Northumbria Research Link

Confirmation Bias in Visual Search

Jason Rajsic[1], Daryl E. Wilson[2], Jay Pratt[1]

[1]University of Toronto

[2]Queen's University

Word Count: 8890

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

48   **Introduction**

49   Although the claim that humans are rational is central to traditional economic and legal

50   thinking, experimental psychology has uncovered many situations where our reasoning is limited

51   or biased (Tversky & Kahneman, 1981). One of the most well-known cognitive biases is

52   confirmation bias, wherein selection and evaluation of information that would confirm a focal

53   hypothesis is given priority – or even exclusivity (Nickerson, 1998). As a consequence, ill-

54   founded beliefs can persist, as contradictory evidence tends to be ignored, underweighted, or

55   even misinterpreted as evidence in favor of existing beliefs. The bias can be found in a wide

56   variety of domains, from problem-solving and reasoning (Wason, 1960; 1966), to real-world

57   settings including law (Kassin, Dror, & Kukuchka, 2013), medicine (Pines, 2006), and science

58   (Fugelsang, Stein, Green, & Dunbar, 2004). Although confirmation bias is often studied in the

59   context of explicit reasoning, selection occurs in nearly every stage of human information

60   processing, including vision, where attentional mechanisms have been researched extensively

61   (see Carrasco, 2011, for a review). In this paper, we pursue the question of whether visual

62   selection exhibits a confirmation bias; specifically, when searching for a particular stimulus in a

63   noisy environment, is the search confirmatory in nature. First, however, we highlight the

64   connections between several theories of confirmation bias and theories of selective visual

65   processing.

66   Of those theories that seek to account for confirmation bias in terms of psychological

67   processes, many have implicated cognitive mechanisms of selection in one form or another

68   (Kunda, 1990; Doherty, Mynatt, & Dragan, 1993; Neuberg, 1994, Sanbonmatsu et al., 1998). For

69   example, Kunda (1990) has argued that confirmation bias in reasoning is due to a biased search

70   through memory for information that is consistent with one's goal. The core notion is that, when

71   seeking information for the purposes of a particular goal, cognitive processes increase the

72   availability of information from memory that supports the goal. Such selective activation leads to

73   the biased strengthening of the goal-centered proposition, where information that is inconsistent

74   with the proposition is relatively less salient or available than consistent information. Other

75   accounts stress the notion of capacity limits in reasoning, such as Evans' (2006) heuristic-

76   analytic model of reasoning which states that when reasoning about hypothetical possibilities, we

77   are limited to the consideration of a single hypothesis at a given time. Similarly, Doherty,

78   Mynatt, and colleagues (1990; 1991; 1993) suggest that failing to optimally test multiple

79   hypotheses is due to limitations of working memory; only one possible interpretation of evidence

80   (i.e., only one hypothesis) can be held in working memory at a time, and so participants can only

81   reason about the conclusions drawn from evidence contingent on this hypothesis. Both of these

82   proposals bear some similarity to Koehler's notion of conditional reference frames (1991), but

83   Doherty and Mynatt's account points specifically to capacity limitations in working memory as

84   the cause of participants' tendency to evaluate one possibility at a time.

85   While the aforementioned proposals are intended to explain the particular way that we

86   search for information, the features of these accounts are analogous in many ways to features in

87   accounts of another type of search: visual search. Many theories of top-down visual selection

88   also propose that information processing is biased towards goal-relevant information, and that

89   core information processing units have a limited capacity. Guided Search (Wolfe, 1998; 2004),

90   Feature Integration Theory (Triesman & Sato, 1990), the Theory of Visual Attention (Bundesen,

91   1990), the Boolean Map Theory of Visual Attention (Huang & Pashler, 2007), and Biased

92   Competition (Desimone & Duncan, 1995) all state that visual search is guided, biased, or

93   otherwise prioritized towards stimuli matching some template of the stimulus that is being

94   searched for, whether that be through applying gain to template-matching stimuli or through

