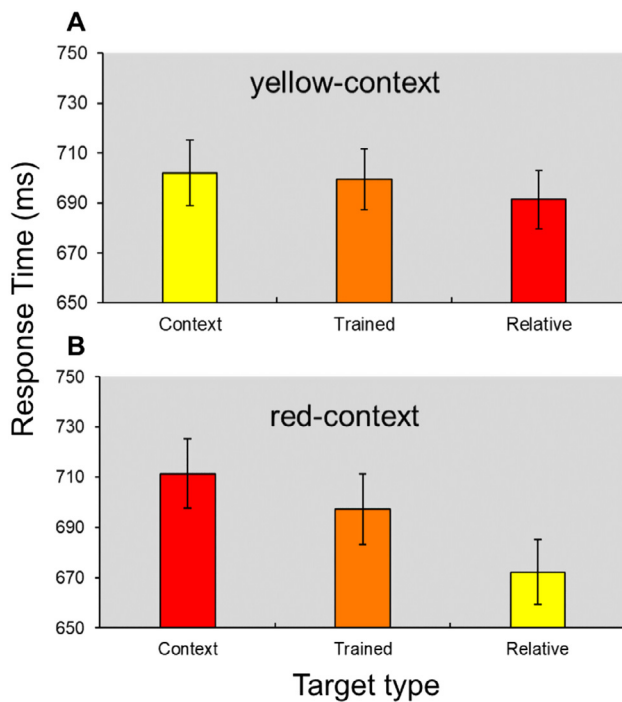
Fig. 6. RT for the test phase of Experiment 2 for context, trained and relative target colors, for the (top) yellow-context condition that encouraged a redder-than bias and for the (bottom) red-context that encouraged a yellower-than bias. Error bars represent standard error of the means. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

consequence of selection history independent of the presence of extrinsic motivation. We importantly show that it is possible to create long-lasting attentional biases towards relative information in both directions – redder targets and yellower targets – to facilitate search performance. Although we again observed an interaction with training condition, in this case the effect for the "redder" context was actually less robust than the effect for the "yellower" context, demonstrating that the perseveration of a relational attentional bias observed in the present study is not particular to the color red or to training in a yellow context. Our results cannot be explained by the physical salience of the colors used or by a general attentional bias toward colors other than orange given that (a) red was more prioritized than orange in Experiment 1 but less prioritized than orange for participants trained in a red context in Experiment 2, and (b) whether red or yellow was the more prioritize color in Experiment 2 varied as a function of training condition.

10. General discussion

Prior studies have investigated how a relational search strategy can be employed in visual search tasks for colors (Becker et al., 2010, 2013), sizes (Becker, 2010), shapes (Becker et al., 2014), as well as conjunctions of color and size (Becker et al., 2017). The findings of the present study suggest that participants can learn to adopt such a strategy via selection history, resulting in involuntary attentional capture by relationally-matching stimuli in a subsequent test phase. In both experiments, participants seemed to extract diagnostic relational information between the target and non-targets during the training phase that generalized to a subsequent search task in which color was task-irrelevant. Searching for an orange target among yellow non-targets yielded a "redder than" relational tuning that persistently biased attention towards red distractors, and vice versa for red non-targets that yielded a "yellower than" bias.

Our results suggest that relational search is similar to feature search mode and singleton search mode, in that these strategies persist once adopted, despite changes in the task (Leber & Egeth, 2006a, 2006b; Leber et al., 2009). Our results further suggest that such persistence can occur when it is explicitly counter-productive and the search mode is no longer useful in localizing the target, attesting to the involuntary nature of this selection history bias. Future work might investigate whether relational search strategies can be overridden if context changes drastically between search tasks.

Compared to prior studies of relational attentional templates and search mode perseveration, our study design is novel insofar as we present a training and test phase with separate task goals and in that the trained (orange) and relationally better (red) color directly compete for attention within test phase trials. Red never appears during the training phase, but participants already have their attention system tuned to it during the test phase. Our results are unlikely to be explained by an attentional bias toward novel stimuli (Horstmann & Ansorge, 2006; Anderson, Laurent, & Yantis, 2012; Retell, Venini, & Becker, 2015), because the same effect is not seen for blue stimuli in Experiment 1, and effects of novelty on attention are often transient and typically studied on the level of an individual surprise trial (Horstmann & Ansorge, 2016; Horstmann & Herwig, 2016; Horstmann, 2002) or when novel distractors remain infrequent for the entirety of the task (e.g., Neo & Chua, 2006; Folk & Remington, 2015). If participants had learned a robust feature-specific attentional bias, this bias must have been completely overshadowed by an attentional bias toward an initially novel color that was frequently presented throughout the test phase, which is inconsistent with the transience of novelty effects.

