Visual attention to features by associative learning

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ABSTRACT

Expecting a particular stimulus can facilitate processing of that stimulus over others, but what is the fate of other stimuli that are known to co-occur with the expected stimulus? This study examined the impact of learned association on feature-based attention. The findings show that the effectiveness of an uninformative color transient in orienting attention can change by learned associations between colors and the expected target shape. In an initial acquisition phase, participants learned two distinct sequences of stimulus–response–outcome, where stimuli were defined by shape ('S' vs. 'H'), responses were localized key-presses (left vs. right), and outcomes were colors (red vs. green). Next, in a test phase, while expecting a target shape (80% probable), participants showed reliable attentional orienting to the color transient associated with the target shape, and showed no attentional orienting with the color associated with the alternative target shape. This bias seemed to be driven by learned association between shapes and colors, and not modulated by the response. In addition, the bias seemed to depend on observing target–color conjunctions, since encountering the two features disjunctively (without spatiotemporal overlap) did not replicate the findings. We conclude that associative learning – likely mediated by mechanisms underlying visual object representation – can extend the impact of goal-driven attention to features associated with a target stimulus.

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1. Introduction

Our perceptual world is rich with regularities, and it is reasonable to assume that our nervous system takes advantage of these regularities (e.g., Bar, 2007; Chun & Turk-Browne, 2008). The environment we are in (e.g., classroom, driving a car, etc.) can constrain our expectation about the kinds of perceptual events we might encounter; similarly, identifying objects in front of us (e.g., a whiteboard) shapes our assumptions about other objects that we might see nearby (e.g., markers). The present study examines the impact of learned associations on prioritization of visual features. We introduced participants to two arbitrary shape–color combinations in an initial acquisition phase.

Following that acquisition, we examined whether expecting to see one feature (shape) could lead to prioritizing the other feature (color). Finding evidence in support of this possibility, we propose that attention to a feature partly relies on the prioritization of the episode to which it belongs.

Previous work on visual attention has examined the impact of learned regularities, with perhaps the simplest form of regularity being probability of target appearance in space. If a location has a relatively high probability of containing the visual target, participants can learn this and begin to respond more efficiently to targets at this location, relative to low-probability locations (Shaw & Shaw, 1977). The task, however, could involve multiple locations and multiple potential targets, with each visual target having a unique spatial probability distribution. Employing such a design, Miller (1988) found that learning about a high-probability location does not confer an equal

benefit for all visual targets, but rather benefits only the specific target associated with that location.

A more complex type of regularity has to do with the relationship between a visual item and its surrounding items. In general, exposure to arrangements of visual objects can lead to learning pattern consistencies, including where particular shapes are likely to appear in relation to one another (Fiser & Aslin, 2001). Examining the impact of such learning on visual attention, Chun and Jiang (1998) employed a visual search task in which the spatial arrangement of distractors reliably predicted target location, and found faster performance relative to when distractor locations were not predictive. Similarly, when distractor shapes predicted target shape, performance was faster than when distractor shapes were not predictive (Chun & Jiang, 1999).

Another consequence of visual learning, pertaining to the present study, is that learning can give a non-target stimulus attentional advantage due to its association to a target stimulus. In such a scenario, the non-target stimulus is said to enjoy *derived attention* (James, 1890). Lambert, Naikar, McLachlan, and Aitken (1999) demonstrated an example of derived attention in a visual detection task. On each trial, participants responded to a target appearing inside the left or right placeholder. Just prior to target onset, the letters 'S' and 'W' were presented near the two placeholders, with one letter having a high probability (80%) of appearing near the upcoming target. After some exposure to the task, participants' performance demonstrated signs of learning this letter–target association. The time-course of this form of bias mirrors stimulus-driven spatial orienting (facilitation and inhibition with short and long cue–target delays, respectively; Posner & Cohen, 1984), but further experiments suggested dissociation between the two (Geng & Behrmann, 2002, 2005; Lambert, Norris, Naikar, & Aitken, 2000).

Although previous work supports the notion of derived attention, this form of attention has thus far been obtained in rather simple conditions. For instance, participants can learn to prioritize the space near 'S' over 'W' when the two letters are laterally presented (Lambert et al., 1999, 2000), the left half of an object over its right half (Kristjánsson, Mackeben, & Nakayama, 2001), or the green portion of an object over the red portion (Kristjánsson & Nakayama, 2003). What these tasks have in common is the requirement to continually select a *single* feature over an alternative feature. It is, therefore, unclear whether a more flexible form of derived attention (i.e., attention to non-target stimuli) could develop for both possible features. For instance, in the experiments by Lambert et al. (1999, 2000), could participants learn to differently prioritize between the two letters ('S' and 'W') based on other information? There is, indeed, some evidence against such possibility.

In an experiment by Kristjánsson et al. (2001), the target predictably switched from appearing on the left or right portion of a cueing object. Interestingly, this fully predictable pattern (an association between trial order and target location) did not lead to better performance compared to a fully randomized condition. In a variant of this design, Kristjánsson and Nakayama (2003) tested whether participants could benefit from a relationship between cue feature (e.g., color) and the segment of the cue that contained the target (left vs. right). When target location was contingent on a cue color (or cue shape), there was no performance benefit relative to complete randomization. The authors concluded that while repetitive selection of one feature facilitates further selection of that feature (similar to continuously selecting 'S' over 'W' in Lambert et al., 1999), second-order relationships between features (i.e., multiple rules in the form of "*if green then left*") are not possible. It is worth noting that the type of learning reported by (Kristjánsson et al., 2001; Kristjánsson & Nakayama, 2003; for a review, see Kristjánsson, 2006) emerged quite rapidly and within a few trials. This time frame may not be sufficient for higher-order learning or its impact on attention.

Another reason Kristjánsson and Nakayama (2003) did not find any attentional benefit with second-order relationships could be that the cue features (itself a task-irrelevant dimension) predicted an irrelevant target feature (within-cue location) rather than the relevant target feature (i.e., target identity). Given the complex task structure, involving four separate dimensions (target identities, target locations, cue features, and within-cue locations), the irrelevant dimensions may receive reduced processing weight compared to when the irrelevant dimension is set on a constant feature and is selected on every trial (e.g., Kristjánsson et al., 2001; Lambert et al., 1999, 2000). In effect, binding between the two irrelevant features, and the subsequent associative learning, may have been prevented. As demonstrated by Hommel (1998), the chance of feature binding between two irrelevant dimensions is lower than the chance of binding between a relevant dimension and an irrelevant dimension.

In addition to task-irrelevance of the to-be-learned features, another problem may be with the brief exposure time of the stimuli used in Kristjánsson and Nakayama (2003). Requiring extraction of information from thin slices of time (i.e., masked, briefly-presented displays) may artificially alter the contribution of the magnocellular pathway (Westheimer & Pettet, 1990). Although an increase in magnocellular activity would facilitate perception through higher temporal acuity, it may interfere with feature binding (Gozli, Ardron, & Pratt, 2014; Kelly & Brockmole, 2014) and, therefore, with visual associative learning.

For all of the aforementioned reasons, there remains the possibility that people can learn second-order associations and this learning can impact visual attention. It is exploring this possibility that is the major goal of the present study, and to assist associative learning between features, we implemented an initial acquisition phase (addressing the issue of sufficient learning time), utilized a task in which one of the two features was task-relevant, and did not use briefly-presented, masked visual targets.

