More than a memory: Confirmatory visual search is not caused by remembering a visual feature

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Abstract

Previous research has demonstrated a preference for positive over negative information in visual search; asking whether a target object is green biases search towards green objects, even when this entails more perceptual processing than searching non-green objects. The present study investigated whether this confirmatory search bias is due to the presence of one particular (e.g., green) color in memory during search. Across two experiments, we show that this is not the critical factor in generating a confirmation bias in search. Search slowed proportionally to the number of stimuli whose color matched the color held in memory only when the color was remembered as part of the search instructions. These results suggest that biased search for information is due to a particular attentional selection strategy, and not to memory-driven attentional biases.

Keywords: Visual attention, Working memory, Visual search, Heuristics, Confirmation bias

1. Introduction

The environment is full of information, but from moment-to-moment, we only want answers to particular questions (e.g., is there a car in my blind spot?). Top-down control allows us to attend to information that pertains to our goals; it allows us to selectively query our environment (Schneider & Shiffrin, 1977; Folk, Remington, & Johnston, 1992; Bacon & Egeth, 1994). What questions we ask, and how we ask them, can affect what information is processed and what information is not (Neisser & Becklen, 1975; Simons & Chabris, 1999). Simply asking whether a target object is green will lead observers to attend to green objects, even when non-green objects provide an equal amount of information about the target's color (Rajsic, Wilson, & Pratt, 2015). Thus, top-down visual attention can lead to a sort of confirmation bias (Wason, 1968; Klayman & Ha, 1987) where confirmation occurs faster than disconfirmation. In this paper, we investigate the cognitive mechanisms underlying this bias; specifically, whether the confirmation bias in visual search is an involuntary consequence of holding target information in memory.

Given that what we need to know about our environment changes from moment-to-moment, it stands to reason that top-down control depends on some sort of short-term memory system that maintains the current attentional criteria. Several models of attention have proposed that memory for attention is enabled by visual working memory (VWM; Luck, 2008), the memory store used to recognize (Luck & Vogel, 1997) and recall (Wilken & Ma, 2004) recently seen visual information (Duncan & Humphreys, 1989; Desimone & Duncan, 1995). Indeed, a considerable amount of evidence shows that maintaining a visual feature in memory for a later test can prioritize processing of objects that possess that feature (Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005; Olivers, Meijer, & Theeuwes, 2006; Olivers, 2009; but see

Downing & Dodds, 2004; Woodman & Luck, 2007). Such findings lead to an interesting situation; attentional selection that is endogenous (depending on the internal state of the organism, not properties of its input) but also involuntary (not due to current goals of the organism). This is not to say that all top-down control is necessarily of this sort. This memory-driven capture effect is subject to cognitive control (Carlisle & Woodman, 2011; Kiyonaga, Egner, & Soto, 2012), and thus depends on its goal-related utility. Nonetheless, memory-driven attentional capture presents a simple "null hypothesis" of the degree of intention that should be attributed to observers' attentional control state in a given situation: potentially nothing more than sustaining a memory for relevant information is required for goal-driven selection.

As noted earlier, a consequence of top-down attention is that information outside of the attentional set may be missed (Simons & Chabris, 1999; Lavie & Tsal, 1994). Recently, we have shown that this failure can take the form of a confirmation bias: when asked whether a target object has a particular property or not (e.g., is green or not green), attention is biased towards objects with this property (Rajsic et al., 2015). To do so, we have used a search task where two colored variants of a target can appear in search, for example, either a red or a green p among red and green non-p's (d, b, and q's). On every trial, one, and only one, of the two targets is present. Critically, participants are instructed to report whether the target letter is a particular color or not (e.g., is the p green or not). This allows one color to provide "positive information" and the other color to provide "negative information" with respect to the tested proposition (Klayman & Ha, 1987). What we are interested in is whether visual search will exhibit a bias towards positive information; that is, whether search times will depend on the number of matching colors (i.e., the number of green letters, in the example given), as search for color-defined targets can be restricted to color subsets (Egeth, Virzi,& Garbart, 1984; Bacon & Egeth, 1997). Our previous investigations (Rajsic et al., 2015; Rajsic, Taylor & Pratt, 2016; Rajsic, Wilson, & Pratt, 2017) have shown that a bias towards positive information does win out over the alternative strategy of attending to the smaller color subset (Sobel & Cave, 2002).