Stimuli rendered in the blue-green color space produced ambiguous evidence in the present study, supporting neither a relational nor a feature-specific attentional bias that persisted into the test phase. Although a blue-green color space has been used in prior studies pertaining to relational search (Becker et al., 2017; Martin & Becker, 2018), blue-green stimuli were not directly compared with red–orange stimuli or presented in a situation in which participants were asked to search for two color-defined targets in two different contexts. It is unclear why a relational attentional bias was only evident in the red-yellow color space in the present study, although across both experiments we find evidence for relational attentional bias that cannot be explained by color differences per se and no evidence for a feature-specific bias. Thus, our findings are clearly inconsistent with the learning and persistence of a feature-specific bias and are much better explained by a relational account of selection history effects on attentional control.

Although the neural mechanism that supports feature tuning is increasingly well understood (e.g., Itthipuripat et al., 2009; Ling et al., 2015; Maunsell, 2015; Serences, 2008; Sprague & Serences, 2013), the same cannot be said for relational priorities or relational tuning. Becker (2014) contends that theories claiming that feature maps and feature detectors guide attention (Martinez-Trujillo & Treue, 2004; Motter, 1994; Nakayama & Martini, 2011) are flawed because opponent-color cells do not respond to a specific color, and that 'relational neurons' may aggregate inputs from different cones and pass them to later cortical areas to be transformed into feature relationships (Conway, 2001; De Valois, Cottaris, Elfar, Mahon, & Wilson, 2000). However, direct neurophysiological evidence in support of this assertion is lacking. Another possibility is that relational tuning is influenced by mechanisms of stimulus suppression (e.g., Gaspelin et al., 2015, Gaspelin & Luck, 2018). Rather than, or in addition to, learning to prioritize the reddest stimuli, perhaps participants are suppressing stimuli on the yellow end of the color spectrum. Many color-responsive neurons have tuning curves in which a range of colors elicit above-baseline activation (Hubel & Wiesel, 1962; Johnson, Hawken, & Shapley, 2008; Schein & Desimone, 1990), so it is possible that when suppressing yellow, orange stimuli elicit some of this suppression but red less so. There are several sources of evidence that selection history can give rise to learned

suppression of a stimulus feature (e.g., Anderson & Kim, 2020; Gregoire, Britton, & Anderson, in press; Vatterott, Mozer, & Vecera, 2018). This would allow relational tuning and feature tuning to work in tandem, rather than in opposition, since one prioritizes a feature while the other suppresses.

Functional Magnetic Resonance Imaging (fMRI) can be paired with multivariate analyses (Lewis-Peacock & Norman, 2013; Mahmoudi, Takerkart, Regragui, Boussaoud, & Brovelli, 2012) and more sophisticated modeling (Serences, 2008; Brouwer & Heeger, 2009; Itthipuripat et al., 2009; Sprague & Serences, 2013) to investigate how populations of neurons in the brain prioritize relational information. Another interesting and related issue for future research concerns the precision of relational tuning of attention. It is presently unclear which color boundaries define a relational attentional set. If a participant's attentional set is tuned to "redder-than" stimuli, for instance, a magenta stimulus (or another color mixture substantially incorporating red) might—or might not—be perceived as "redder than" an orange stimulus. Lastly, our experiment provides no evidence that associative reward learning affects the strength with which search strategies are employed and/or persist into extinction. This finding further corroborates prior evidence that associative reward learning and target history effects reflect independent sources of attentional bias (Anderson, Chiu, DiBartolo, & Leal, 2017; Anderson & Britton, 2019; Kim & Anderson, 2019a, 2019b). It remains unclear whether reward learning can influence the rate at which particular search strategies are selected and utilized, which would require a training phase with differential reward that allows for the assessment of strategy throughout the course of learning.

In conclusion, our study demonstrates that relational attentional orienting can be learned from task experience and that it persistently guides attention in a different task context, even though it is no longer useful in localizing the target. In this way, target history effects on the control of attention (Anderson & Britton, 2019; Kim & Anderson, 2019b; Kyllingsbaek et al., 2001; Kyllingsbæk et al., 2014; Qu et al., 2017; Shiffrin & Schneider, 1977) need not reflect feature-specific learning or tuning and can, at least under appropriate learning conditions, reflect something more akin to search mode perseveration (Leber & Egeth, 2006a, 2006b; Leber et al., 2009). In this way, the present study highlights a role of relational information in selection history (Awh, Belopolsky, & Theeuwes, 2012) as it pertains to the control of attention.