2. Experiment 1

Like all of the experiments in the present study, this experiment consists of two separate phases. First, in the acquisition phase, participants learned the

stimulus–response–outcome mappings. A target stimulus was defined by shape (letters 'S' and 'H'); a response was a left or right keypress; an outcome was a color (red or green) produced immediately after a response (e.g., after pressing the right key all items on the display turned red). Next, we test the attentional consequence of this learning in a test phase. On each trial of the test phase, one of the two shapes was indicated as the most likely target (shape cue) at the beginning of the trial. Critically, after presentation of the shape cue and before presentation of the target stimuli, an irrelevant color transient was presented at one of the possible target locations (Fig. 1). The extent to which attention is allocated to this color transient is reflected in the difference between response times to targets at the location of the color transient and response times to targets the opposite location (i.e., cueing effect; Posner, Snyder, & Davidson, 1980).

We predict selective attention to colors to be modulated based on learned shape–color association. For instance, expecting the letter 'S' would bias selection toward the color that is consistently perceived after selecting the target letter 'S'. Alternatively, selection may be biased against the alternative color, and here we should see a weaker spatial orienting effect produced by color transients that are incongruent with the activated sequence compared to color transients that are congruent with the activated sequence.

Assuming that there is a difference in attention to congruent and incongruent color transients, we were interested in examining whether this difference could be attributed to a bias toward the congruent colors (i.e., facilitation) or a bias against incongruent colors (i.e., inhibition). To this end, we included a neutral color among possible color transients. This color was not associated with either of the two target shapes and, therefore, a bias toward one of the targets should not modulate attention to the neutral color. We reasoned that if incongruent transients are significantly less effective than both congruent and neutral colors, then we could infer inhibition of the incongruent colors. On the other hand, if congruent transients are significantly more effective than both

incongruent and neutral colors, then we could infer facilitation of the congruent colors.

2.1. Method

2.1.1. Participants

Twenty University of Toronto undergraduate students gave their informed consent and participated in exchange for course credit. All participants reported normal or corrected-to-normal vision and were unaware of the purpose of the study. All experimental protocols were approved by the University of Toronto Research Ethics Board.

2.1.2. Apparatus and stimuli

The experimental program was run in Matlab (Math-Works, Natick, MA), using the Psychophysics toolbox (Brainard, 1997; Pelli, 1997; version 3.0.8) on Windows-run PCs. Participants performed the task in dimly lit rooms. Stimuli were presented on 19″ CRT monitors set at 1024 × 768 resolution and 85 Hz refresh rate. Using a head-rest, participants' distance from the display was fixed at about 45 cm.

The display structure and the sequence of events are shown in Fig. 1. Stimuli appeared in white (CIE-Lab coordinates = 100, −5.3, 5.4), red (46.10, 78.96, 29.79), green (83.57, −72.52, 50.84), or blue (26.87, 72.88, −190.92), against a black background (0,0,0). Two horizontally aligned squares (size = 2° × 2°) functioned as placeholders for shape stimuli (targets: 'S' and 'H'; distractors: 'E' and 'U', approximately .5° × 1° in size, presented in Arial font). The center of each placeholder deviated by 5° of visual angle from fixation.

2.1.3. Procedure

For the acquisition phase, each trial began with the presentation of empty placeholders and the central fixation cross "+" (1° × 1°). Participants were instructed to begin each trial by looking at the fixation cross. After a 1000-ms delay, letter stimuli appeared inside the placeholders, consisting of one target letter ('S' or 'H') and one distractor letter ('U' or 'E'). Participants were instructed to respond as
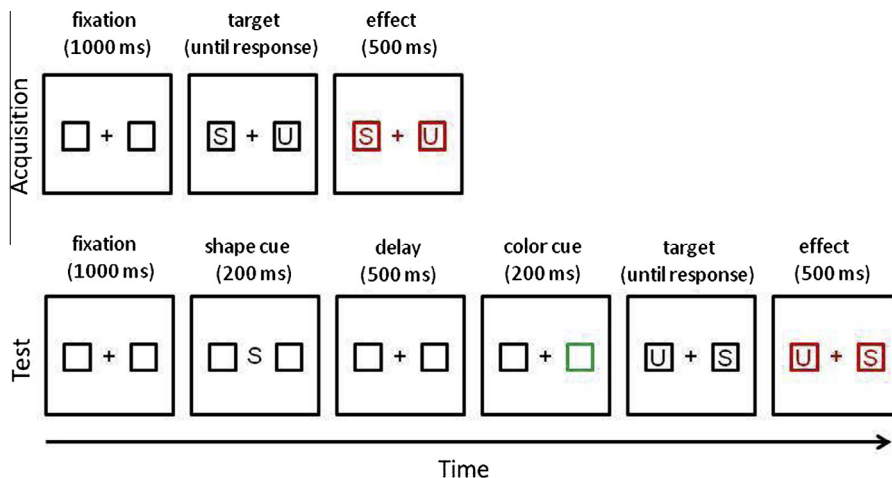

Fig. 1. Sequence of events on a sample trial of Experiment 1.

quickly as possible with a right-hand keypress (the '/' button on the keyboard) when identifying 'S' and with a left-hand keypress (the 'Z' button on the keyboard) when identifying 'H'. The letters remained on the screen until one of the two possible responses was recorded. Immediately after a response, all items on the display changed color (turning red after a right-hand keypress, and green after a left-hand keypress). This color outcome remained on the screen for 500 ms, and was produced depending on the performed response and regardless of the correctness of the response. After an incorrect keypress, participants first saw the color outcome associated with their performed response (500 ms), and then the error feedback ("MISTAKE", 2000 ms). Participants also received feedback for anticipation errors ("TOO QUICK!") or late responses ("TOO LATE!"), respectively defined as response times faster than 100 ms and slower than 2000 ms.

Each trial of the test phase also began with the presentation of the central fixation cross and the empty placeholders. After a 1000-ms delay, the fixation cross was replaced by a shape cue: one of two possible targets ('S' or 'H'), remaining on display for 200 ms. Participants were informed that the shape cue predicted the target with 80% accuracy. The shape cue was then replaced by the fixation cross, remaining for another 500 ms. Next, the color transient appeared: one of the placeholders changed color (to red, green, or blue) and after a 200-ms delay changed back to white. Participants were informed that the color transient was uninformative.[1] Simultaneously with the disappearance of the color transient the letter stimuli appeared inside the two placeholders. Similar to the acquisition phase, all stimuli changed color immediately after a response. The mapping between the responses and outcomes did not change across the two parts of the experiment.

2.1.4. Design and analysis

Participants completed one acquisition phase, consisting of 200 trials, followed by a test phase that consisted of 240 trials. Both phases preceded by 10 practice trials. Target letter ('S' vs. 'H'), distractor letter ('E' vs. 'U'), and target location (left vs. right) were randomized and equally probable. In addition, during the test phase the central shape cue was equally likely to indicate 'H' or 'S', predicting target shape with 80% validity. On the other hand, location and color of the spatial cue were both uninformative, predicting target location and response with chance-level validity. The color transient coincided with target location on 50% of trials (valid). On a third of the trials, the color transient had the same color as the outcome of the primed sequence (congruent). On another third of the trials, the transient had the color associated with the alternative sequence (incongruent). Finally, on a third of trials the transient was blue, not associated with either sequences (neutral).