In our previous work, we have suggested that this confirmation bias results from a default strategy for testing hypotheses, whether perceptual or otherwise, of attending to features of the positive predictions of a proposition (Klayman & Ha, 1987). Consistent with this, the bias in search is reduced when searches are made more inefficient (Rajsic et al., 2017) and also when tested propositions tend to be false (e.g., targets tend to be non-green; Walenchok, Hout, & Goldinger, 2016). However, in light of the phenomenon of memory-driven attention reviewed earlier, a simpler explanation may exist. Given that participants need to at least encode, if not remember, one of the two stimulus colors to make responses in the search task, it is possible that the bias towards positive information is solely due to the consonance between a color held in memory (presumably VWM, although a verbal code can produce memory-driven capture as well: Soto & Humphreys, 2007) and not because of a hypothesis testing strategy. For example, when asked to report whether a p is green or not, participants may adopt a top-down set for the smaller color subset (i.e., red or green letters, whichever there are fewer of), but the necessity of maintaining the feature “green” in working memory to code the temporary stimulus-response mappings could cause green items to capture attention involuntarily during searches. In the present paper, we present two experiments testing this alternative explanation for the confirmation bias. To preview our findings, in both experiments, we find no evidence of selective search through stimuli whose color matches a color merely held in memory, suggesting that there is more to confirmatory search than the contents of memory.

2. Experiment 1

The goal of Experiment 1 was to test the possibility that confirmatory visual search is a result of one of two colors being held in working memory. To accomplish this, we adapted the design of Experiment 1 of Rajsic et al., (2015) to contrast the instructional manipulation that we presume to underlie confirmatory searching (the Positive information condition) with a stimulus-matched version that required similar maintenance of a color in memory (the Working Memory condition), but did not afford confirmatory searching.

2.1 Methods

2.1.1 Participants

Thirty-two undergraduate students enrolled in a first-year Psychology course at the University of Toronto volunteered for Experiment 1 through an online system. Students did not know the nature of the study for which they had volunteered until arriving at the lab, at which point the procedure was explained and informed consent was given. Participants were compensated for their participation with partial course credit. Half of the participants ($n = 16$) participated in the positive information condition, and half participated in the working memory condition.

2.1.2 Stimuli and Procedure

Stimuli were presented using 16" CRT monitors on a Dell PCs using Matlab and the Psychophysics Toolbox (Kleiner, Brainard, & Pelli, 2007). Responses were collected with a standard USB keyboard. The experiment consisted of a series of displays; instruction displays, that presented participants with search instructions before each block of trials an experimental session, and trials displays, which comprised individual trials. A schematic depiction of these displays is presented in Figure 1.