11. Open practices statement

The reported experiment was not preregistered. Raw data for the experiment are downloadable as supplemental material.

CRediT authorship contribution statement

Ming-Ray Liao: Conceptualization, Methodology, Software, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Formal analysis. **Mark K. Britton:** Conceptualization, Methodology, Investigation, Software, Writing - original draft, Writing - review & editing. **Brian A. Anderson:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision, Formal analysis.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://

References

Anderson, B. A., & Yantis, S. (2012). Value-driven attentional and oculomotor capture during goal-directed, unconstrained viewing. *Attention, Perception, & Psychophysics, 74*, 1644–1653. https://doi.org/10.3758/s13414-012-0348-2.

Anderson, B. A. (2016). The attention habit: How reward learning shapes attentional selection. *Annals of the New York Academy of Sciences, 1369*, 24–39.

Anderson, B. A., & Britton, M. K. (2019). Selection history in context: Evidence for the role of reinforcement learning in biasing attention. *Attention, Perception, & Psychophysics, 81*, 2666–2672.

Anderson, B. A., & Britton, M. K. (in press). On the automaticity of attentional orienting to threatening stimuli. Emotion.

Anderson, B. A., Chiu, M., DiBartolo, M. M., & Leal, S. L. (2017). On the distinction between value-driven attention and selection history: Evidence from individuals with depressive symptoms. *Psychonomic Bulletin & Review, 24*, 1636–1642.

Anderson, B. A., & Folk, C. L. (2010). Variations in the magnitude of attentional capture: Testing a two-process model. *Attention, Perception, & Psychophysics, 72*, 342–352.

Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences, USA, 108*, 10367–10371.

Anderson, B. A., Laurent, P. A., & Yantis, S. (2012). Generalization of value-based attentional priority. *Visual Cognition, 20*, 647–658.

Anderson, B. A., & Kim, A. J. (2020). Selection history-driven signal suppression. *Visual Cognition, 28*, 112–118.

Anderson, B. A., & Kim, H. (2019a). On the relationship between value-driven and stimulus-driven attentional capture. *Attention, Perception, & Psychophysics, 81*, 607–613.

Anderson, B. A., & Kim, H. (2019b). Test–retest reliability of value-driven attentional capture. *Behavior Research Methods, 51*, 720–726.

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences, 16*, 437–443.

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics, 55*, 485–496.

Becker, S. I. (2010). The role of target–distractor relationships in guiding attention and the eyes in visual search. *Journal of Experimental Psychology: General, 139*, 247–265.

Becker, S. I. (2014). Guidance of attention by feature relationships: The end of the road for feature map theories?. In Current Trends in Eye Tracking Research (pp. 37–49). Springer, Cham.

Becker, S. I., Folk, C. L., & Remington, R. W. (2010). The role of relational information in contingent capture. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 1460–1476.

Becker, S. I., Folk, C. L., & Remington, R. W. (2013). Attentional capture does not depend on feature similarity, but on target-nontarget relations. *Psychological Science, 24*, 634–647.

Becker, S. I., Harris, A. M., Venini, D., & Retell, J. D. (2014). Visual search for color and shape: When is the gaze guided by feature relationships, when by feature values? *Journal of Experimental Psychology: Human Perception and Performance, 40*, 264–291.

Becker, S. I., Harris, A. M., York, A., & Choi, J. (2017). Conjunction search is relational: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 43*, 1828–1842.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*(4), 433–436. https://doi.org/10.1163/156856897X00357.

Brouwer, G. J., & Heeger, D. J. (2009). Decoding and reconstructing color from responses in human visual cortex. *Journal of Neuroscience, 29*, 13992–14003.

Buodo, G., Sarlo, M., & Munafò, M. (2010). The neural correlates of attentional bias in blood phobia as revealed by the N2pc. *Social Cognitive and Affective Neuroscience, 5*, 29–38.

Conway, B. R. (2001). Spatial structure of cone inputs to color cells in alert macaque primary visual cortex (V-1). *Journal of Neuroscience, 21*, 2768–2783.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193–222.