Analysis of data from the test phase was performed in two steps. First, we tested the effect of shape cues. In particular, we needed to establish that the central letter cue biased performance without being the sole source of response selection. That is, trials with invalid shape cues (20% of trials) served as catch trials and high accuracy on these trials would suggest that participants processed the target stimuli, rather than solely responding based on the shape cue. In the second step, performance was analyzed as a function of the color of the spatial cue (congruent, incongruent, or neutral in relation to the activated stimulus–response–outcome sequence) and the location of the spatial cue relative to the target (valid vs. invalid). In this step of the analysis valid and invalid shape–cue trials were collapsed together. If attention is biased toward the color cue, we expect faster RTs with valid spatial cues, compared to invalid spatial cues. If the validity effect is sensitive to whether the color of the cue belongs to the expected stimulus–response–outcome sequence, a stronger validity effect generated by congruent spatial cues compared to incongruent spatial cues should be found.

2.2. Results and discussion

2.2.1. Acquisition phase

After excluding incorrect responses and responses faster than 100 ms and those that fell beyond $2.5SDs$ of the total mean (2.6% of trials), mean RT was 551 ms (SE = 14). Mean error rate was 4.0% (SE = 1%). Overall, these data suggest good performance during the acquisition phase.

2.2.2. Test phase: effect of shape cues

To ensure that participants processed the shape cue without actually responding to it, we compared RTs and error rates as a function of the validity of the shape cue. With valid shape cues, responses were faster (M ± SE = 515 ± 18 ms) and more accurate (error rate = 3% ± .6%), compared to the RTs (579 ± 17 ms, $t[19] = 4.86$, SE = 13, $p < .001$) and error rate (7% ± 1.3%, $t[19] = 2.53$, SE = .012, $p = .02$) following invalid shape cues. This suggests that the shape cue, on average, biased performance. On the other hand, with a mean accuracy of 93% on trials with invalid shape cues (all participants had accuracies above 77% on these trials), we reasoned that participants made responses to the target stimuli and not to the shape cue.

2.2.3. Test phase: effect of color transients

Mean RTs were submitted to a 3 × 2 repeated-measures ANOVA, with color (congruent, incongruent, or neutral) and location (valid vs. invalid) as factors (see Fig. 2). This ANOVA revealed no main effect of color, $F(2,38) < 1$, but there was a main effect of location, $F(1,19) = 16.60$, $p < .001$, $\eta_p^2 = .466$, and a two-way interaction, $F(2,38) = 3.68$, $p = .034$, $\eta_p^2 = .162$. Overall, RTs were faster with valid spatial cues (519 ± 16 ms) than invalid spatial cues (534 ± 18 ms). Most importantly, examining the two-way interaction revealed significant validity effects when the color of the transient was congruent [$t(19) = 3.48$, SE = 6.34, $p = .003$] or neutral [$t(19) = 3.04$, SE = 6.55, $p = .007$], but not with incongruent transients [$t(19) < 1$].

An initial analysis of error rates did not reveal any significant finding. To obtain a more sensitive analysis of

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[1] Post-experiment debriefing confirmed that color transients were not voluntarily attended.
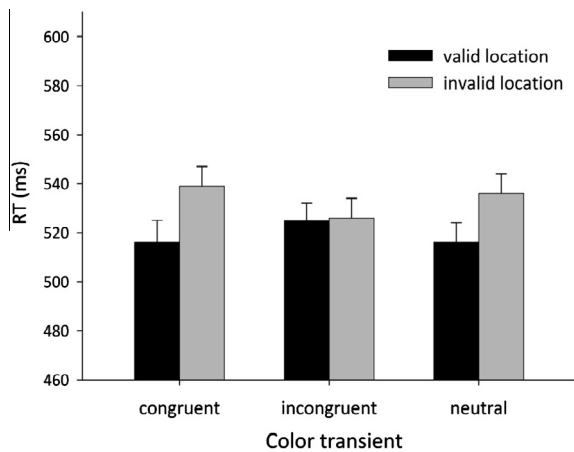
Fig. 2. Response time (RT) data from Experiment 1, as a function of the color and location of the spatial cue (i.e., color transient). The cue color, in relation to the primed shape, could be congruent, incongruent, or neutral. The location, in relation to target location, could be valid or invalid. Error bars represents 95% within-subjects confidence intervals (Cousineau, 2007).

identification errors, missed trials were excluded (those including errors of anticipation or late responses; together constituting only .4% of the total trials). Due to the low percentage of the remaining errors (3.8%), we performed the repeated measures ANOVA on arcsine transformation of the mean error rates. This analysis revealed a marginal effect of cue color ($F[2,38] = 2.79$, $p = .074$, $\eta_p^2 = .128$), but no effect of cue location ($F[1,19] = 1.28$, $p = .271$, $\eta_p^2 = .063$) or a two-way interaction ($F < 1$). The marginal effect of cue color was indicative of a higher error rate with congruent colors (4.5%), compared to incongruent (3.2%) and neutral colors (3.6%). It is important to distinguish the interpretation of this effect from that of a two-way interaction. Whereas a two-way interaction would indicate different attentional treatment of colors, a main effect of color does not indicate such attentional modulation. Instead, the main effect of color likely indicates a response bias (e.g., the color green made subjects more prone to selecting the "H" response, regardless of target location and cue–target spatial relationship). This response bias would increase the likelihood of erroneously reporting a letter that is associated with the color cue, but it will *not* vary based on cue location. In the absence of a two-way interaction in identification errors, we can rule out the possibility that the main RT findings were due to speed-accuracy trade-off.

Next, we submitted percentage of missed trials (arcsine transformed) to the same ANOVA. This analysis did not reveal any main effect or interaction (F values <1.2, p values >.3). In light of the low percentage of missed trials, it stands to reason that anticipatory errors and late responses do not vary systematically with our experimental manipulations.

The findings of the present experiment showed, first of all, that the shape cue successfully biased performance. In addition to faster responses on valid shape–cue trials, shape cues also influenced attention to color transients.

Specifically, a stronger orienting effect by congruent transients relative to incongruent transients suggests a bias toward the color of the activated sequence and/or a bias against the color of the alternative sequence.

There are two indications that the modulation of attentional bias for color transients was, at least partly, due to inhibition of the incongruent colors. The first indication is that the cueing produced by the congruent and neutral colors were statistically indistinguishable. The second indication of inhibition of incongruent colors was revealed in examining individual differences in using the shape cue. We assumed, on the one hand, that any different treatment of color transients (i.e., the difference between congruent and incongruent colors) would be stronger in participants who utilized the shape cue more reliably. On the other hand, those participants who ignored the shape cue or used this cue less reliably were expected to show similar treatment of congruent and incongruent color transients. We divided the participants based on the effect of the shape cue (invalid RT – valid RT), which resulted in a "strong shape cueing" group (mean cueing effect ± SE = 108 ± 16 ms) and a "weak shape cueing" group (21 ± 10 ms). We then submitted the grouped RT data to a mixed $3 \times 2 \times 2$ ANOVA with congruency and validity of the spatial cue as the within-subjects factors and the strength of shape cueing as the between-subjects factor (see Fig. 3). Overall, a main effect of group ($F[1,18] = 8.98$, $p < .01$, $\eta_p^2 = .33$) revealed that participants who utilized the shape cue strongly on average performed faster (484 ± 20 ms) than participants who did not utilize this cue (569 ± 20 ms). Similar to the original analysis, this ANOVA also revealed no main effect of congruency ($F[2,36] < 1$), a significant main effect of validity ($F[1,18] = 16.44$, $p < .001$, $\eta_p^2 = .48$), and a two-way interaction between congruency and validity ($F[2,36] = 4.33$, $p = .020$, $\eta_p^2 = .194$). Most importantly, a three-way interaction ($F[2,36] = 4.31$, $p = .021$, $\eta_p^2 = .193$) pointed to different patterns of findings across the two groups. As seen in the lower panel of Fig. 3, participants who used the shape cue robustly showed spatial cueing by congruent ($t[9] = 2.24$, SE = 7.14, $p = .05$) and neutral ($t[9] = 3.26$, SE = 9.12, $p = .01$) color transients, but no such cueing effect by the incongruent color ($t[9] = 1.67$, SE = 4.40, $p = .13$). Indeed, the direction of the effect by incongruent colors was opposite to what is expected, indicative of inhibition. By contrast, participants who did not reliably use the shape cues showed significant orienting effect by congruent ($t[9] = 2.67$, SE = 10.53, $p = .026$) and incongruent ($t[9] = 2.71$, SE = 5.13, $p = .024$) colors, though they did not show such cueing effect by the neutral color ($p > .2$). This is consistent with a relationship between using the shape cue to activate one of the possible shape–color episodes and inhibiting the alternative shape–color episode.