95   suppressing of template-mismatching stimuli. In addition, research on the role of working

96   memory in visual search guidance has led some investigators to conclude that visual selection

97   can only be guided by a single template at a time (Olivers et al., 2011; but see Beck,

98   Hollingworth, & Luck, 2012). These theorized mechanisms allow for more economical

99   processing of visual information, so that aspects of the visual input that are task-relevant can

100   receive preferential processing. However, prioritizing stimuli that are similar to a target template,

101   paired with the limitation of a single template being maintained, is theoretically sufficient to

102   produce a confirmation bias in visual search. If we consider the target template as a hypothetical

103   visual state, evidence for alternative visual states will take longer to accumulate to the extent that

104   this information is incongruent with features in the template. This sort of visual guidance is

105   confirmatory; information that supports the presence of goal-relevant information is increased in

106   salience. Moreover, in the case where critical visual information is fleeting, alternative states

107   may never reach awareness during episodes of heightened top-down guidance. The latter

108   possibility has been demonstrated in studies of inattentional blindness, where conspicuous events

109   go unnoticed while one is engaged in a demanding visual task, despite no change in sensory

110   input (Mack & Rock, 1998; Simons & Chabris, 1999). For example, observers are readily able

111   to maintain the mundane percept of "people playing basketball" in the face of visual information

112   that is grossly inconsistent with this interpretation: namely, a gorilla walking through the middle

113   of the group.

114   Though the evidence to date supports the possibility that top-down visual selection

115   mechanisms may automatically lead to confirmatory searching, the design of visual search tasks

116   encourages confirmatory selection as a useful strategy, and so confirmatory searching could be a

117   voluntarily adopted strategy. In the typical visual search task, the task goal is to report whether a

118   target is present or absent in a given array of stimuli, any one of which could be the target

119   stimuli. In such tasks, where a target can be present or absent, distractors (or non-targets) provide

120   no information about the potential target, making a confirmatory search strategy optimal. The

121   proposition "there is a target" can be verified in less time (on target-present trials) than it can be

122   falsified because registration of the presence of a target stimulus can occur before every stimulus

123   in the display is fully processed, providing sufficient information to execute the correct response.

124   Falsification of target presence, however, cannot be completed until all stimuli are analysed to

125   the level of response-discriminating categories. Therefore, it is unclear whether visual selection

126   is confirmatory by its nature, or whether confirmatory selection is simply adopted as a useful

127   strategy for visual search.

128   To determine whether top-down visual guidance has a confirmation bias by default, or

129   whether this potential bias may simply result from tasks demands, it is necessary to provide a

130   direct measurement of the perceptual hypothesis testing used in visual search. To this end we

131   used a task where on each trial a target stimulus could have one of two features, with each

132   conjunction of target identity and target feature being equally probable. To assess confirmatory

133   searching, one particular conjunction was designated as a target template by framing the search

134   as a question that was to be answered about a given search display. In each search, a variable

135   proportion of distractor stimuli possessed the template-matching feature, with the remaining

136   proportion possessing the template-mismatching feature. By measuring search times, we are able

137   to determine whether participants perseverate on searching through template matching stimuli –

138   those that could confirm the presence of the target defined in the template, if inspected with

139   covert attention – instead of opting to search through template mismatching stimuli – those that

140   could, when inspected, disconfirm the presence of the target defined in the template.

141   For example, imagine a search where one is instructed to report whether the letter "p"

142   that appeared once in a given display was blue, knowing that a lone p, amongst other letters,

143   would be present in the display in some color. Eight letters onset, two of which are red, and six

144   of which are blue. If one takes "p is blue" as a perceptual hypothesis, and searches so as to

145   confirm this hypothesis, then one will prioritize the blue stimuli in search, as they are potential

146   exemplars of the target template. On the other hand, a clever observer may realize that, in this

147   situation, disconfirming the hypothesis "p is blue" would require less work, as only two stimuli

148   need be expected before sufficient information has been collected to provide a response. If this

149   searcher scans the red letters and finds a p, they may report that the p is not blue. If a red p is not

150   found, one can then conclude that the p must be blue.

