Confirmation Bias in Visual Search

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Abstract

In a series of experiments, we investigated the ubiquity of confirmation bias in cognition by measuring whether visual selection is prioritized for information that would confirm a proposition about a visual display. We show that attention is preferentially deployed to stimuli matching a target template, even when alternate strategies would reduce the number of searches necessary. We argue that this effect is an involuntary consequence of goal-directed processing, and show that it can be reduced when ample time is provided to prepare for search. These results support the notion that capacity-limited cognitive processes contribute to the biased selection of information that characterizes confirmation bias.

Keywords: Attention, Visual Search, Decision-Making, Confirmation Bias

Introduction

Although the claim that humans are rational is central to traditional economic and legal thinking, experimental psychology has uncovered many situations where our reasoning is limited or biased (Tversky & Kahneman, 1981). One of the most well-known cognitive biases is confirmation bias, wherein selection and evaluation of information that would confirm a focal hypothesis is given priority – or even exclusivity (Nickerson, 1998). As a consequence, ill-founded beliefs can persist, as contradictory evidence tends to be ignored, underweighted, or even misinterpreted as evidence in favor of existing beliefs. The bias can be found in a wide variety of domains, from problem-solving and reasoning (Wason, 1960; 1966), to real-world settings including law (Kassin, Dror, & Kukuchka, 2013), medicine (Pines, 2006), and science (Fugelsang, Stein, Green, & Dunbar, 2004). Although confirmation bias is often studied in the context of explicit reasoning, selection occurs in nearly every stage of human information processing, including vision, where attentional mechanisms have been researched extensively (see Carrasco, 2011, for a review). In this paper, we pursue the question of whether visual selection exhibits a confirmation bias; specifically, when searching for a particular stimulus in a noisy environment, is the search confirmatory in nature. First, however, we highlight the connections between several theories of confirmation bias and theories of selective visual processing.

Of those theories that seek to account for confirmation bias in terms of psychological processes, many have implicated cognitive mechanisms of selection in one form or another (Kunda, 1990; Doherty, Mynatt, & Dragan, 1993; Neuberg, 1994, Sanbonmatsu et al., 1998). For example, Kunda (1990) has argued that confirmation bias in reasoning is due to a biased search through memory for information that is consistent with one's goal. The core notion is that, when seeking information for the purposes of a particular goal, cognitive processes increase the availability of information from memory that supports the goal. Such selective activation leads to the biased strengthening of the goal-centered proposition, where information that is inconsistent with the proposition is relatively less salient or available than consistent information. Other accounts stress the notion of capacity limits in reasoning, such as Evans' (2006) heuristic-analytic model of reasoning which states that when reasoning about hypothetical possibilities, we are limited to the consideration of a single hypothesis at a given time. Similarly, Doherty, Mynatt, and colleagues (1990; 1991; 1993) suggest that failing to optimally test multiple hypotheses is due to limitations of working memory; only one possible interpretation of evidence (i.e., only one hypothesis) can be held in working memory at a time, and so participants can only reason about the conclusions drawn from evidence contingent on this hypothesis. Both of these proposals bear some similarity to Koehler's notion of conditional reference frames (1991), but Doherty and Mynatt's account points specifically to capacity limitations in working memory as the cause of participants' tendency to evaluate one possibility at a time.

While the aforementioned proposals are intended to explain the particular way that we search for information, the features of these accounts are analogous in many ways to features in accounts of another type of search: visual search. Many theories of top-down visual selection also propose that information processing is biased towards goal-relevant information, and that core information processing units have a limited capacity. Guided Search (Wolfe, 1998; 2004), Feature Integration Theory (Triesman & Sato, 1990), the Theory of Visual Attention (Bundesen, 1990), the Boolean Map Theory of Visual Attention (Huang & Pashler, 2007), and Biased Competition (Desimone & Duncan, 1995) all state that visual search is guided, biased, or otherwise prioritized towards stimuli matching some template of the stimulus that is being searched for, whether that be through applying gain to template-matching stimuli or through suppressing of template-mismatching stimuli. In addition, research on the role of working memory in visual search guidance has led some investigators to conclude that visual selection can only be guided by a single template at a time (Olivers et al., 2011; but see Beck, Hollingworth, & Luck, 2012). These theorized mechanisms allow for more economical processing of visual information, so that aspects of the visual input that are task-relevant can receive preferential processing. However, prioritizing stimuli that are similar to a target template, paired with the limitation of a single template being maintained, is theoretically sufficient to produce a confirmation bias in visual search. If we consider the target template as a hypothetical visual state, evidence for alternative visual states will take longer to accumulate to the extent that this information is incongruent with features in the template. This sort of visual guidance is confirmatory; information that supports the presence of goal-relevant information is increased in salience. Moreover, in the case where critical visual information is fleeting, alternative states may never reach awareness during episodes of heightened top-down guidance. The latter possibility has been demonstrated in studies of inattentional blindness, where conspicuous events go unnoticed while one is engaged in a demanding visual task, despite no change in sensory input (Mack & Rock, 1998; Simons & Chabris, 1999). For example, observers are readily able to maintain the mundane percept of “people playing basketball” in the face of visual information that is grossly inconsistent with this interpretation: namely, a gorilla walking through the middle of the group.

Though the evidence to date supports the possibility that top-down visual selection mechanisms may automatically lead to confirmatory searching, the design of visual search tasks encourages confirmatory selection as a useful strategy, and so confirmatory searching could be a voluntarily adopted strategy. In the typical visual search task, the task goal is to report whether a target is present or absent in a given array of stimuli, any one of which could be the target stimuli. In such tasks, where a target can be present or absent, distractors (or non-targets) provide no information about the potential target, making a confirmatory search strategy optimal. The proposition "there is a target" can be verified in less time (on target-present trials) than it can be falsified because registration of the presence of a target stimulus can occur before every stimulus in the display is fully processed, providing sufficient information to execute the correct response. Falsification of target presence, however, cannot be completed until all stimuli are analysed to the level of response-discriminating categories. Therefore, it is unclear whether visual selection is confirmatory by its nature, or whether confirmatory selection is simply adopted as a useful strategy for visual search.

To determine whether top-down visual guidance has a confirmation bias by default, or whether this potential bias may simply result from tasks demands, it is necessary to provide a direct measurement of the perceptual hypothesis testing used in visual search. To this end we used a task where on each trial a target stimulus could have one of two features, with each conjunction of target identity and target feature being equally probable. To assess confirmatory searching, one particular conjunction was designated as a target template by framing the search as a question that was to be answered about a given search display. In each search, a variable proportion of distractor stimuli possessed the template-matching feature, with the remaining proportion possessing the template-mismatching feature. By measuring search times, we are able to determine whether participants perseverate on searching through template matching stimuli – those that could confirm the presence of the target defined in the template, if inspected with covert attention – instead of opting to search through template mismatching stimuli – those that could, when inspected, disconfirm the presence of the target defined in the template.

For example, imagine a search where one is instructed to report whether the letter “p” that appeared once in a given display was blue, knowing that a lone p, amongst other letters, would be present in the display in some color. Eight letters onset, two of which are red, and six of which are blue. If one takes “p is blue” as a perceptual hypothesis, and searches so as to confirm this hypothesis, then one will prioritize the blue stimuli in search, as they are potential exemplars of the target template. On the other hand, a clever observer may realize that, in this situation, disconfirming the hypothesis “p is blue” would require less work, as only two stimuli need be expected before sufficient information has been collected to provide a response. If this searcher scans the red letters and finds a p, they may report that the p is not blue. If a red p is not found, one can then conclude that the p must be blue.