In this experiment, the stimulus–response–outcome mappings were completely consistent across the acquisition phase and the test phase. This consistency did not allow us to narrow down the mechanism underlying the bias for colors. In particular, a shape cue may have modulated attentional bias to colors due to the shape–color associations and/or due to the response–color associations.
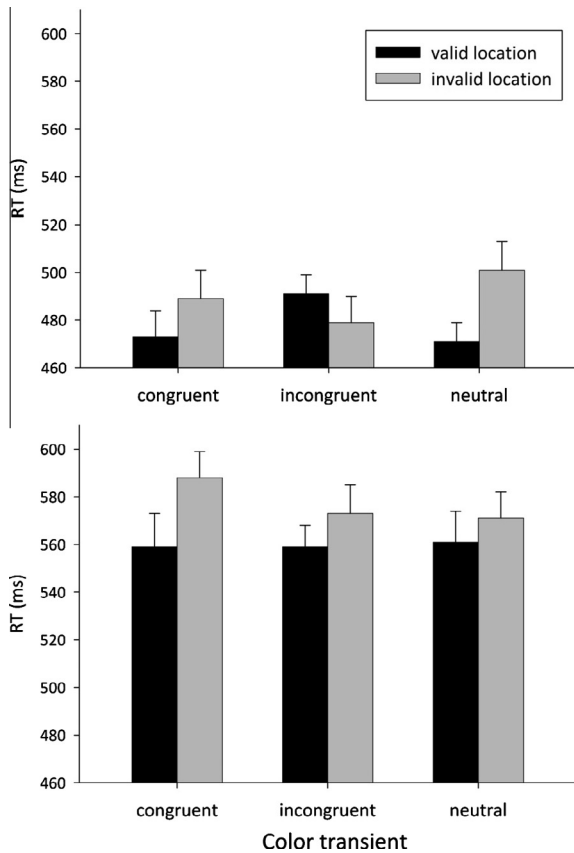
Fig. 3. Response time (RT) data from Experiment 1. The data are divided based on the strength of the effect of the shape cue. The upper panel represents the group with a strong shape cueing effect, whereas the lower panel represents the group with a weak shape cueing effect.

The next experiment aimed to test the potential role of response–color associations.

3. Experiment 2

In this experiment, we ask whether learned shape–color associations alone can drive the modulated attention to colors. In this case, after the acquisition phase, we switched the responses assigned to the target shape, thus switching both response–shape associations and response–color associations. This switch, however, preserved the shape–color association. Consequently, shape and response will be activating two different colors. Congruency of color transients was defined based on the shape–color relationships. Similar pattern of results to Experiment 1 would suggest that the altered bias for colors is indeed driven by learned shape–color associations. Finding the opposite pattern of results would indicate that response–color associations were the sole underlying mechanisms that modulate attentional bias for colors.

3.1. Method

The stimuli, procedure, and design were identical to Experiment 1, with the following exception. After completing

the acquisition phase, participants were instructed to switch the response keys assigned to each target letter. That is, in the test phase participants responded with the left-hand key to 'S' and with the right-hand key to 'H'. The color effects associated with the keys were also switched, which means the shape–color associations were preserved across the two phases of the experiment. Twenty-one University of Toronto undergraduate students participated in this experiment. They reported normal or corrected-to-normal vision and were unaware of the purpose of the study.

3.2. Results and discussion

3.2.1. Acquisition phase

After excluding incorrect responses and responses faster than 100 ms and those that fell beyond 2.5SDs of the total mean (2.3% of trials), mean response time (RT) was 519 ms (SE = 9). Mean error rate was 3.9% (SE = .5%). Overall, these data suggest good performance during the acquisition phase.

3.2.2. Test phase: effect of shape cues

Participants had faster (mean RT ± SE = 477 ± 14 ms) and more accurate (mean error rate ± SE = 4% ± 1%) responses with valid shape cues than with invalid shape cues (RT = 536 ± 12 ms, percent error = 7% ± 1%). The effect of shape cue was significant on both RTs [$t(20)$ = 6.04, SE = 9.72, $p < .001$] and error rates [$t(20)$ = 3.73, SE = .010, $p < .01$], which suggests the shape cues successfully biased performance. On the other hand, with a mean accuracy of 92% on trials with invalid shape cues (all participants had accuracies above 78% on these trials), we reasoned that responses were not solely made based on shape cues.

3.2.3. Test phase: effect of color transients

RT data were submitted to a 3×2 repeated-measures ANOVA, with color (congruent, incongruent, or neutral) and location (valid vs. invalid) of the transients as factors (see Fig. 4). This analysis did not reveal a main effect of color [$F(2,40)$ = 2.27, $p = .116$, $\eta_p^2 = .102$], but revealed a marginally significant effect of location [$F(1,20)$ = 3.89, $p = .063$, $\eta_p^2 = .162$], and a significant two-way interaction [$F(2,40)$ = 10.04, $p < .001$, $\eta_p^2 = .333$]. When the color was congruent with the shape cue, location validity had a robust effect, i.e., faster responses with valid cues (475 ± 14 ms) compared to invalid cues (507 ± 15 ms, $t[20]$ = 4.59, SE = 7.06, $p < .001$). By contrast, incongruent ($p = .43$) or neutral ($p = .18$) color transients did not produce a reliable effect.

In analyzing identification error data, missed trials were excluded (anticipations and late responses; these constitute .3% of the total trials). The remaining error rates (4%) were arcsine transformed and analyzed using the same ANOVA. The main effects of cue color and cue location did not reach significance (F values <1), but a marginally significant interaction was found ($F[1,40]$ = 2.69, $p = .08$, $\eta_p^2 = .108$). Examining this trend further showed the same pattern as the RTs. When the color transient was congruent with the shape cue, its validity produced a significant reduction in errors (2.8% and 5% for valid and invalid trials,
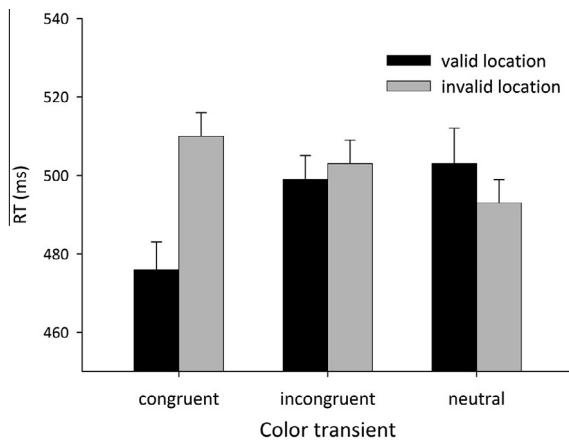
Fig. 4. Response time (RT) data from Experiment 2, as a function of the color and location of the spatial cue (i.e., color transient). Cue color, in relation to the primed target shape, could be congruent, incongruent, or neutral. Cue location, in relation to the target location, could be valid or invalid. Error bars represents 95% within-subjects confidence intervals.

respectively, $t[20] = 3.18$, SE = .007, $p < .01$). No such cueing effect was observed with incongruent ($p = .98$) or neutral ($p = .27$) color transients. The similar patterns in RTs and errors, rule out the possibility of a speed-accuracy trade-off.