151   Because the target letter is always present in a display, participants can always infer the

152   feature of the target stimulus by an exhaustive search through the smallest subset of colored

153   stimuli. Although a number of studies have investigated the guidance of attention to a subset of a

154   display (Bacon & Egeth, 1997; Sobel & Cave, 2002), in these tasks no stimuli on their own can

155   provide information against the target's presence, and so it is not possible for the observer to

156   adopt a strategy of disconfirmation.

157   Our goal in using this paradigm was to determine whether visual search exhibited

158   confirmation bias. A confirmation bias would comprise any tendency to prioritize search stimuli

159   that matched the target template over those that did not; in other words, a bias to search stimuli

160   that would lead to a "yes" response, with respect to the question of whether the target defined by

161   the template was present in the display. In Experiment 1, we demonstrate that indeed it does, and

162   subsequent experiments were conducted in order to home in on the locus of the bias. In doing so,

163   we entertained two broad possibilities: that confirmation bias in search results from failure of a

164   top-down search strategy (i.e., a failure to recognize that the minimal search strategy exists), or

165   that confirmation bias in search results from relatively automatic search heuristics, possibly

166   arising from mechanisms underlying intertrial priming (Kristjánsson, Wang, & Nakayama,

167   2002). Specifically, intertrial priming could lead to confirmatory searching if stimulus selection

168   is primarily driven by a biased selection history for template-matching colors initiated by early

169   confirmatory searches.

<center>**Experiment 1**</center>

171   Experiment 1 was designed to assess whether confirmation bias exists in visual search.

172   More specifically, our goal was to determine whether participants would perseverate in searching

173   using a given target template even when this strategy was inefficient (i.e., more stimuli had to be

174   examined). By manipulating the proportion of search stimuli possessing a template-matching

175   feature, we were able to track participants' search behavior by measuring the response time cost

176   associated with increasing the size of the target-matching stimulus subset. This allows us to

177   contrast two theoretically possible search styles; a confirmatory search strategy (i.e.,

178   confirmation bias; search through the template-matching color), and a minimal search strategy

179   (i.e., an ideal performer; search through the minority color). Although both strategies allow for

180   the eventual, veridical confirmation or disconfirmation of the target template, they differ in the

181   priority of the two conclusions: under a confirmatory strategy, confirmation of the presence of

182   stimuli matching the target template will take less time than disconfirmation. This difference can

183   be seen in the predicted search times that follow from the two search strategies.

184   The confirmatory search strategy, in which stimulus selection is biased towards those

185   stimuli that would confirm the target template, predicts a monotonic increase in search time as

186   the proportion of template-color matching stimuli increase, and a response time benefit when the

187   search target matches the search template.[1] The minimal search strategy, in which stimulus

188   selection is intended to minimize the number of stimulus inspections necessary to produce a

189   response, predicts a quadratic relationship between the proportion of template-color matching

190   stimuli and response time, with the longest searches occurring when there is an equal proportion

191   of template-color matching stimuli and template-color mismatching stimuli, and a reduction in

192   search time as the smaller subset of stimuli reduces in size. In addition, the minimal search

193   strategy predicts no consistent relationship between whether the target stimulus matches or does

194   not match the search template, as the template adopted for a given search would depend on

195   which stimulus color was in the minority. The two factors, Color Proportion and Color Match,

196   should therefore produce a cross-over interaction effect on search times with a minimal search

197   strategy. A sample search instruction and illustration of the predictions of these two strategies is

198   provided in Figure 1.

199   A third possible strategy, not pictured, is that participants will not use color to guide

200   search at all, but instead inspect items randomly and, after finding the target letter, report its

201   color. Because this strategy is insensitive to color in the selection stage, it predicts a flat search

202   slope across the target-matching subset conditions, and an overall response time cost for

203   reporting the target when it appears in a template-mismatching color.