Because the target letter is always present in a display, participants can always infer the feature of the target stimulus by an exhaustive search through the smallest subset of colored stimuli. Although a number of studies have investigated the guidance of attention to a subset of a display (Bacon & Egeth, 1997; Sobel & Cave, 2002), in these tasks no stimuli on their own can provide information against the target’s presence, and so it is not possible for the observer to adopt a strategy of disconfirmation.

Our goal in using this paradigm was to determine whether visual search exhibited confirmation bias. A confirmation bias would comprise any tendency to prioritize search stimuli that matched the target template over those that did not; in other words, a bias to search stimuli that would lead to a “yes” response, with respect to the question of whether the target defined by the template was present in the display. In Experiment 1, we demonstrate that indeed it does, and subsequent experiments were conducted in order to home in on the locus of the bias. In doing so, we entertained two broad possibilities: that confirmation bias in search results from failure of a top-down search strategy (i.e., a failure to recognize that the minimal search strategy exists), or that confirmation bias in search results from relatively automatic search heuristics, possibly arising from mechanisms underlying intertrial priming (Kristjánsson, Wang, & Nakayama, 2002). Specifically, intertrial priming could lead to confirmatory searching if stimulus selection is primarily driven by a biased selection history for template-matching colors initiated by early confirmatory searches.

Experiment 1

Experiment 1 was designed to assess whether confirmation bias exists in visual search. More specifically, our goal was to determine whether participants would perseverate in searching using a given target template even when this strategy was inefficient (i.e., more stimuli had to be examined). By manipulating the proportion of search stimuli possessing a template-matching feature, we were able to track participants' search behavior by measuring the response time cost associated with increasing the size of the target-matching stimulus subset. This allows us to contrast two theoretically possible search styles; a confirmatory search strategy (i.e., confirmation bias; search through the template-matching color), and a minimal search strategy (i.e., an ideal performer; search through the minority color). Although both strategies allow for the eventual, veridical confirmation or disconfirmation of the target template, they differ in the priority of the two conclusions: under a confirmatory strategy, confirmation of the presence of stimuli matching the target template will take less time than disconfirmation. This difference can be seen in the predicted search times that follow from the two search strategies.

The confirmatory search strategy, in which stimulus selection is biased towards those stimuli that would confirm the target template, predicts a monotonic increase in search time as the proportion of template-color matching stimuli increase, and a response time benefit when the search target matches the search template.[1] The minimal search strategy, in which stimulus selection is intended to minimize the number of stimulus inspections necessary to produce a response, predicts a quadratic relationship between the proportion of template-color matching stimuli and response time, with the longest searches occurring when there is an equal proportion of template-color matching stimuli and template-color mismatching stimuli, and a reduction in search time as the smaller subset of stimuli reduces in size. In addition, the minimal search strategy predicts no consistent relationship between whether the target stimulus matches or does not match the search template, as the template adopted for a given search would depend on which stimulus color was in the minority. The two factors, Color Proportion and Color Match, should therefore produce a cross-over interaction effect on search times with a minimal search strategy. A sample search instruction and illustration of the predictions of these two strategies is provided in Figure 1.

A third possible strategy, not pictured, is that participants will not use color to guide search at all, but instead inspect items randomly and, after finding the target letter, report its color. Because this strategy is insensitive to color in the selection stage, it predicts a flat search slope across the target-matching subset conditions, and an overall response time cost for reporting the target when it appears in a template-mismatching color.

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[1] In addition, a 2:1 ratio between search slopes for trials where the target appears in the template mismatching color and trials where the target appears in the template matching color could occur. However, this prediction requires the very strict assumption that selection of stimuli is completely color-based, i.e., that information is accumulated about items in one color subset exclusively. Given our relatively small display size (eight items), and the fact that all items are in view, it is not clear that this assumption can be upheld, and so we put forward a more robust prediction that response times should be proportional to the number of template-matching stimuli. We thank Derrick Watson for bringing this issue to our attention.

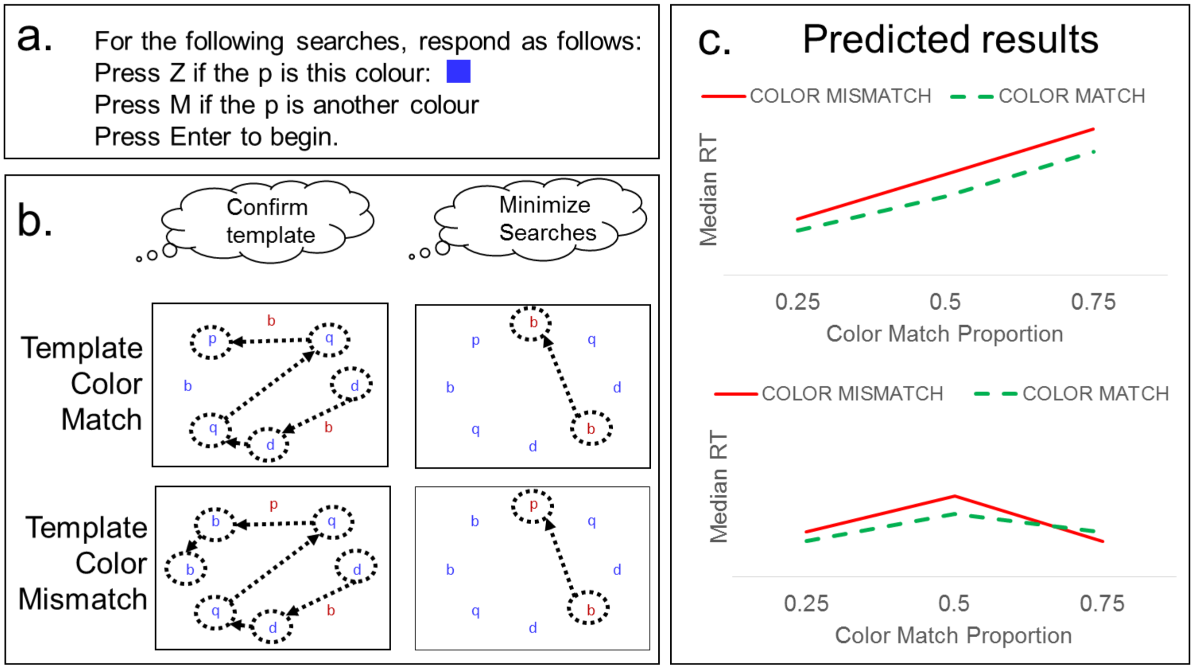

Figure 1. A sample of stimuli used, with predictions for the confirmatory search strategy and minimal search strategy. Panel (a) depicts a sample instruction for a block of searches where the target letter is p, and the template color is blue. For this search block, then, a Color Match trial would be a trial where the target p appeared in blue, and a Color Mismatch trial would be when the target p appeared in red. Panel (b) illustrates two possible searches for this search block where predictions for the two hypothetical strategies most strongly differ; when the majority color of stimuli does not match the template color. Potential search paths are overlaid for each search strategy. Predictions in (c) are derived by counting the number of expected inspections, depicted as dashed circles in panel (b), for each possible search display type. In panel (c), the expected results for confirmatory searching are shown in the top graph and for minimal searching in the bottom graph.