Next, we submitted percentage of missed-trial errors (arcsine transformed) to the same ANOVA. This analysis did not show a main effect of cue color ($F[2,40] = 2.15$, $p = .130$, $\eta_p^2 = .097$), cue location ($F < 1$), or a two-way interaction ($F < 1$).

Similar to Experiment 1, we divided participants into two groups of 10 (excluding the median) based on the strength of shape cueing effect (invalid RT – valid RT), with a "strong shape cueing" group ($M \pm SE = 96 \pm 8$ ms) and a "weak shape cueing" group (21 ± 9 ms). We submitted the RT data to a mixed $3 \times 2 \times 2$ ANOVA with color congruency and location validity as the within-subjects factors and the strength of shape cueing as the between-subjects factor (see Fig. 5). The main effect of group ($F[1,18] = 3.10$, $p < .095$, $\eta_p^2 = .147$) did not reach significance. Furthermore, this analysis revealed a main effect of location [$F(1,18) = 4.73$, $p = .043$, $\eta_p^2 = .210$] and a marginally significant group × location interaction [$F(1,18) = 3.76$, $p = .068$, $\eta_p^2 = .208$]. As Fig. 5 shows, these effects are driven by a general orienting effect by all three color transients in the "weak-shape-cueing" group [mean valid RT ± SE = 515 ± 21 ms; invalid RT = 534 ± 21 ms, $t(9) = 3.02$, SE = 6.26, $p = .014$]. By contrast, no such orienting pattern was obtained in the "strong-shape-cueing" group [valid RT = 472 ± 21 ms; invalid RT = 473 ± 21 ms, $p > .8$). We also found a congruency × validity interaction, matching the results of the initial analysis. The three-way interaction did not reach significance [$F(2,36) = 2.30$, $p = .118$, $\eta_p^2 = .113$].

The results of this experiment are consistent with a relationship between using the shape cue to prime one of the possible sequences of stimuli and inhibiting the color feature that is not identical to the primed sequence. Spatial
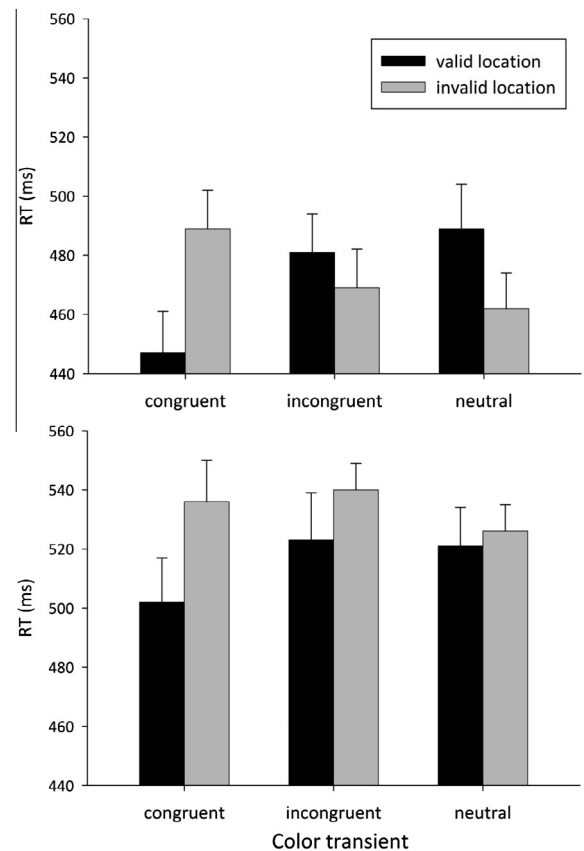

Fig. 5. Response time (RT) data from Experiment 2, divided based on the strength of the effect of the shape cue. The upper panel represents the group with a strong shape cueing effect, whereas the lower panel represents the group with a weak shape cueing effect.

orienting effects by congruent colors were similar across weak and strong shape cueing groups. By contrast, incongruent color transients had different effects across weak and strong shape cueing groups. Although this is consistent with the idea that the source of these effects is the inhibition of colors incongruent with the activated stimulus–outcome sequence, the effect of neutral transients does not support an account that is purely based on selective inhibition of incongruent colors. Such an account cannot explain why strong shape cueing was also associated with a disadvantage for neutral color transients. It is likely that facilitated processing of congruent colors might also play a role in the congruent–incongruent difference.

4. Experiment 3

The findings thus far suggest that the differential treatment of congruent and incongruent colors relies on the learned target–color associations. We are, however, faced with two possible interpretations of these findings, one of which is that this effect may depend on seeing the shape–color conjunction. Participants saw the target *in* the congruent color after performing a correct response. Does this shape–color conjunction play a critical role in

the associative learning and the derived attention to colors? If not, then it is possible that simply completing the sequence of shape–response–color is sufficient for altering the attentional treatment of colors. This latter possibility is consistent with previous work on learning sequences of perceptual elements and the ability to predict the next stimulus based on the present (e.g., Remillard, 2003). The former possibility would be consistent with the notion that continually encountering feature conjunction will lead to formation of multi-featured object representations, which then drive the attentional modulation effect. To discriminate between these two accounts, we modified Experiment 1 such that the shapes were now presented only for 100 ms (unmasked). With this modification, the target shapes were still consistently followed by colors (immediately after a response was performed), but the two never occupied the same location at the same time. Although temporal proximity of features can still lead to their inclusion into a single object representation, it is thought that the proximity needs to be shorter than 350 ms (e.g., Zmigrod & Hommel, 2011). Binding would be unlikely to occur because subjects do not see the color associated with a target shape appear until after this critical period (given the average RT was around 500 ms). Therefore, replicating the pattern found in the previous experiment would support the sequential-learning account, while not finding the same pattern would support an account based on visual object representation.

4.1. Method

The stimuli, procedure, and design were identical to Experiment 1, with the following exception. The letter stimuli ('S', 'H', 'E', and 'U') appeared for 100 ms only (instead of remaining until response), during both acquisition and test phases. After performing a response, the remaining items on the display (the two placeholders and fixation cross) changed color. Participants were twenty-two University of Toronto undergraduate students who reported normal or corrected-to-normal vision and were unaware of the purpose of the study.

4.2. Results

4.2.1. Acquisition phase

After excluding incorrect responses and responses faster than 100 ms and those that fell beyond 2.5SDs of the total mean (2.7% of trials), mean response time (RT) was 540 ms (SE = 9). Mean error rate was 6.3% (SE = .8%). Overall, these data suggest good performance during the acquisition phase.

4.2.2. Test phase: effect of shape cues

Participants had faster and more accurate responses with valid shape cues (mean RT ± SE = 516 ± 13 ms, error rate ± SE = 5% ± 1%) than with invalid shape cues (RT = 534 ± 15 ms, error rate = 4% ± 1%). The effect of shape cue was significant on RTs ($t[21] = 4.93$, SE = 6.73, $p = .01$), but not on errors ($t[21] = 1.61$, SE = .005, $p = .121$). On the other hand, with a mean accuracy of 95% on catch trials (all participants had accuracies above 87% on catch trials),

we reasoned that responses were not made solely based on the shape cue.