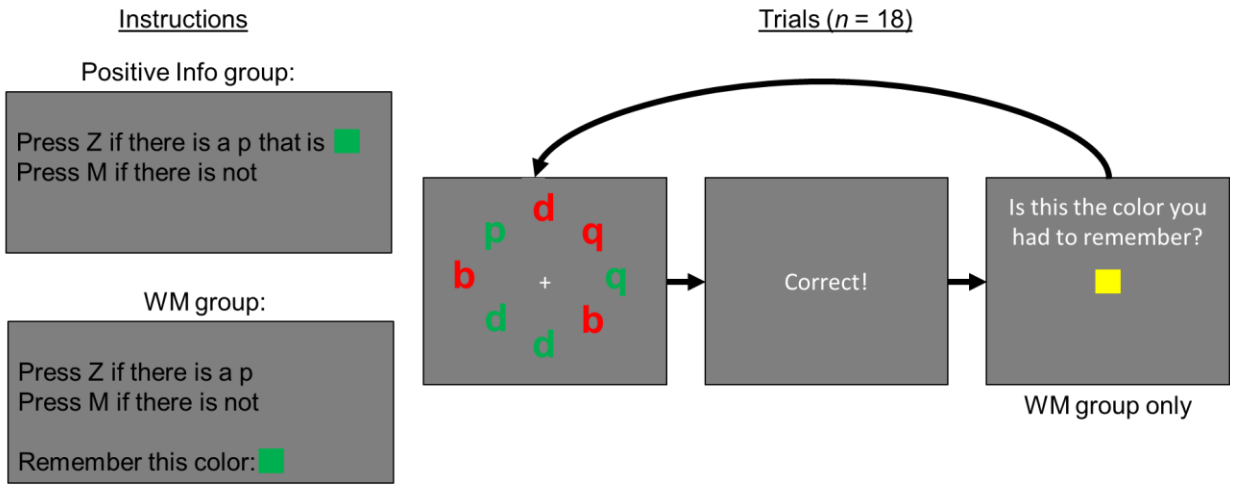

Figure 1.

A schematic of the events in Experiment 1. Instructions were presented before each block of 18 trials. Stimuli are not drawn to scale.

Before beginning the experiment, the experiment program displayed a written description of the task, which was closely matched between the two conditions. Both instructions emphasized that two possible target colors would be used. Participants pressed Enter to move past this screen, with a minimum 3-second duration.

Instruction displays for the positive information condition consisted of the instruction "Press *a* if the *target* is this colour: *color*. Press *b* if it is not." printed in the upper left of the screen. Instruction displays for the working memory condition used the instruction "Press *a* if the *target* is present. Press *b* if it is not." For both instruction types, the keys Z and M were used in a counterbalanced order to stand for responses *a* and *b*, and the *target* letter could be either p, b, d, or q. For the positive information condition, the *color* consisted of a small (1° by 1°) square colored in with the RGB coordinates of the template-matching color used for all subsequent search displays for that instruction. Instruction displays were presented until the participant pressed the Enter key to begin the experiment, with a minimum 1-second duration to ensure the instructions were not skipped by accident.

Each trial began with a fixation display, for 2000ms, consisting of a white + symbol, subtending 0.8° by 0.8°, on a dark grey background. The search display followed, with an identical fixation mark and 8 search letters (p, d, b, and q), positioned evenly around the circumference of an imaginary circle, radius 8°, centered on fixation. The letters subtended approximately 0.8° in width and 1.2° in height and were printed in Arial font.

On Target Present trials, one of the letters was the target letter, and the other seven distractor letters were chosen from the three remaining letters, randomly sampled with replacement. On color-matching trials, the target appeared in the color presented during the instructions. On color-mismatching trials, the target appeared in the color not presented during the instructions. On Target Absent trials, all distractors were selected from the three non-target letters.

The colors of the search stimuli were also manipulated in three levels, orthogonally to the target present factor. Before each search instruction display, two colors were selected to be used for a search block: one color to be presented in the instruction and one that would not, from a pool of seven colors (purple, yellow, green, orange, pink, blue, and red; see Rajsic et al., 2015 for RGB values). Either two, four, or six of the letters were colored using the color presented in the instructions, with the remaining letters colored in the color not presented. The search display was presented until a response was provided, using the Z or M keys. Once a response had been given, a feedback display appeared, with the word “Correct!” or “Incorrect” displayed at the center of the screen. This display lasted for 2000ms. In the working memory condition only, a memory test display followed this feedback screen. The memory test screen presented a single colored square, 1° by 1°, whose color either matched the remembered color or did not (i.e., it was selected from one of the six non-remembered colors). A memory response prompt was presented 12° above fixation, asking "Is this the colour that you had to remember? Z = yes, M = No.", centered horizontally. On half of the trials, the color matched the remembered color, and on half it did not. After a response was provided, the next trial began immediately.

Participants completed 16 blocks of 18 trials, where each block began with a new instruction screen. Within a block, the 18 trials were composed of an equal distribution of the three target present conditions and the three template color match conditions (i.e., 3 trials of each) in a random order.

2.2 Results

Our primary unit of interest was correct response time for each condition. Trials were selected for inclusion as long as responses were correct, and as long as response times were not greater or less than three standard deviations from each participant's average correct response time. For the working memory condition, an additional constraint was added: memory responses at the end of the trial needed to be correct. In addition, three participants from both conditions were excluded for having an overall accuracy of less than 75% (statistical results were similar without these participants' exclusion). In the positive information condition, 10.6% of trials, on average, were excluded due to incorrect search responses and 1.6% of trials, on average, were excluded for slow responses. In the working memory condition, 11.7% of trials, on average, were excluded due to incorrect search responses, 1.1% of trials were excluded due to slow responses, and 2.8% of trials were excluded due to incorrect memory responses. Overall, 11.7% of trials were excluded in the positive information condition and 15.1% of trials were excluded in the working memory condition.