Methods

Participants

Twelve undergraduate students volunteered to participate for course credit. All participants provided informed consent.

Stimuli

Search displays were composed of eight letters, spread evenly along the perimeter of an imaginary circle centred on a fixation cross. Each letter in a search display was a lowercase p, q, b, or d, approximately 2° in height and 1° in width, and was drawn approximately 8° from fixation using Arial font. The letters were always one of four similar letters (lowercase b's, p's, q's, and d's), chosen to discourage the possibility of target pop-out. Search displays had a dark grey background display. In addition, stimulus colors were selected from a pool of seven possible colors; purple, yellow, green, orange, pink, blue, and red (RGB values, respectively: 200, 0, 255; 200, 200, 0; 0, 255, 0; 255, 128, 0; 255, 128, 255; 50, 50, 255; 255, 50, 50). Before each block of searches, a set of instructions were presented on the screen.

Procedure

In a given block, one letter was selected as the target letter, and two stimulus colors were selected from the aforementioned pool of eight colors. At the outset of each block, participants were instructed to report whether the chosen target letter was one of the two colors, or not, using one of two keys (M and Z, on a standard keyboard) for each response. For example, if the target letter on a given block was p, and the two selected colors were red and blue, the participant may have seen the instruction, "For each search, respond as follows: Press Z if the p is this color (blue), press M if the p is another color." The particular response mapping changed from block to block, such that no key was constantly mapped to either type of response. Once participants had read and memorized the search rule, they initiated a block of 30 searches by pressing the Enter key. Each participant completed 16 different blocks.

For each search, the target letter was always present, accompanied by seven distractor letters. The participant's task was to determine, for a given display, which of two possible colors the target letter appeared in. Distractor letters were each colored with one of the two colors selected for the block, which we will refer to as the template matching color and template mismatching color, with the former referring to the color explicitly mentioned in the block's search rule. Two factors were manipulated within search blocks: which color the target was drawn in (template matching or template mismatching; each equally likely), and the proportion of search stimuli of the template matching color (0.25 – two of eight letters, 0.5 – four of eight letters, and 0.75 – six of eight letters; each equally likely). Each block contained an equal number of trials from each condition, and their order was randomized so that participants' global strategy could be measured. Distractor letters were randomly sampled with replacement from the pool of non-target letters. Search stimuli remained on screen until a response was provided, after which the word "Correct" or "Incorrect" was presented at fixation as feedback.

Results and Discussion

To determine which strategy was implemented by participants, we conducted a 3 X 2 repeated measures ANOVA on median response time (RT) for trials with a correct response, with Color Proportion (0.25, 0.5, 0.75) and Match-Color (template match, template mismatch) as factors. Unless otherwise noted, all RT analyses include only trials with a correct response. Predicted results for the confirmatory search strategy are a monotonic effect of Color Proportion and a main effect of Match-Color, whereas the minimal search strategy predicted a quadratic (i.e., non-monotonic) effect of Color Proportion and an interaction between Match-Color and

Color Proportion, as searches should terminate with template matching targets and template mismatching targets, respectively, when the template matching color is in the minority and majority, respectively. Our results (Figure 2) showed that search indeed slowed when proportionally more hypothesis-confirming stimuli were present in the display. Response times increased as the proportion of template-matching colors increased, $F(2, 22) = 28.37$, $p < .001$, partial $\eta^2 = .72$; a linear contrast proved statistically reliable, $F(1, 11) = 47.03$, $p < .001$, partial

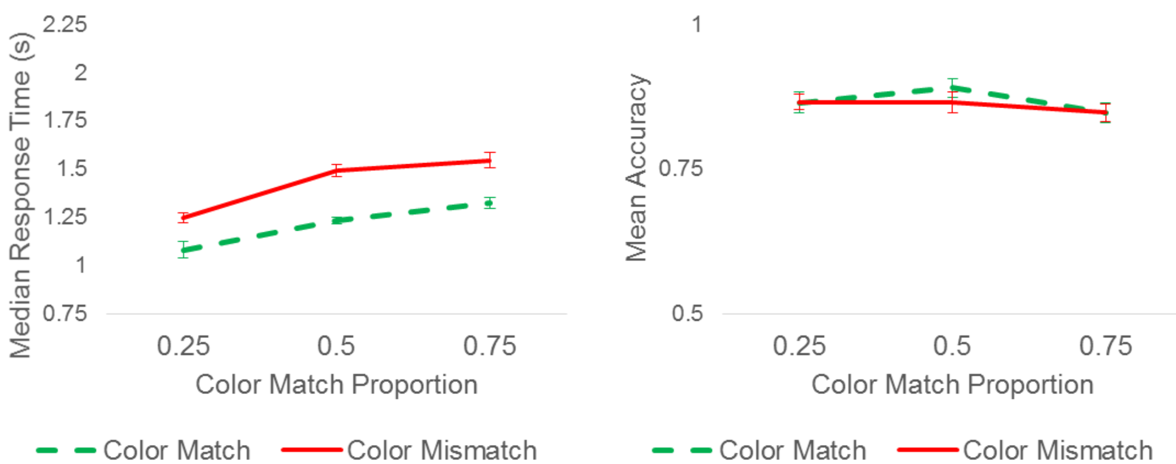

Figure 2. Median Response Times (left) and Mean Accuracy (right) for the search task in Experiment 1. Error bars in this and all other figures depict one within-subjects standard error (Cousineau, 2005).

$\eta^2 = .81$, accompanied by a marginally significant quadratic contrast, $F(1, 11) = 4.33$, $p = .06$, partial $\eta^2 = .28$. These results show that search time indeed increased as more template-matching colors appeared in the search display, although the increase in search time was not completely linear (we return to this point in Experiment 3).

Responses were also overall slower for template mismatching colors, $F(1, 11) = 58.39$, $p < .001$, partial $\eta^2 = .84$, and, crucially, this effect did not interact with Color Proportion, $F(2, 22)$

= 1.21, p = .32, partial η^2 = .10. Although we observed a quadratic trend of Color Proportion on search time, the lack of an interaction between Color Proportion and Color Match contradicts the possibility that participants adaptively switched search strategies to minimize their searches when the target-mismatching color was the smaller color subset, as in that case, the Color Mismatch trials would now be those where the target *matched* the updated template, and therefore ought to have exhibited a reduction in search time. We return to the issue of this quadratic trend in the results section of Experiment 3. In addition to supporting the confirmatory selection strategy, these results rule out a post-selection strategy, where stimuli are selected randomly and color is only analysed after the target letter is identified.

We analysed overall accuracy using a similar repeated measures ANOVA to determine whether results may have been due to a speed-accuracy trade-off. No main effects or interactions were observed, Fs < 1.75, ps > .20, partial η^2s < .14, ruling out the possibility of a trade-off between speed and accuracy.

One possible source of perseveration on selection of the template-matching color is inter-trial priming. Inter-trial priming refers to the facilitation of target selection when one of the targets' features repeat across sequential trials. Such priming is known to occur when a target's presence varies (Olivers & Meeter, 2006), and Experiment 1's design meets that criterion if we consider template matching and template mismatching targets to be distinct target representations.