4.2.3. Test phase: effect of color transients

Mean RTs were submitted to a 3×2 repeated-measures ANOVA, with color (congruent, incongruent, or neutral) and location (valid vs. invalid) of the spatial cue as factors (Fig. 6). This analysis did not reveal a main effect of color ($F[2,42] = 2.26$, $p = .12$, $\eta_p^2 = .097$), but did reveal a significant effect of location ($F[1,21] = 4.28$, $p = .05$, $\eta_p^2 = .17$). Most importantly, there was no interaction ($F < 1$). Both congruent and incongruent color transients caused attentional orienting, with faster responses after valid transients (520 ± 14 ms) relative to invalid transients (531 ± 13 ms).

Identification error rates (arcsine transformed) were submitted to the same ANOVA. Neither the main effects nor the interaction reached significance (F values < 1.3, p values > .25). Thus, identification errors (4.7% ± .7%) did not vary with the independent variables. Next, we analyzed percentage of missed trials (.4% in total). This analysis also revealed no main effect or interaction (F values < 1).

Once again, we divided participants into two equal groups based on the magnitude of shape cueing effect (invalid RT – valid RT), with a "strong shape cueing" group (mean cueing effect ± SE = 42 ± 8 ms) and a "weak shape cueing" group (−4 ± 5 ms). We then submitted the RT data to a mixed $3 \times 2 \times 2$ ANOVA with color and location as the within-subjects factors and the strength of shape cueing as the between-subjects factor. Unlike previous experiments, the main effect of group did not reach significance ($F[1,20] = 1.18$, $p = .29$). We also did not find an interaction between group and any other factor (F values < 1). Instead, we only found a marginally significant effect of cue location ($F[1,20] = 3.67$, $p < .07$, $\eta_p^2 = .155$), similar to the original analysis.

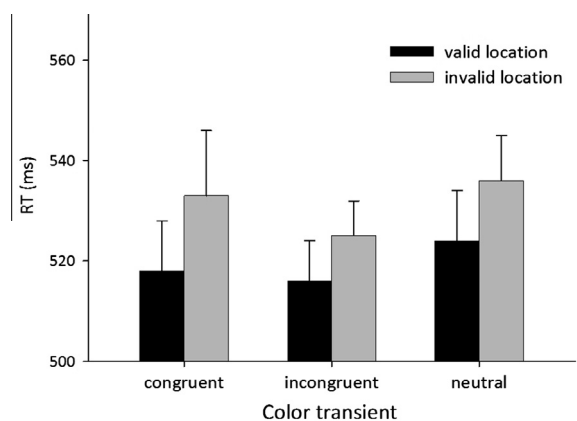The findings of the present experiment revealed no difference between the effect of congruent and incongruent

Fig. 6. Response time (RT) data from Experiment 3, graphed as a function of the color and location of the spatial cue (i.e., color transient). Cue color, in relation to the primed target shape, could be congruent, incongruent, or neutral. Cue location, in relation to the target location, could be valid or invalid. Error bars represents 95% within-subjects confidence intervals.

color transients in orienting attention. Not only were the effects of congruent and incongruent color transients indistinguishable, the findings were also not modulated by the strength of shape cueing (i.e., strong vs. weak shape cueing groups). This leaves us with two conclusions. First, complementary to the findings of Experiment 2, the difference in attention to colors is attributed to shape–color associative learning (and not, response–color association). Second, the effect seems to rely on perception of shape–color conjunction (as an object) instead of disjunctive shape–color sequences. Of course, at this point we cannot determine whether the learning of shape–color sequence did not take place or whether this learning did not affect attention to colors. Although participants encountered the shape–color sequences (Experiment 3) with the same degree of consistency as they encountered the shape–color conjunctions (Experiments 1–2), it appears that encountering the sequences failed to either (a) give rise to shape–color sequence learning, or (b) give rise to a robust-enough associative learning, such that a bias for shape would modulate attentional bias for colors.

Two observations are worth noting. First, the effect of the shape cue was significantly reduced in Experiment 3 (18 ± 7 ms), compared to Experiments 1 (64 ± 13 ms, $t[40] = 3.2$, $p < .01$) and Experiment 2 (61 ± 10 ms, $t[41] = 3.46$, $p < .01$). Second, the overall effect of color transients in spatial orienting was significantly reduced in Experiment 3 (12 ± 6 ms) compared to Experiment 1 (43 ± 11 ms, $t[40] = 2.73$, $p < .01$), though the effect did not significantly differ across Experiments 2 and 3 (27 ± 14 ms, $t[41] = 1.16$, $p = .25$; nor did this effect differ across Experiments 1 and 2, $p = .42$). Although this could simply be due to individual differences across the experiments, it may also be a consequence of the modified presentation method. Namely, in Experiment 3, targets were characterized by brief exposure to new objects inside placeholders (i.e., rapid onset and offset of new objects). As such, participants' sensitivity to events that are not characterized by brief exposure of new objects might have been reduced (Burnham, 2007; color transients and shape cues both consisted of transformations in already-present visual objects, as opposed to onset and offset of new objects). Nonetheless, given that the effect of transient cues was not completely eliminated in Experiment 3 we could still draw the conclusion that congruent and incongruent colors were treated in a similar way.

The small effect of the shape cue in Experiment 3 is perhaps more problematic. One could argue that because shape cues were not utilized reliably, the congruent and incongruent color transients were also not treated differently. If that is true, then some indication of a difference between congruent and incongruent colors should be present in the subset of the participants who did show a relatively strong effect of the shape cue. The shape–cueing effect in those participants (Cohen's $d = 1.72$) was not weaker than the overall shape–cueing effects obtained in Experiments 1–2 (Cohen's d values = 1.09 and 1.34, respectively). Even if we confine analysis to those eleven participants, the effects of congruent and incongruent colors would not only remain indistinguishable ($t[10] < 1$, $p = .84$), but also highly correlated ($r = .70$, $p = .016$). In short, the findings of this experiment suggest the learned associations in the present paradigm require the conjunctive presentation of the shape and color (i.e., a single object that contains both features).

5. General discussion

The present study examined the effect of associative learning on feature-based visual attention. Orienting of attention toward transient events is an extensively studied phenomenon, although the role of associative learning has not been examined in this paradigm (although see Kristjánsson & Nakayama, 2003). The majority of previous research on attentional orienting paradigms attributes the effect of a transient to stimulus properties (Theeuwes, 2010), goal-driven processes (Egeth & Yantis, 1997; Folk & Remington, 2006), or repetition effects (Awh, Belopolsky, & Theeuwes, 2012; Theeuwes, 2010). Importantly, the benefit of repetition is often restricted to a single feature (Kristjánsson, 2006) or a single dimension (Found & Müller, 1996; Müller, Reimann, & Krummenacher, 2003). Here, we argue that a learned association between the shape and color extended the bias for shape to a bias for color. While expecting a target shape, participants showed reliable attentional orienting to the color transient associated with the target shape while showing no attentional orienting with the color associated with the alternative target shape. Experiment 2 confirmed that the advantage of congruent colors over incongruent colors was indeed due to learning shape–color associations and was not driven by a response–color association. Experiment 3 indicated that this bias depended on having viewed the two features in conjunction, as part of the same object, and not as disjunctive events of a sequence.