Mean correct response times were calculated for each cell of our design: Target Presence (color matching, color mismatching, target absent) by Color Subset (2 matching, 4 matching, or 6 matching), and analysed with a 3 x 2 x 2 mixed model ANOVA, with the instruction condition included as a between-subjects factor. Search bias, as assessed by the color subset factor, differed by search instruction, $F(2, 48) = 39.15$, $p < .001$, $\eta^2_p = .62$, as did the target presence effect, $F(2, 48) = 29.59$, $p < .001$, $\eta^2_p = .55$, and their interaction, $F(4, 96) = 9.55$, $p < .001$, $\eta^2_p = .29$.

As can be seen in Figure 2, search under the positive information instructions closely resembled a serial search *for* targets matching the color held in memory: the target absent (*M* =

233ms, *SE* = 27ms) and color mismatching search slopes (*M* = 248ms, *SE* = 27ms) were approximately double those of color matching search slopes (*M* = 75ms, *SE* = 19ms). In contrast, in the working memory condition, search slopes were considerably flatter (M_{match} = 16ms, SE_{match} = 19ms, $M_{mismatch}$ = 10ms, $SE_{mismatch}$ = 27ms, $M_{targ\ absent}$ = -20ms, $SE_{targ\ absent}$ = 27ms). For both instruction conditions, however, color matching targets were reported faster than color mismatching targets. When targets matched the color in the search instructions, color matching targets were reported faster, *M* = 1709ms, *SE* = 157ms, than color mismatching targets, *M* = 2075ms, *SE* = 232ms, $F(1, 12) = 15.183$, $p = .002$, $\eta^2_p = .56$. When colors were simply held in memory, memory matching targets were still reported faster, *M* = 1959ms, *SE* = 146ms, than memory mismatching targets, *M* = 2124ms, *SE* = 135ms, $F(1, 12) = 10.01$, $p = .008$, $\eta^2_p = .46$.

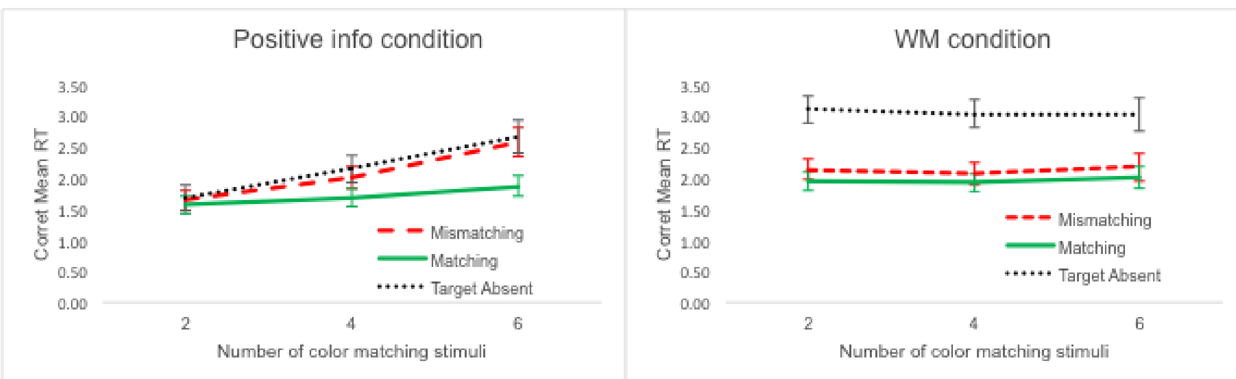

Figure 2. Search performance in Experiment 1 as a function of instruction type (left and right panels), target type, and color subset size. Error bars depict one within-subjects standard error (Cousineau, 2005).