De Valois, R. L., Cottaris, N. P., Elfar, S. D., Mahon, L. E., & Wilson, J. A. (2000). Some transformations of color information from lateral geniculate nucleus to striate cortex. *Proceedings of the National Academy of Sciences, USA, 97*, 4997–5002.

Eimer, M., & Kiss, M. (2007). Attentional capture by task-irrelevant fearful faces is revealed by the N2pc component. *Biological Psychology, 74*, 108–112.

Elliot, A. J., & Maier, M. A. (2007). Color and psychological functioning. *Current Directions in Psychological Science, 16*, 250–254.

Elliot, A. J., Maier, M. A., Moller, A. C., Friedman, R., & Meinhardt, J. (2007). Color and psychological functioning: The effect of red on performance attainment. *Journal of Experimental Psychology: General, 136*, 154–168.

Failing, M., & Theeuwes, J. (2018). Selection history: How reward modulates selectivity of visual attention. *Psychonomic Bulletin & Review, 25*, 514–538.

Failing, M., Wang, B., & Theeuwes, J. (2019). Spatial suppression due to statistical regularities is driven by distractor suppression not by target activation. *Attention, Perception, & Psychophysics, 81*, 1405–1414.

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 847–858.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1030–1044.

Folk, C. L., & Remington, R. W. (2015). Unexpected abrupt onsets can override a top-down set for color. *Journal of Experimental Psychology: Human Perception and*

Performance, 41, 1153–1165.

Gaspelin, N., Leonard, C. J., & Luck, S. J. (2015). Direct evidence for active suppression of salient-but-irrelevant sensory inputs. *Psychological Science, 26*, 1740–1750.

Gaspelin, N., & Luck, S. J. (2018). Distinguishing among potential mechanisms of singleton suppression. *Journal of Experimental Psychology: Human Perception and Performance, 44*, 626–644.

Gregoire, L., Britton, M. K., & Anderson, B. A. (in press). Motivated suppression of value- and threat-modulated attentional capture. Emotion.

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience, 18*, 604–613.

Horstmann, G. (2002). Evidence for attentional capture by a surprising color singleton in visual search. *Psychological Science, 13*, 499–505.

Horstmann, G., & Ansorge, U. (2006). Attentional shifts to rare singletons. *Visual Cognition, 14*, 295–325.

Horstmann, G., & Ansorge, U. (2016). Surprise capture and inattentional blindness. *Cognition, 157*, 237–249.

Horstmann, G., & Herwig, A. (2016). Novelty biases attention and gaze in a surprise trial. *Attention, Perception, & Psychophysics, 78*, 69–77.

Hubel, D. H., & Wiesel, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *The Journal of Physiology, 160*, 106–154.

Itthipuripat, S., Vo, V. A., Sprague, T. C., & Serences, J. T. (2019). Value-driven attentional capture enhances distractor representations in early visual cortex. *PLoS Biology, 17*, e3000186.

Johnson, E. N., Hawken, M. J., & Shapley, R. (2008). The orientation selectivity of color-responsive neurons in macaque V1. *Journal of Neuroscience, 28*, 8096–8106.

Kiss, M., Jolicœur, P., Dell'Acqua, R., & Eimer, M. (2008). Attentional capture by visual singletons is mediated by top-down task set: New evidence from the N2pc component. *Psychophysiology, 45*, 1013–1024.

Kim, H., & Anderson, B. A. (2019a). Dissociable components of experience-driven attention. *Current Biology, 29*, 841–845.

Kim, H., & Anderson, B. A. (2019b). Dissociable neural mechanisms underlie value-driven and selection-driven attentional capture. *Brain Research, 1708*, 109–115.

Kim, H., & Anderson, B. A. (in press). How does the attention system learn from aversive outcomes? Emotion.

Kyllingsbaek, S., Schneider, W. X., & Bundesen, C. (2001). Automatic attraction of attention to former targets in visual displays of letters. *Perception & Psychophysics, 63*, 85–98.

Kyllingsbæk, S., Van Lommel, S., Sørensen, T. A., & Bundesen, C. (2014). Automatic attraction of visual attention by supraletter features of former target strings. *Frontiers in Psychology, 5*, 1383.

Le Pelley, M. E., Pearson, D., Griffiths, O., & Beesley, T. (2015). When goals conflict with values: Counterproductive attentional and oculomotor capture by reward-related stimuli. *Journal of Experimental Psychology: General, 144*, 158–171.