It is worth noting that these novel attention findings have some precedence in the learning literature from Fiser and Aslin (2001), who demonstrated associative learning between visual items in an implicit learning paradigm. In their experiments, sets of (two) distinct shapes could consistently co-occur in the same spatial arrangement and recognition performance for the associated sets was not only better than chance, but it could not be solely attributed to recognition of individual items. It would seem reasonable that associative learning of this kind should also influence attention (i.e., attention to one element of the set may bias attention toward the other element). Kristjánsson and Nakayama (2003) did not find such an effect, perhaps because their features of interest were both task-irrelevant and did not receive the same degree of attention as the stimuli in Fiser and Aslin. In the present study we implemented an initial simple-to-perform acquisition phase of two hundred trials, to maximize the possibility of associative learning. In addition, color features were not entirely task-irrelevant by virtue of being associated to the visual targets (shapes). These findings also fit nicely with the idea that co-occurrence of features results in their automatic binding into unified events (Hommel, 2004b). Once a stable representation of an event is formed, activating one feature will activate other features belonging to the same event file.

The idea that one cognitive process can automatically set in motion a stream of processes was introduced by Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977), who compared conditions where targets and distractors were defined consistently and inconsistently. They argued, for instance, that a stimulus that has been consistently treated as a target could later recruit attentional resources in a way that cannot be controlled. In other words, the cognitive representation of the target can become stronger over repeated exposure, causing efficient activation of the corresponding response. In a similar way, it could be argued that consistent association between perceptual features will cause formation of cognitive representations strong enough that a feature cannot be selected without an automatic bias toward an associated feature (Gibson, 1969; LaBerge, 1973). Logan (1988) emphasized the role of repeated exposure to consistent episodes, which supports development of an automatic response to a stimulus (cf. Hommel, 2000). Within this framework, extending attentional bias to other features of an episode, besides the target feature, can be regarded as an automatic attentional response.

Given that presenting shape and color as two (temporally) separate visual events did not give rise to the same finding (Experiment 3), it seems that conjunctive presentation of shape–color objects is essential in observing modulated bias for colors. We propose that what participants really acquire during the acquisition phase were not two sets of sequences, but two distinct visual objects. Assuming the object representations included both shape and color, anticipating one object feature would necessarily have predictive consequences regarding other features.

It has been argued that regarding objects as the units of attention, as opposed to features or locations, may be more appropriate (Duncan, 1984), and two classes of findings have supported this idea. First, we seem to have an involuntary tendency to select objects over non-objects items (e.g., Arrington, Carr, Mayer, & Rao, 2000; Kimchi, Yeshurun, & Cohen-Savransky, 2007). And, second, once one feature of an object is selected, a selective advantage is given to other features of that object, relative to features of other objects (e.g., Duncan, 1984; Wannig, Stanisor, & Roelfsema, 2011). A possible exception may be when a perceptual dimension (e.g., color) is consistently irrelevant to the task, in which case it may receive reduced processing weight, not participate in the object-based feature binding process, and not receive attentional benefit (Hommel, 1998; Memelink & Hommel, 2013).

This object-based framework can offer novel interpretation with regard to some of the previous findings. Namely, Kristjánsson et al. (2001) found that if the visual target is consistently presented, say, in the left portion of the cue, participants rapidly learn to select the target-containing portion of the cue. One could argue that participants were forming representation of a single visual object (consisting of the cue and the target), whose center of mass, due to the target, was shifted leftward. After acquiring this representation, even viewing a portion of the object (the cue alone) would activate the entire object representation, causing attentional orienting toward the object's center of mass (Kravitz & Behrmann, 2008).

It is generally thought that the neural correlates of multi-featured object representations are situated along the ventral visual pathway (e.g., the perirhinal cortex, Barense, Gaffan, & Graham, 2007; Barense et al., 2005). Assuming that motor interaction with visual objects would reduce the contribution of the ventral pathway to visual processing (increasing the contribution of the action-oriented dorsal pathway), we predict that the shape–color associative learning and its attentional consequences will be weaker in conditions where participants engage in motor actions directed at the visual objects (Ganel & Goodale, 2003; Goodale, Cant, & Króliczak, 2006; Gozli et al., 2014).

5.1. Were colors and locations associated?

One possibility that should be considered concerns the impact of response locations on processing colors.[2] Since keypress responses were spatially defined (left vs. right), it is possible that each color was associated with a location. That is, even though colors were always presented at both locations during the acquisition phase, keypress responses might have encouraged binding between color and location. For instance, given that red consistently resulted from a right-hand response, one could argue that right and left are, respectively, the "primary" and "secondary" locations with regard to the color red. Consequently, a color transient at its primary location might generate a stronger cueing effect, while its effect might be weaker (or absent) at the secondary location. To test this idea, we submitted the RT data from Experiments 1–2 to a $2 \times 2 \times 2$ repeated measures ANOVA, with cue color (congruent vs. incongruent), cue location (primary vs. secondary), and cue validity as factors. The crucial question was whether cue validity would interact with cue location. For Experiment 1, this analysis found no interaction between cue location and validity ($F[1,19] = 2.45$, $p = .134$). We also found no three-way interaction ($F[1,19] < 1$), which suggests that the difference between congruent and incongruent colors did not depend on cue location. As it is apparent in Fig. 7, congruent cues produced reliable attentional orienting both at their primary (cueing effect = 30 ms, Cohen's $d = .60$, $p = .016$) and secondary locations (cueing effect = 15 ms, Cohen's $d = .54$, $p = .035$). Incongruent cues, on the other hand, produced no attentional orienting at primary (cueing effect = 1 ms, Cohen's $d = .03$, $p = .89$) or secondary (cueing effect = 0 ms, Cohen's $d < .01$, $p = .99$) locations.

The same analysis was performed for Experiment 2, although we should emphasize that the response–color association was switched across the two phases of this experiment. For the sake of this analysis, we defined "primary" and "secondary" locations based on the response–color assignment in the acquisition phase (e.g., *right* was labeled as the primary location for *red*, since red was the outcome of a right-hand response during acquisition). Once again, cue location did not interact with cue validity ($F[1,20] < 1$). The three-way interaction also did not reach significance ($F[1,20] < 1$). As shown in Fig. 8, congruent

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[2] We thank an anonymous reviewer for pointing out this possibility.
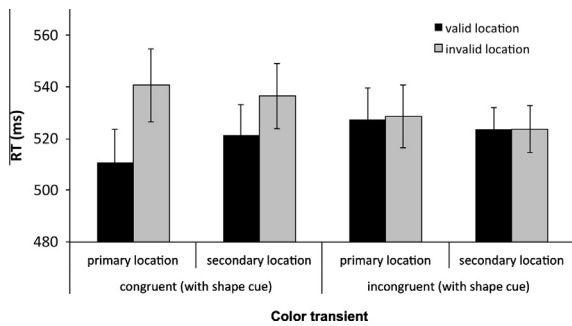
Fig. 7. Response time data from Experiment 1, graphed as a function of the color and location of the transient cue. The cue color was either congruent or incongruent in relation to the preceding shape cue. The location of the transient was either "primary" or "secondary" (i.e., corresponding or non-corresponding to the location of the response that produced it). The cue location was also either valid or invalid (in relation to the upcoming target location). Error bars represents 95% within-subjects confidence intervals.
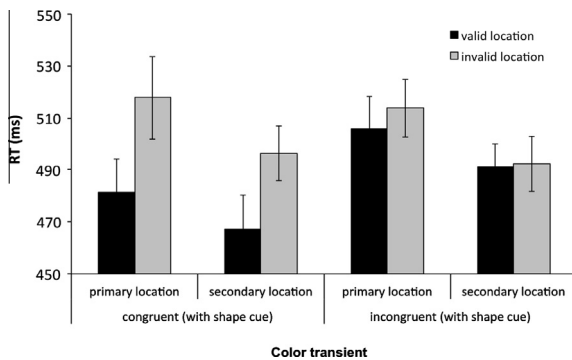

Fig. 8. Response time data from Experiment 2, graphed as a function of the color and location of the transient cue. The cue color was either congruent or incongruent in relation to the preceding shape cue. The location of the transient was either "primary" or "secondary" (i.e., corresponding or non-corresponding to the location of the response that produced it during acquisition). The cue location was also either valid or invalid (in relation to the upcoming target location). Error bars represents 95% within-subjects confidence intervals.

cues produced reliable attentional orienting both at their primary (cueing effect = 36 ms, Cohen's $d = .70$, $p < .01$) and secondary (cueing effect = 29 ms, Cohen's $d = .66$, $p = .012$) locations. Incongruent cues produced no attentional orienting at their primary (cueing effect = 8 ms, Cohen's $d = .22$, $p = .33$) or secondary (cueing effect = 1 ms, Cohen's $d = .03$, $p = .90$) locations. In short, it is safe to assume that even if colors were to some degree associated to some locations, this association did not modulate the effectiveness of color transients.