2.3 Discussion

Overall, the results of Experiment 1 show that confirmatory search patterns are not simply a function of having to maintain a particular visual feature in memory during search. Search slopes over the memory-matching color subset were considerably steeper when participants were asked to report the presence of a particular colored target than when they were asked to search for a particular target while holding a color in memory. However, targets matching the color held in memory (for the search task, or merely during the search task) were reported faster in both cases. Nonetheless, the results clearly support the conclusion that a search setting requires more than a particular color being stored in memory.

3. Experiment 2

Although the results of Experiment 1 demonstrated that confirmatory search patterns are unlikely to be due simply to a color being stored in memory, the inclusion of target absent trials could have compromised our measure of the extent of the subset slope difference. In our original experiments (Rajsic et al., 2015), the target letter was always present. This was a very important design implementation, as it allowed for the existence of negative information (i.e., information that could negate one perceptual hypothesis). By including target absent trials in Experiment 1, this considerably reduced the utility of negative information; while it was true that finding a color mismatching target allowed the correct inference that a color matching target was not present, failing to find a given target did not allow for the inference that the other target was present. For this reason, the search strategy observed in our positive information condition in Experiment 1 cannot be clearly deemed a bias; a correct “yes” response can only be given by encountering a matching target, making a bias towards this color reasonable.

In Experiment 2, we modified the design of Experiment 1 so that only target-present trials were used, as in our previous work (Rajsic et al., 2015). For the working memory condition, participants discriminated the hemifield (left or right) that the target appeared in. As in Experiment 1, if confirmatory search patterns are simply due to the maintenance of a particular color in working memory, we should observe a matching-subset search slope in both the positive information and working memory conditions.

3.1 Methods

3.1.1 Participants

Twenty-four undergraduates enrolled in a first-year Psychology class at the University of Toronto participated in Experiment 2. None of the participants in Experiment 2 had participated in Experiment 1. Half of the participants (12) participated in the positive information condition, and the other half participated in the working memory condition. All participants gave informed consent before participating.

3.1.2 Stimuli and Procedure

The apparatus used in Experiment 2 were identical to those used in Experiment 1. The stimuli as well were identical with the following exceptions: the instructions of Experiment 2 were changed to reflect the new task, emphasizing the fact that the target letter would always be present in the display. In addition, before each block of trials, search instructions were given as "Press *a* if the *target* is this colour: *color*. Press *b* if it is not." for the positive information condition, and "Press Z if the *target* is on the left. Press M if it is not" for the working memory condition. The trials were also adjusted by removing all target absent trials. As such, the number of trials was reduced (16 blocks of 12 trials). Finally, to allow all targets to be reported as being on the left or right in the WM condition, stimulus positions were rotated by 22.5° (around fixation), such that all stimuli appeared in either the left or right hemifield.

3.2 Results

Trials for analysis were selected using the same procedure as Experiment 1; only trials with accurate responses and responses that fell within three standard deviations of participants' respective mean correct response time were included. For the positive information condition, this led to the exclusion of 12.3% of trials on average per person, comprising 1.9% slow responses and 11.1% search errors, and 10.5% of trials on average per person in the working memory condition, comprising 1.0% slow responses, 4.6% search errors, and 5.4% memory errors. The resulting search data are plotted in Figure 3.