To assess the possibility that inter-trial priming contributed to confirmatory selection, we divided trials into those that were preceded by a template matching target trial, and those that were preceded by a template mismatching target trial, which we will refer to as the Priming condition. Prime X Match-Color X Color Proportion repeated measures ANOVA revealed a main effect of Prime, $F(1, 11) = 14.96$, $p = .003$, but no interactions between Prime and other factors, Fs < 1.92, ps > .17. It therefore appears that inter-trial priming did not greatly affect selection performance, but that trials requiring falsification of the target template led to a small overall reduction (M = 59ms, SE = 11ms) in search time on the subsequent trial.

Experiment 2

The results of Experiment 1 show a robust effect of confirmatory searching. Overall, search tended to be biased by the target template provided in initial search instructions, despite the fact that both bottom-up saliency and top-down strategy should have encouraged selection of the smaller subset when the template matching stimuli were more numerous. In the present experiment, we sought to determine whether search may have been confirmatory because it is less cognitively demanding to retain a single template across a number of trials (Shiffrin & Schneider, 1977), rather than switch templates based on the properties of any one search display. To examine this, a new search target template was presented before each search trial in Experiment 2. This allows us to test the possibility that maintaining a consistent mapping between a given target letter and color as a search template was the source of confirmatory search behavior in the previous experiment. If confirmatory searching occurs due to a resistance to template-switching across trials, then we would expect a minimal search pattern of results (see Figure 1c). However, if confirmatory searching is an automatic consequence of guiding search, then the results of Experiment 2 will mirror those of Experiment 1.

Methods

Participants

Twelve new undergraduate students were recruited for the present experiment. All participants provided informed consent and were compensated with course credit. We chose twelve participants in order to match Experiment 1 for statistical power, and this general approach was also adopted for all subsequent experiments.

Stimuli and Procedure

The stimuli and procedure for Experiment 2 were identical to those of Experiment 1, with the exception that participants now completed 300 trials where search displays on every trial were preceded by a new set of search instructions providing a new target template. With this change, the two possible stimulus colors, the target letter, template color, and response mapping were randomized before every trial.

Results and Discussion

We analysed median response time (Figure 3) and accuracy using separate 3 X 2 repeated measures ANOVAs as in Experiment 1. Once again, a main effect of Color Proportion was present, $F(2, 22) = 44.04$, $p < .001$, partial $\eta^2 = .80$. Consistent with confirmatory searching, we observed a significant linear trend, $F(1, 11) = 59.78$, $p < .001$, partial $\eta^2 = .84$, but no reliable quadratic trend, $F(1, 11) = 1.40$, $p = .26$, partial $\eta^2 = .11$. In addition, a main effect of Color-Match was again observed, $F(1, 11) = 49.97$, $p < .001$, partial $\eta^2 = .82$, such that RT was faster when the target matched the template color, and, critically, no interaction was present, $F(2, 22) = 0.16$, $p = .85$, partial $\eta^2 = .02$. These results suggest that template-color matching stimuli were prioritized for search, and that searches terminated upon the detection of a template-color matching target. Search template repetition, then, does not appear to be necessary for a confirmatory search strategy to emerge.

Unlike Experiment 1, we observed an accuracy effect in Experiment 2. Color Proportion did not reliably alter accuracy, $F(2, 22) = 1.21$, $p = .32$, partial $\eta^2 = .10$, nor did Color Proportion interact with Color-Match, $F(2, 22) = 0.92$, $p = .41$, partial $\eta^2 = .08$, but Color-Match did, F(1,

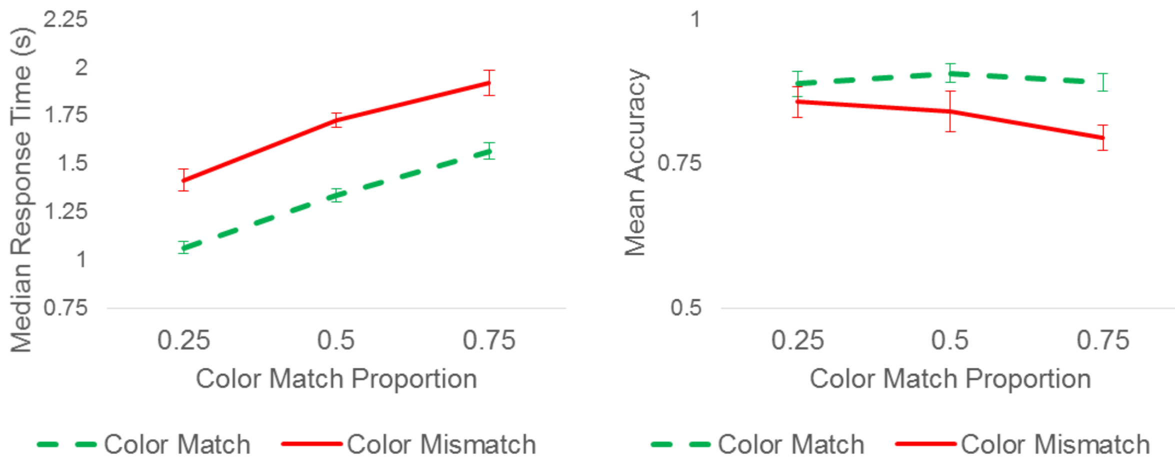

Figure 3. Median Response Times (left) and Mean Accuracy (right) for the search task in Experiment 2.

11) = 5.03, $p < .001$, partial $\eta^2 = .31$, such that more errors were made in reporting a template mismatching target than in reporting a template matching target. Combined with the RT effects, the overall picture is that template-color mismatching targets were associated with poorer performance in general.

Experiment 3

The results of Experiment 2 shows that confirmatory selection still occurs when the target template changed from trial to trial, meaning that confirmatory searching does not occur simply as a result of an attempt to minimize cognitive effort. However, memorizing a new target template on every trial would certainly tax working memory; for example, Carlisle and Woodman (2011) have shown that new search targets are held in visual working memory, but the working memory load decreases as searches continue with the same template. The lack of an optimal selection strategy in Experiments 1 and 2, then, may have been due to the relatively high working memory load associated with adopting new search targets. In Experiment 3, we reduced cognitive load by having participants maintain the same search template for the entire experiment. This allowed us to determine whether a flexible selection strategy could be adopted when working memory demands were minimized. We anticipated two possibilities; that confirmatory searching would again occur, showing that - while not necessary – template repetition could be sufficient to encourage a confirmation bias, or that confirmatory searching would cease, showing that it was the increased cognitive load associated with adopting new target templates that prevented the use of an optimal search strategy.

Methods

Participants

Twelve undergraduate students were recruited for the third experiment. All participants provided informed consent and were compensated with course credit.

Stimuli and Procedure

We used the same stimuli and procedure as Experiments 1 and 2, with the exception of the number of trials and blocks, which were changed to 300 and 1, respectively. As a consequence, each participant received a single pair of stimulus colors, target template instruction, and response mapping that persisted for all searches in the experiment.