5.2. Were colors and responses associated?

The present findings included virtually no evidence of associative learning between responses and colors. If such evidence was available, what would it look like? In the case of Experiment 2, a strong response–color association could have eliminated, or reversed, the difference between

congruent and incongruent colors, because the response–color mapping was reversed after the acquisition phase. In the case of Experiment 3, a strong response–color association could have resulted in a replication of the pattern found in Experiments 1 (i.e., a benefit for congruent relative to incongruent color transients).

It is possible that strong response–color associative learning simply did not take place. Although there is evidence that action–outcome learning can be acquired with exposure to consistent mapping (e.g., Elsner & Hommel, 2001; Gozli, Goodhew, Moskowitz, & Pratt, 2013b; Hommel, 2004a), as argued by Herwig, Prinz, and Waszak (2007) and Herwig and Waszak (2009), such association is weakened when participants focus on the relationship between stimulus–response mapping (i.e., the first two elements in the stimulus–response–outcome sequence). Herwig et al. (2007) proposed a distinction between sensorimotor and ideomotor modes of action. Whereas the former mode is characterized by a focused on the stimulus, to which an appropriate response should be made, the latter mode is focused on planned outcomes, and the appropriate response that would bring about the outcome (see also, Pfister, Kiesel, & Hoffmann, 2011). It is possible that our task encouraged a dominantly sensorimotor mode of acting, resulting in attenuating the action–outcome link.

Alternatively, it is possible that the response–color associations were learned, but that the shape cues did not induce a bias in action selection, despite being an effective source of perceptual bias. Although the shape cues were 80% valid, participants still had to wait before determining the correct response. Consistent with this possibility, Ziessler and Nattkemper (2011) showed that learned action–outcome association impact behavior after an action has been selected. Prior to action selection, on the other hand, the learned association between action and outcome did not seem to exert an impact. Gozli et al. (2013b) employed a stimulus-driven signal to bias action selection and found that an action-selection bias can indeed cause a perceptual bias in favor of the corresponding action–outcome. In the present study, by contrast, there is no evidence that shape cues induced an action bias. Therefore, even if colors and responses were to some degree associated, this association did not impact performance.

5.3. Interpreting the effect of neutral colors

In designing of the test phase, we also implemented "neutral" (blue) transient cues in order to assess whether different effectiveness of congruent and incongruent colors were due to facilitation (of the congruent color) or inhibition (of the incongruent color). Interpreting the effect of the neutral transient cue seems rather difficult in light of the different pattern of findings in Experiments 1 and 2. Whereas in Experiment 1, neutral and congruent cues were quite similar, in Experiment 2 the effect of neutral cues were more similar to the effect of incongruent cues. In explaining the discrepancy between the two findings, we should also keep in mind that the neutral color was also less frequently presented and may, therefore, have had a benefit due to its relative novelty. Given that in Experiment

1 the target–response mapping was consistent across the acquisition phase and the test phase, the novelty of the neutral cue might have given it a selective advantage. By contrast, switching the target–response mapping across the two phases of the experiments means that the neutral color is no longer the only novel aspect of the test phase. Regardless, based on the effect of the neutral cues alone, we cannot attribute the different effect of congruent and incongruent cues exclusively to facilitation or inhibition of the latter.

5.4. Other considerations

Our findings represent a new way in which goal-driven attention can generate contingent bias for non-target features. Traditionally, top-down attention is thought to influence feature processing based on the match between stimulus feature and the target (Becker, Folk, & Remington, 2010, 2013; Folk, Remington, & Johnston, 1992), or a match between stimulus feature and recently selected features (Kristjánsson, 2006). We argue, however, that another factor that can dictate attentional bias is inclusion of the irrelevant distractor in the same episodic trace as the target. If the irrelevant distractor resembles an element in the target episode, then it will receive selective benefit. By contrast, if the irrelevant distractor resembles an element in the alternative episode it will not receive the same selective benefit. The link between goal-driven attention and the modulation of color selection is apparent in the between-subjects analyses in Experiments 1 and 2. Looking at Figs. 3 and 5, it seems that participants who were disregarding the shape cues remained susceptible to all three types of transients. Arguably, they adopted a mode of processing that is relatively unequipped with predictions about the upcoming visual events. No prediction about the target shape translated to an equal advantage for all transients.

A similar argument could be made regarding objects that tend to co-occur in daily life. Taking advantage of such real-world associations, Moores, Laiti, and Chelazzi (2003) found observers who looked for a visual object (e.g., table) prioritized distractors related to the target object (e.g., chair) compared with unrelated distracters (e.g., chicken), an effect that could be attributed to visual, semantic relatedness, and perhaps in some cases even feature similarity. For instance, although tables and chairs do tend to co-occur in our visual world, they are also semantically related, and resemble each other in some visual features. The present findings, by contrast, can only be explained in terms of visual associative learning, and not semantic relatedness or visual feature similarity.

There are several benefits to allocating attention to an entire episode rather than just to a relevant target feature. The secondary features of a task will further disambiguate which episodes the observer is currently experiencing, enabling more accurate perceptual decision and response selection (Trapold, 1970; Urcuioli & DeMarse, 1996). Moreover, the secondary features of a task can possess positive or negative valence and including them into a unified cognitive representation will have adaptive value (O'Brien and Raymond, 2012). Indeed, the concept of attentional weight

that is often used in regard to the treatment of individual features (Bruhn & Bundesen, 2012; Bundesen, Habekost, & Kyllingsbæk, 2011) could be extended to describe the treatment of perceptual episodes that contain multiple features (Hommel, 2004b). Associative learning may also provide the mechanism underlying automatic attentional bias for features or locations generated by symbols (e.g., Fischer, Castel, Dodd, & Pratt, 2003; Gozli, Chasteen, & Pratt, 2013a; Tipples, 2002). Consistent co-activation of the linguistic representation of "green" and the perceptual representation of the color *green*, or the linguistic representation of "bird" and the perceptual representation of *above*, is likely the reason that uninformative words have been shown to automatically bias perceptual tasks (e.g., Ansorge & Becker, 2012; Gozli et al., 2013a; Yee, Ahmed, & Thompson-Schill, 2012).

6. Conclusion

The present study adds to the growing body of research that places attentional operations in a broader context that includes learning and memory (Chun & Turk-Browne, 2008; Hutchinson & Turk-Browne, 2012; Stokes, Atherton, Patai, & Nobre, 2012). The present findings point out the benefit of regarding multi-featured episodes as units of attention rather than single features. Considering the role of prior knowledge and the complexity of events in our visual world would provide a more accurate picture of how the attentional system works in everyday situations.

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