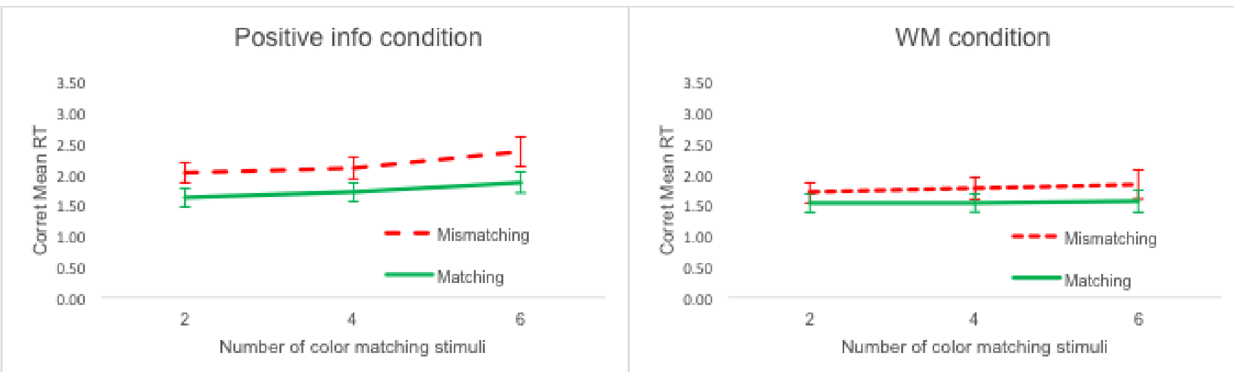

Figure 3. Search performance in Experiment 2 as a function of instruction type (left and right panels), target type, and color subset size. Error bars depict one within-subjects standard error (Cousineau, 2005).

As in Experiment 1, our critical interest was in whether the subset slopes differed between the two conditions. A mixed-model ANOVA showed an interaction between search condition and color matching subset size, $F(2, 44) = 5.11$, $p = .01$, $\eta^2_p = .19$. For the positive information condition, search slopes were steep, but near parallel ($M_{\text{color matching}}$ = 63ms, $SE_{\text{color matching}}$ = 14ms, $M_{\text{color mismatching}}$ = 84ms, $SE_{\text{color matching}}$ = 22ms). In the working memory condition, slopes were considerably less steep, $F(1, 22) = 9.86$, $p = .005$, $\eta^2_p = .31$, ($M_{\text{color matching}}$ = 8ms, $SE_{\text{color matching}}$ = 14ms, $M_{\text{color mismatching}}$ = 34ms, $SE_{\text{color matching}}$ = 22ms).

Despite the lack of a strong bias towards color-matching stimuli in the working memory condition, we nonetheless observed an advantage in response time for matching-targets, *M* = 1538ms, *SE* = 72ms, over mismatching targets, *M* = 1766ms, *SE* = 105ms, $F(1, 11) = 11.34$, $p = .006$, $\eta^2_p = .51$.

3.3 Discussion

Experiment 2 demonstrated that, in a search for targets that were always present, confirmatory search emerged when one color was framed as positive information, but not when that same color was simply held in memory. Only in the former condition did search slopes clearly indicate a selection of matching-colored search items. However, in both conditions, we observed an overall advantage in the speed of reporting a memory-matching target.

4. General Discussion

The goal of the present investigation was to determine whether confirmatory visual search occurs because of the need to maintain particular visual information in memory. Given that asking whether a target object has a particular property (e.g., greenness) requires remembering the property in question (green), this memory representation alone could lead to confirmatory search patterns if it involuntarily drove attention to matching visual information (Soto, Heinke, Humphreys, & Blanco, 2005; Soto & Humphreys, 2007). Across two experiments, we showed that this is not the case. With identical search displays, searches were biased to particular colored stimuli only when searchers were asked about whether a target had a particular feature (the positive information condition), but not when they were asked to search for a target while remembering that same feature (the working memory condition). These results show that confirmatory search is not simply due to feature-priming (see also Rajsic et al., 2016).

One noteworthy observation from the present experiments is that while a search slope over feature-matching stimuli occurred only in the positive information condition, both conditions showed a response-time benefit when the target possessed the feature maintained in memory. We take this to reflect the involvement of features held in memory in the target recognition stage of search, but not in the guidance stage. Recent evidence shows that variations in the precision, category, and prevalence of target types can affect both guidance and the speed of recognition (Hout & Goldinger, 2015; Hout, et al., 2017; Hout, Walenchok, Goldinger, & Wolfe, 2015). Repetition benefits for conjunction targets and distractor context also seem to largely produce intercept, not slope, changes in visual search (Kristjánsson, Wang, & Nakayama, 2002; Kunar, Flusberg, Horowitz, & Wolfe, 2007; but see Becker & Horstmann, 2009). Interpreted through the lens of a two-stage search theory, like Guided Search 4.0 (Wolfe, 2007), our results suggest that, at least in our task, activating a feature in working memory affects the speed of object recognition, either by lowering a "target" threshold for objects possessing features in working memory, or by increasing the rate of "target" evidence accrual for object whose features match those in working memory; our experiments were not designed to provide the detailed speed-accuracy data needed to tease these two possibilities apart. Importantly, our data suggest that settings of the guidance system are, appropriately, related to the search task and not the contents of memory. Even memory-driven capture effects are affected by task-demands (Carlisle & Woodman, 2011; Olivers & Eimer, 2011; Dalvit & Eimer, 2011; Kiyonaga, Egner, & Soto, 2012), demonstrating that the information currently held in memory is only part of the process of allocating visual attention (if at all: Woodman, Carlisle, & Reinhart, 2013).