Lewis-Peacock, J.A., & Norma, K.A. (2013). Multi-voxel pattern analysis of fMRI data. In M.S. Gazzaniga & G.R. Mangun (Eds.), The Cognitive Neurosciences (5th ed., pp. 911-920). Cambridge, MA: MIT Press.

Liao, M. R., & Anderson, B. A. (2020). Reward learning biases the direction of saccades. *Cognition, 196*, 104145.

Ling, S., Jehee, J. F., & Pestilli, F. (2015). A review of the mechanisms by which attentional feedback shapes visual selectivity. *Brain Structure and Function, 220*, 1237–1250.

Leber, A. B., & Egeth, H. E. (2006a). Attention on autopilot: Past experience and attentional set. *Visual Cognition, 14*, 565–583.

Leber, A. B., & Egeth, H. E. (2006b). It's under control: Top-down search strategies can override attentional capture. *Psychonomic Bulletin & Review, 13*, 132–138.

Leber, A. B., Kawahara, J. I., & Gabari, Y. (2009). Long-term abstract learning of attentional set. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1385–1397.

Mahmoudi, A., Takerkart, S., Regragui, F., Boussaoud, D., & Brovelli, A. (2012). Multivoxel pattern analysis for FMRI data: A review. *Computational and Mathematical Methods in Medicine, 2012*, 961257.

Martin, A., & Becker, S. I. (2018). How feature relationships influence attention and awareness: Evidence from eye movements and EEG. *Journal of Experimental Psychology: Human Perception and Performance, 44*, 1865–1883.

Martinez-Trujillo, J. C., & Treue, S. (2004). Feature-based attention increases the selectivity of population responses in primate visual cortex. *Current Biology, 14*, 744–751.

Maunsell, J. H. (2015). Neuronal mechanisms of visual attention. *Annual Review of Vision Science, 1*, 373–391.

Moreland, K. (2009). Diverging color maps for scientific visualization. In International Symposium on Visual Computing (pp. 92–103). Springer, Berlin, Heidelberg.

Motter, B. C. (1994). Neural correlates of attentive selection for color or luminance in extrastriate area V4. *Journal of Neuroscience, 14*, 2178–2189.

Nakayama, K., & Martini, P. (2011). Situating visual search. *Vision Research, 51*, 1526–1537.

Nissens, T., Failing, M., & Theeuwes, J. (2017). People look at the object they fear: Oculomotor capture by stimuli that signal threat. *Cognition and Emotion, 31*, 1707–1714.

Qi, S., Zeng, Q., Ding, C., & Li, H. (2013). Neural correlates of reward-driven attentional capture in visual search. *Brain Research, 1532*, 32–43.

Qu, Z., Hillyard, S. A., & Ding, Y. (2017). Perceptual learning induces persistent attentional capture by nonsalient shapes. *Cerebral Cortex, 27*, 1512–1523.

Retell, J. D., Venini, D., & Becker, S. I. (2015). Oculomotor capture by new and unannounced color singletons during visual search. *Attention, Perception, & Psychophysics, 77*, 1529–1543.

Reynolds, J. H., & Chelazzi, L. (2004). Attentional modulation of visual processing. *Annual Review of Neuroscience, 27*, 611–647.

Robertson, A. R. (1977). The CIE 1976 color-difference formulae. *Color Research & Application, 2*, 7–11.

Serences, J. T. (2008). Value-based modulations in human visual cortex. *Neuron, 60*, 1169–1181.

Schein, S. J., & Desimone, R. (1990). Spectral properties of V4 neurons in the macaque. *Journal of Neuroscience, 10*, 3369–3389.

Schönhammer, J. G., Grubert, A., Kerzel, D., & Becker, S. I. (2016). Attentional guidance by relative features: Behavioral and electrophysiological evidence. *Psychophysiology, 53*, 1074–1083.

Schubö, A., & Müller, H. J. (2009). Selecting and ignoring salient objects within and across dimensions in visual search. *Brain Research, 1283*, 84–101.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84*, 127–190.

Sprague, T. C., & Serences, J. T. (2013). Attention modulates spatial priority maps in the human occipital, parietal and frontal cortices. *Nature Neuroscience, 16*, 1879–1887.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics, 51*, 599–606.

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review, 11*, 65–70.

Vatterott, D. B., Mozer, M. C., & Vecera, S. (2018). Rejecting salient distractors: Generalization from experience. *Attention, Perception, & Psychophysics, 80*, 485–499.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review, 1*, 202–238.

Yantis, S. (1993). Stimulus-driven attentional capture and attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 676–681.