Results and Discussion

The results of a 3 X 2 repeated measures ANOVA again showed a main effect of Color Proportion, $F(2, 22) = 8.20$, $p = .002$, partial $\eta^2 = .43$ on search times (Figure 4). Polynomial contrasts revealed that the effect of Color Proportion was linear, $F(1, 11) = 11.12$, $p = .007$, partial $\eta^2 = .50$, and not quadratic, $F(1, 11) = 1.06$, $p = .33$, partial $\eta^2 = .09$. In addition, a main effect of Color Match was also evident, $F(1, 11) = 7.36$, $p = .02$, partial $\eta^2 = .40$, with no interaction between the two factors, $F(2, 22) = 0.38$, $p = .69$, partial $\eta^2 = .03$. The results of the

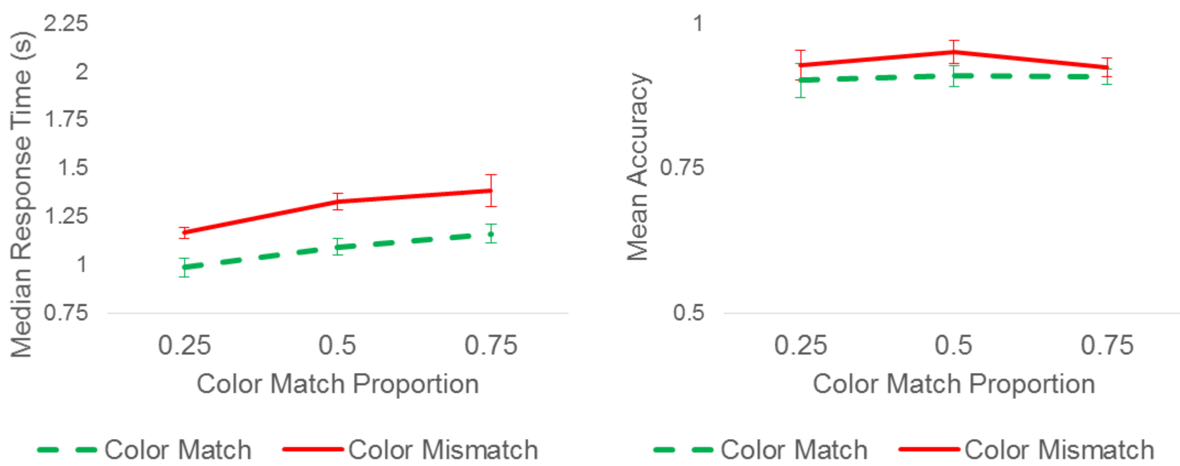

Figure 4. Median Response Times (left) and Mean Accuracy (right) for the search task in Experiment 3

search time analyses were quite clear: search time was consistently slower when more stimuli matched the target template, and when the target did not match the template. Both of these main effects showed that despite the reduced working memory load in Experiment 3, confirmatory selection once again occurred.

A 3X2 repeated measures ANOVA on accuracy showed no main effects or interactions, $Fs < 1.015$, $ps > .38$, partial $\eta^2s < .085$, thus ruling out the possibility of speed-accuracy trade-offs. Furthermore, adding reported strategy as a between-subjects factor yielded no reliable interactions with any factors for either RT or accuracy, *F*s < 0.69, *p*s > .52, partial η^2s < .06, suggesting that explicit search strategies did not substantially alter participant's searches. Overall, the results of Experiment 3 suggest that repeated search does not reduce the confirmatory nature of visual search. Thus, the results of Experiment 2 cannot be attributed solely to the increased cognitive load of the switching search targets.

As can be seen from Figures 3 and 4, the Color Proportion X RT slopes were more shallow in Experiment 3 than in Experiment 2; the average RT cost incurred for each additional template-color matching stimulus in Experiment 2 was 151 ms, whereas in Experiment 3, this cost was reduced to 56 ms, $t(11) = 2.68$, $p = .02$. Experiment 3, then, shows that experience with a given template increases search efficiency, driven presumably by accumulated priming (Kristjánsson, Wang, & Nakayama, 2002). Coupled with the results of Experiment 2, we tentatively suggest that the quadratic trend in Experiment 1 reflects the contribution of economical color selection – that is, selection of the Color Mismatching subset when it is smaller – once sufficient experience has been acquired with a given template. This suggestion may seem paradoxical given that in Experiment 3, where only one template is ever used, no quadratic trend emerged, but this could reflect the fact that, as guidance is practiced, the costs of switching to the Color Mismatching subset exceed the costs of searching through the larger, Color Matching subset.

Experiment 4

When the cognitive load of juggling multiple target templates was eliminated in Experiment 3, confirmatory searching nonetheless persisted. In Experiment 4, we evaluated the role of search strategy. In our previous experiments, the participants were simply instructed to respond to searches as set out in the instructions, and we aimed to observe which strategy they would adopt. Although the strategy evident in the search behavior appeared to be a confirmatory strategy, it is possible that this strategy was adopted because participants did not recognize the other strategies made available by task structure; namely, that if a target was not observed in a given color set, one could infer that, on that trial, it appeared in the opposite color set. In Experiment 4, we explicitly told this fact to participants at the outset of the experiment. In addition, participants were informed that the fastest way to complete a search would be to examine the stimuli in the smallest color subset to check for a target letter. We expected that, if confirmatory search was the default, or preferred, strategy, these instructions would not affect search behavior. However, if confirmatory searches were simply an artifact of participants' lack of familiarity with the task and its idiosyncrasies, these instructions would eliminate confirmatory searching. In the former case, a linear effect of Color Proportion on search time and a main effect of Color Match on search time should again be found. However, if instructions are able to curb the use of confirmatory selection, then a quadratic effect of Color Proportion on search time, and an interaction between Color Proportion and Color Match should be found.

Methods

Participants

Twelve undergraduate students were again recruited for the present experiment. All participants provided informed consent and were compensated with course credit.

Stimuli and Procedure

The stimuli and procedure for Experiment 4 were identical to those of Experiment 1. Only the instructions given at the outset were modified. This consisted of the addition of the following sentences:

> "The fastest way to do these searches is to look through whichever colored letters there are fewer of. If you see the target letter, you can respond appropriately, but if you don't, you will know it must be in the other group, and can make the opposite response."

Participants were then led through an example where the template mismatching color was in the minority, and told that if the target letter was in that set, they could immediately report the absence of the target-letter in the template-matching color. In addition to verbally describing the strategy, participants were asked to identify the stimulus that would be best to inspect first in the example mentioned above. If the participant indicated that a template mismatching stimulus would be the best to inspect first, this was taken to mean that the participant had understood the strategy. However, if the participant failed to identify the mismatching stimulus, the optimal strategy and illustrative example were reiterated until the participant chose a template mismatching stimulus in the example.

Results and Discussion

Search behavior once again exhibited a confirmatory search pattern. A 3X2 repeated measures ANOVA on search RT (Figure 5) showed a main effect of Color Proportion, $F(2, 22) = 8.66$, $p = .002$, partial $\eta^2 = .44$, which consisted of a linear trend, $F(1, 11) = 9.00$, $p = .012$, partial $\eta^2 = .45$, and a marginally significant quadratic trend, $F(1, 11) = 4.74$, $p = .052$, partial $\eta^2 = .30$. In addition, a main effect of Color Match was again present, $F(1, 11) = 35.36$, $p < .001$, partial $\eta^2 = .76$, and Color Match did not interact with Color Proportion, $F(2, 22) = 1.30$, $p = .29$, partial $\eta^2 = .11$. A 3X2 repeated measures ANOVA on search accuracy showed no main effects or interactions, Fs < 0.10, ps $> .91$, partial η^2s $< .01$.