It thus seems clear that there is more to the guidance of attention than information maintained in memory: but what else is involved? Given that working memory representations are considered to be the format shared by many cognitive operations (Luck, 2008), there must be additional states or processes that code the current function, or use, of the information maintained in memory. Indeed, this would mirror the way we talk about these cognitive activities (e.g., I can search for red or for green objects, and I can also list foods I know of that are red or green). Oberauer (2010) referred to this second set of functions as procedural working memory, and suggests that cognitive actions are the result of cognitive bindings between the content (red) and the conduct (look-for), both maintained in short term memory stores. This proposal would make similar predictions to the “special status” proposal of Olivers, Peters, Houtkamp, and Roelfsema (2011), who proposed that only one working memory representation can guide attention at a time, if it were the case that only one binding could be maintained. However, available empirical evidence suggests that the one-item limit is not always observed (Beck, Hollingworth, & Luck, 2012; Hollingworth & Beck, 2016), though it is not clear whether multiple-feature templates should be considered one or several templates (Huang & Pashler, 2007). We suggest, along with Irons and Leber (2016), that the relative utility of different attentional guidance strategies may be critical in resolving these issues.

To be clear, although our results show that maintenance of a color in memory is not sufficient to induce a visual confirmation bias, active working memory representations might nonetheless be the source of the bias when memories are relevant to search (i.e., when they are involved in maintaining features of the search instructions). We follow previous researchers in suggesting that voluntary attentional guidance requires additional cognitive processes (Olivers & Eimer, 2011; Carlisle & Woodman, 2011). A recent discussion of internal attention by Myers, Stokes, and Nobre (2017) provides a useful perspective on this issue by highlighting how an "attended memory" may be better thought of in terms of reformatting a memory to prepare for particular tasks and actions. They suggest that the difference between remembering several colors for a memory test and focusing one of those colors that has been cued as likely to be tested may be a change in the temporary mappings between representations of remembered colors and potential responses (same/different from any color, same/different from cued color). Our results are quite compatible with this line of reasoning; this is, after all, our primary manipulation. Similar manipulations of remembering versus implementing instructions during a stimulus-response task have revealed considerable neural differences between these two cognitive states, both in terms of regions associated with control (e.g., lateral prefrontal and parietal cortices) and regions associated with stimulus coding (e.g., visual areas, such as the fusiform face area; Muhle-Karbe, Duncan, De Baene, Mitchell, & Brass, 2016). We suggest that top-down guidance of visual attention may be a special case of this broader class of memory-action couplings.

In referring to the search patterns we have observed as a "confirmation bias", we are suggesting that participants' lack of flexible subset selection in our task amounts to a failure to actively entertain alternative perceptual hypotheses (Kunda, 1990; Koehler, 1991; Mynatt, Doherty, & Dragan, 1993; Buttaccio, Lange, Thomas, & Dougherty, 2015). Ruling out a simple memory-driven attentional bias explanation provides some support to this interpretation. As such, we consider our results to be indicative of the cognitive strategies participants employ in visual search, and, perhaps too, other forms of visual reasoning. The notion that confirmatory searches are a simple, default method of querying visual data is congruent with research on sentence-picture comparisons, where verifying that a previously presented sentence described a picture tends to be faster than denying the match (Clark & Chase, 1972; but see Underwood, Jebbett, & Roberts, 2004) as well as recent work on the interpretation of graphical data representations by Michal and colleagues (Michal, Uttal, Shah, & Franconeri, 2016), which shows a tendency to inspect graphs in the order suggested by a question.

To conclude, the present study shows that the confirmation bias in search is not the result simply of the contents of memory. We suggest instead that it reflects an information search strategy (i.e., template-matching) that allows for a cognitively economical solution to visual hypothesis testing.

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