These results of Experiment 4 were qualitatively identical to Experiment 1, supporting the notion that confirmatory search was not an artifact of a lack of awareness of proper strategy. Although the results suggest that a quadratic relationship between the number of template-color matching stimuli and search time was present, the lack of an interaction between Color Match and Color Proportion again indicates that participants were not consistently switching templates when the template-color matching stimuli outnumbered the template-color matching stimuli. As outlined in the discussion of Experiment 3, we suggest that this may reflect the contribution of some economical searches, which become possible once the template becomes learned through use.

Further supporting the conclusion that explicit strategy did not reduce confirmatory searching is the observation that only five of twelve participants reported using the minimal search strategy when debriefed, despite having been informed of it at the outset. Indeed, reported search strategy did not reliably interact with any factors for either RT, Fs < 0.63, ps $> .55$, partial η^2s $< .06$, or for accuracy, Fs < 0.71, ps $> .42$, partial η^2s $< .07$.

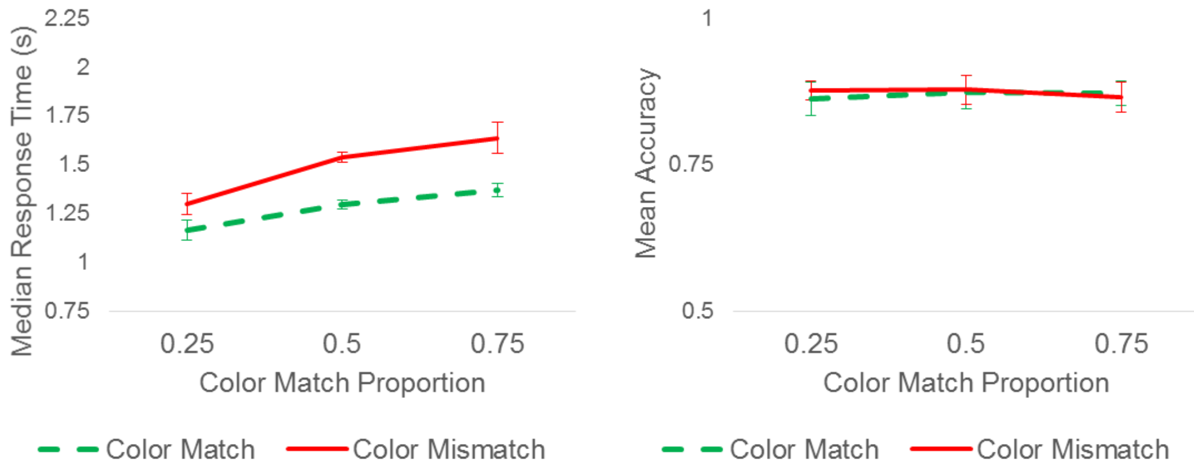

Figure 5. Median Response Times (left) and Mean Accuracy (right) for the search task in Experiment 4.

Given that explicitly instructing participants to use a particular strategy did not affect their search performance, we combined the data from Experiment 1 and 4, where the procedure had been otherwise identical, to provide a more powerful analysis of the effect of learned strategy on search behavior. Although the cost of reporting template-color mismatching targets was slightly attenuated for those reporting a minimal search strategy, $F(1, 22) = 4.05$, $p = .06$, partial η^2s < .16, as in Experiment 1, all other interactions were still unreliable for both search time, Fs < 1.29, ps > .29, partial η^2s < .06, and for accuracy, Fs < 2.43, ps > .13, partial η^2s < .10. If anything, it seems that a reported minimal search strategy manifests only in a reduced RT and accuracy cost associated with finding the template-color mismatching target. This demonstrates that, at least in this task, search performance and metacognitive strategy are dissociable; participants appear to know how to complete the task most efficiently, but do not behave in accordance with this approach.

Experiment 5

Thus far, our results have consistently provided evidence for a confirmatory search bias. The effect is largely insensitive to the presence or lack of repetitions of template use, as well as knowledge of the task. In Experiment 5, we tested whether the confirmatory search bias could be reduced by presenting a preview of the color of search stimuli in advance of the search. Given the robustness of confirmatory selection observed thus far, it is tempting to conclude that confirmatory selection of stimuli matching a template is a relatively automatic process. In previous experiments, participants often did report using a minimal selection strategy, even though their search times told a different story. It may be the case that the strategic guidance of search lags behind the more automatic orienting towards template matching stimuli. An alternative to automatic guidance to template matching stimuli that one could reasonably expect is for automatic orienting to be towards the fewest, and therefore most perceptually salient stimuli. However, at least for our search task, confirmation bias seems to be the default tendency that must be overcome.

To test this possibility, we presented a color preview in advance of the search stimuli on every trial. Our reasoning is that, if given the chance to observe the statistics of the colors while not having the ability to begin searching, participants might more appropriately plan their search in advance. If strategic control of selection is simply slower than template-guided selection, we predict a quadratic trend between search time and the proportion of Color Proportion, and an interaction between Color Match and Color Proportion.

Methods

Participants

Twelve undergraduate students were recruited for the present experiment. All participants provided informed consent and were compensated with course credit.

Stimuli and Procedure

The stimuli and procedure were very similar to Experiment 1; 16 blocks of 30 trials were again implemented, and a search template was provided prior to each search block, but search stimuli themselves were slightly changed. For each search, a color preview display was presented for 1000 ms in which colored squares, approximately 1.2° x 1.2º, appeared centered on the positions of their respectively colored search stimuli. After 1000 ms had elapsed, the letters used as search stimuli onset in front of the colored squares. These letters were uniformly colored in white. Instructions were changed accordingly, such that participants were now asked to respond regarding whether the target letter was *on* a particular color.

Results and Discussion

Preliminary RT analyses showed a number of outlying trials, consisting of both suspiciously long search times (>10s, 0.013% of all trials), and anticipatory responses (<100ms, 0.06% of all trials). Trials with search times falling outside of either of the aforementioned bounds were excluded before conducting the following analyses. The extended color preview display led to a change in the pattern of search RT (Figure 6), but this change was also accompanied by changes in search accuracy. A 3X2 repeated measures ANOVA on RT revealed a main effect of Color Proportion, $F(2, 22) = 17.05$, $p < .001$, partial $\eta^2 = .61$, which was comprised of a linear, $F(1, 11) = 8.70$, $p = .013$, partial $\eta^2 = .44$, and quadratic, $F(1, 11) = 46.97$, $p < .001$, partial $\eta^2 = .81$, trend. The effect of Color Proportion was accompanied by a main effect of Color Match, $F(1, 11) = 15.62$, $p = .002$, partial $\eta^2 = .59$, but no interaction was observed, $F(2, 22) = 2.34$, $p = .12$, partial $\eta^2 = .18$.

The RT data alone is suggestive of a flexible selection strategy, but a repeated measures ANOVA on accuracy revealed speed-accuracy trade-offs. A main effect of Color Match, with template-color matching targets being reported with lower accuracy, approached significance, $F(1, 11) = 4.41$, $p = .06$, partial $\eta^2 = .29$. In addition, Color Proportion decreased search accuracy, $F(2, 2) = 13.88$, $p < .001$, partial $\eta^2 = .56$, in a monotonic fashion, $F(1, 11) = 37.38$, p

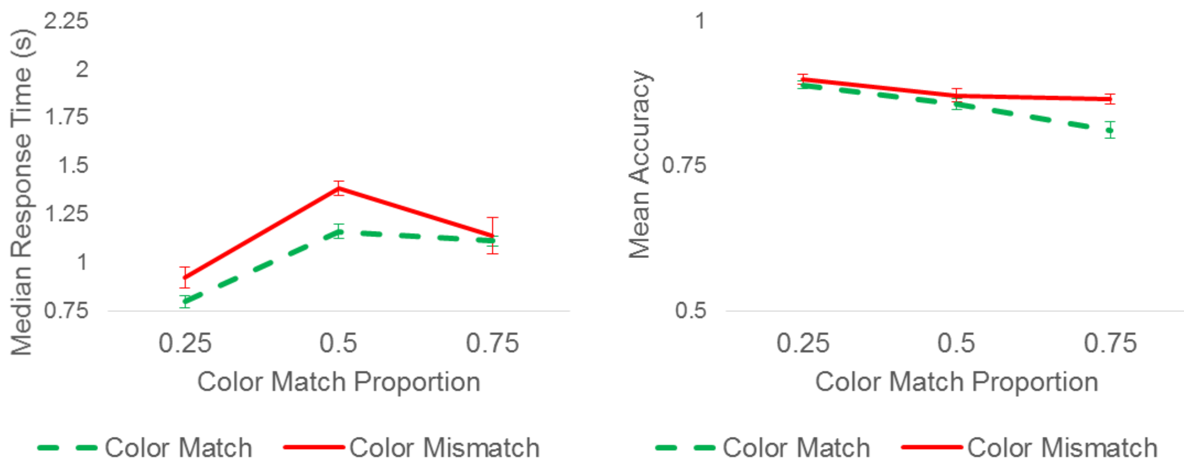

Figure 6. Median Response Times (left) and Mean Accuracy (right) for the search task in Experiment 5.

$< .001$, partial $\eta^2 = .77$, such that search responses were less accurate as more stimuli matched the template color. In addition, Color Match and Color Proportion interacted, $F(2, 22) = 3.71$, $p = .04$, partial $\eta^2 = .25$, such that the difference in accuracy between Color Match conditions increased as the proportion of template-matching colors increased, $F(1, 11) = 6.71$, $p = .025$, partial $\eta^2 = .38$, with accuracy suffering most when the target appeared in the template matching color. Combined with the increase in the number of participants reporting a minimal search strategy (10 of 12), these results suggest that while participants improved their search speed on trials when the task demands encouraged prioritizing the color not mentioned in the instructions, this also led to more search errors. Participants may have opted to switch templates for these searches, but the increased cognitive load of these switches led to more errors at the response planning stage.

To further clarify the effect of color previews on search strategy, we supplemented these analyses by computing efficiency scores (mean accuracy divided by median response time for correct and incorrect trials). Efficiency was greatest with 2 of 8 stimuli matching the template color ($M_{Color\ Match}$ = 1.23, *SE* = 0.10; $M_{Color\ Mismatch}$ = 1.10, *SE* = 0.09), worst with 4/8 matching the template color ($M_{Color\ Match}$ = 0.79, *SE* = 0.06; $M_{Color\ Mismatch}$ = 0.68, *SE* = 0.04), and slightly better with 6/8 matching the template color ($M_{Color\ Match}$ = 0.81, *SE* = 0.08; $M_{Color\ Mismatch}$ = 0.88, *SE* = 0.10). Estimates of efficiency were affected by Color Proportion, $F(2, 22) = 74.95$, $p < .001$, partial $\eta^2 = .51$, with both linear, $F(1, 11) = 27.31$, $p < .001$, partial $\eta^2 = .71$, and quadratic, $F(1, 11) = 40.97$, $p < .001$, partial $\eta^2 = .79$, components. Although Color Match was only marginally significant, $F(1, 11) = 4.23$, $p = .062$, partial $\eta^2 = .28$, it critically interacted with Color Proportion, $F(2, 22) = 7.98$, $p = .002$, partial $\eta^2 = .42$. This interaction was such that, when the number of template-matching colors was greater than the number of template-mismatching colors, template-color matching targets were *less* efficiently detected than template-color mismatching targets, suggesting that participants indeed did adapt their search strategy to the proportion of colors in a search display. However, that this effect was accompanied by a linear effect of Color Proportion suggests that the strategic search strategy coexisted with a confirmatory tendency. Searches where confirmatory searching was strategically optimal were overall more efficient than trials where it was not, as indicated by a pairwise comparison between 25% template-matching color trials and 75% template-matching color trials, $F(1, 11) = 27.31$, $p < .001$, partial $\eta^2 = .71$. Nonetheless, the previews did alter the extent of confirmatory searching; a Mixed Model ANOVA comparing efficiency scores between Experiments 1 and 5 showed that Experiment interacted with the effect of Color Proportion, $F(2, 44) = 15.88$, $p < .001$, partial $\eta^2 = .42$, as well as with the interaction between Color Proportion and Color Match, $F(2, 44) = 4.12$, $p = .023$, partial $\eta^2 = .16$. Overall, these results show that color preview displays can attenuate confirmatory searching, but not completely.

General Discussion

Across five experiments, we measured visual search performance in a novel task designed to examine the use of confirmatory search strategies. Participants were asked to report whether a target letter was a target color or not, and across searches we varied the proportion of stimuli in search displays that were the target color or non-target color. Despite the fact that this search task allowed participants to adopt a strategy of target disconfirmation – that is, they could examine the stimuli in a non-target color – the target confirmation strategy dominated performance. We conclude, therefore, that a confirmation bias exists even in simple visual search tasks. This conclusion is supported by the conjunction of two general findings; first, that participants were slower to report the target identity when proportionally more search stimuli matched the target template, as defined in search instructions, even though a more economical selection strategy was available, and second, that participants were faster to report the target identity when the target was the color of the template than when the target was another color.

The first finding is reminiscent of studies of subset search (e.g., Bacon & Egeth, 1997; Sobel & Cave, 2002), where participants perseverate in selecting stimuli possessing a particular guiding feature if instructed, even when this feature is present in the larger of two equally useful search subsets. While subset search research speaks to the strength of instructions in dictating top-down selection, these results cannot, by themselves, demonstrate confirmatory searching, as no other search strategy (i.e., disconfirmation of target presence) is available in these tasks as a viable alternative to confirmatory searching. Similarly, the finding of slower search times for targets not matching the template may be considered to be an instantiation of the classic finding of slower searches for targets defined by the absence of a feature (Wolfe, 2001). If this comparison is valid, then our results provide a demonstration that feature absence may be relative to task set. That is, the particular stimulus that would be considered “feature-present” and “feature-absent” in our task was a consequence of an arbitrary assignment of one of two colors in the search instructions.

The results of these experiments converge on the conclusion that the default, or preferred, search strategy is one in which searcher prioritizes stimuli that share features with a target template, and opts to determine the status of a target by matching it to the template rather than by switching to a disconfirmation strategy of searching for stimuli that would provide evidence against the presence of a template-matching target. Our results therefore rule out the possibility that confirmatory searching is task-contingent selection strategy. In our search task, matching search stimuli to a single color-letter conjunction entailed conducting more analysis than strictly necessary to complete a search. However, search times indicated that this is how participants opted to search. It is important to note that, because our data rely only on overall response time, increases in response time caused by increases in the proportion of template-matching stimuli may not simply reflect increases in the total number of stimuli inspected in search, but may also reflect increases in time spent processing the color statistics in the display to plan searches, updating templates, processing individual stimuli, or selecting responses. While additional stimulus manipulations, or within-trial search metrics (e.g., eye tracking) are needed to resolve this uncertainty, from a purely performance based perspective, we may still conclude that visual search is successfully terminated faster when a target’s presence is confirmed, not disconfirmed.

Confirmatory search may stem from a number of underlying sources. The first possibility is, as has been suggested before, that visual search can only be guided by one template at a time. A number of studies investigating the control of visual search guidance by representations in visual working memory have demonstrated that only one representation appears to be prioritized to guide search at a time (reviewed in Olivers et al., 2011). Although contrary findings exist (Beck, Hollingworth, & Luck, 2013; Irons, Folk, & Remington, 2012), a sufficiently sophisticated notion of search templates, such as the Boolean Map Theory of Visual Selection (BMTVS) can accommodate guidance by multiple *features*, but via a single template. In the BMTVS, multiple features may be combined using Boolean (conjunctive and disjunctive) operations, with the critical consequence that any stimuli selected using a given Boolean setting cannot be distinguished from each other on the selection dimension (e.g., color); further template adjustments would need to be made in order to distinguish these selected stimuli from each other on any a particular dimension. In our selection task, because color is a dimension that is necessary to select the appropriate response, BMTVS predicts that only a single color can be used to guide selection and analysis, because color is necessary for deciding between responses in addition to selecting potential target stimuli. A single template architecture introduces costs associated with updating the target template to the appropriate template for a particular display. The costs associated with calculating and updating to the appropriate template to use may simply outweigh the benefits of updating in terms of overall search time. Thus, capacity limitations in search template guidance from working memory are a potential culprit in the source of confirmatory searching. As suggested earlier, a similar limitation has been suggested in reasoning (Mynatt, Doherty, & Dragan, 1993), which requires search for information through a possibility space.

On the other hand, confirmatory searching in our task may be due to difficulties in guiding search with negative information. In the instructions, we framed the search such that the target could either be one particular color, or not that particular color. While the search performance appears to reflect a confirmatory, template matching stimulus prioritization, it may be that search cannot be strategically guided by negative information (e.g., "not blue"). As noted earlier, search for absent features is well-known to be difficult. If it is the case that our mere framing of the non-template color as the absence of the template color was sufficient to recode the non-template color as an absent feature, this may account for why selection was preferentially guided towards the template color. In this case, the template color would have been treated as a "present" feature, and therefore would lead to easier selection, making the perseveration of selection on this color optimal for participants. While plausible, this account would require an additional interpretation of feature-absent effects: until now, these effects have been taken to reflect a property of the visual system's coding, as opposed to task demands. The nearest approximation of a cognitive, rather than perceptual, interpretation of feature-absent effects that we are aware of stems from work on familiarity as a feature in visual search (e.g., Wang, Cavanagh, & Green, 1994; Shen & Reingold, 2001). These studies have shown that stimuli whose low-level visual properties are otherwise identical interact with search efficiency depending on whether they are meaningful stimuli: finding an unfamiliar stimulus (a rotated letter) among familiar stimuli (un-rotated stimuli) is easier than finding a familiar stimulus amongst many unfamiliar stimuli. If the negative-framing of the search task in our instructions is indeed the reason for confirmatory searching, then we will have incidentally provided a demonstration of the top-down construction of what defines a feature in visual search.

Although in this task, participants performed in a way that was not strategically optimal, confirmatory searching is likely a globally optimal strategy for visual search. For falsification to be an economical strategy requires some features or stimuli exist that are negatively correlated with the presence of whatever is being searched for. When target presence and absence is independent of other environmental features, only confirmation of the target's presence can reduce search times compared to an exhaustive search. In light of arguments that visual search may be optimized for foraging (Klein & MacInnes, 1998; Cain, Vul, Clark, & Mitroff, 2012), confirmatory searching would prove beneficial, in that the analysis of the environment would be tailored towards the goal of finding any extant resources, and promote the sustained pursuit of a goal even in situations where positive evidence is scant. Friedrich (1993) has argued for a related basis of confirmation bias in reasoning, noting that different types of errors produce more or less costs in the context of particular goals, and that it is more pragmatic to minimize costly errors than to simply minimize all errors, irrespective of their consequences. In the context of our visual search, additional covert costs – such as switching templates in working memory – may simply be more costly than the additional time spent searching in those cases where more stimuli match target templates. More broadly, expending cognitive (and motoric, in the case of saccades) resources to sustain a purely visual search for signs of prey is a relatively low cost investment, given the potential payoffs. Mechanisms in visual search, therefore, may be tuned to allow perseveration on the possibility that a real resource is indeed present, so that visual inspections can be sufficiently thorough. Cognition in general may be seen as a (relatively) biologically cheap way of tuning our actions in advance so as to acquire proportionally greater survival gains.

While we have shown that visual search tends to prioritize the confirmation of the presence of a target stimulus, even when suboptimal, it is not yet clear whether the confirmatory tendencies of top-down visual attention are related to confirmation bias as it exists in more cognitively complex social behavior and problem solving. A surface relationship between visual search and reasoning has been suggested by Mercier (2012), who noted the utility of using visual search as an analogy for how individuals seek arguments in order to persuade another person. In principle, both vision and reasoning are subject to the problem of combinatorial explosion

(Tsotsos, 1995; Evans, 2006) where the number of possible interpretations of observations exceeds any reasonable estimate of computability. In both cases, selection is necessary in order to arrive at any conclusion, and goal-driven selection is a sensible implementation for motivated agents. Despite the differences in complexities, visual selection and complex cognition may be related on the basis of shared executive processes or working memory, as suggested by Mynatt, Doherty, and colleagues (1990, 1991, 1993). Indeed, Hills and colleagues (2006; 2014) argue that goal directed cognition may find its evolutionary roots in foraging behavior, and has shown that search styles can be primed across domains – for example, between a visual foraging task and a lexical search task (Hills, Todd, & Goldstone, 2008) – suggesting shared cognitive control mechanisms. Clearly, goal-driven selection is a broad feature of the human mind, and while globally beneficial, it can lead us to flawed beliefs or behaviors when the assumptions borne by particular goal-driven attentional settings are themselves flawed, irrespective of the domain of analysis. Of course, all is not lost; flawed beliefs and interpretations can be corrected by a sufficient amount of inconsistent evidence. The effect of selection is merely a bias towards certain conclusions, not utter hegemony of beliefs and expectations in the face of all available evidence. Our primary proposal is that the effects of selection on evaluation of information will occur regardless of the domain in question.

Conclusions

By using a modified visual search task, we measured whether stimuli that could confirm the presence of a target are prioritized over those that could disconfirm the presence of a target. Our results provide support for the notion that top-down attention prioritizes stimuli that match a template, even when this strategy is not optimal for the task at hand. This constitutes a confirmatory search tendency, and given the similarities between features of theories of limits in both visual search and reasoning, we take these results as suggesting that mechanisms of top-down, selective attention, to the extent that they are shared across cognitive domains, may contribute to confirmation bias beyond visual search.

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