---

[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.

204
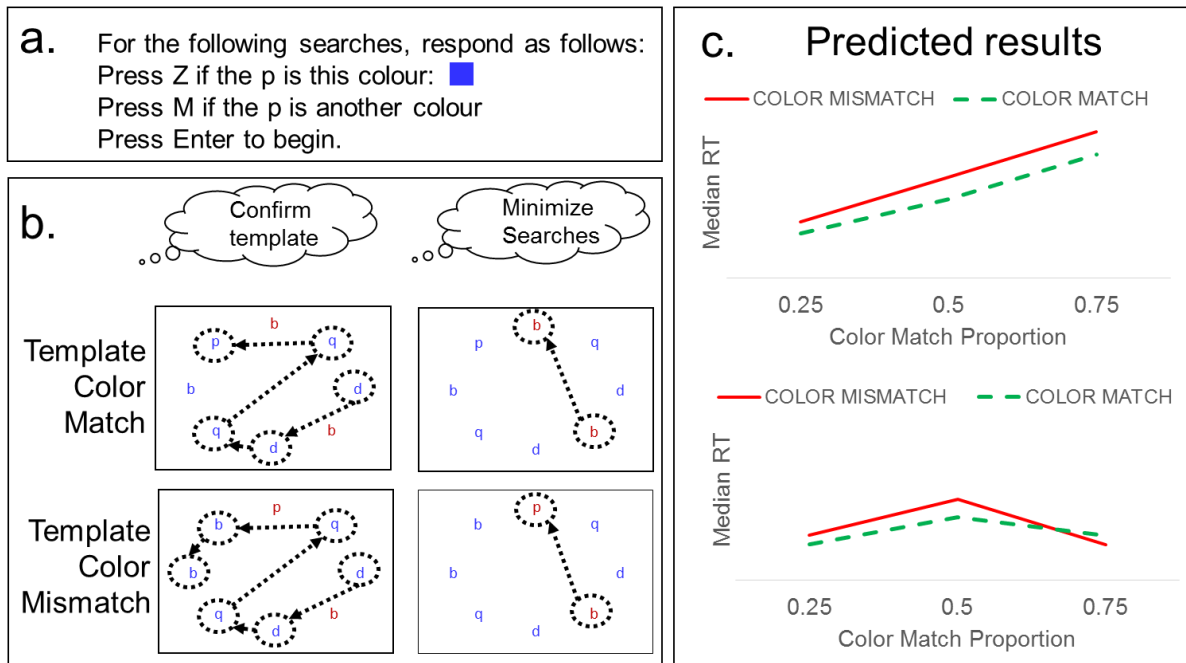
Figure 1. A sample of stimuli used, with predictions for the confirmatory search strategy and

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.

216   **Methods**

217   **Participants**

218   Twelve undergraduate students volunteered to participate for course credit. All

219   participants provided informed consent.

220   **Stimuli**

221   Search displays were composed of eight letters, spread evenly along the perimeter of an

222   imaginary circle centred on a fixation cross. Each letter in a search display was a lowercase p, q,

223   b, or d, approximately 2° in height and 1° in width, and was drawn approximately 8° from

224   fixation using Arial font. The letters were always one of four similar letters (lowercase b's, p's,

225   q's, and d's), chosen to discourage the possibility of target pop-out. Search displays had a dark

226   grey background display. In addition, stimulus colors were selected from a pool of seven

227   possible colors; purple, yellow, green, orange, pink, blue, and red (RGB values, respectively:

228   200, 0, 255; 200, 200, 0; 0, 255, 0; 255, 128, 0; 255, 128, 255; 50, 50, 255; 255, 50, 50). Before

229   each block of searches, a set of instructions were presented on the screen.

230   **Procedure**

231   In a given block, one letter was selected as the target letter, and two stimulus colors were

232   selected from the aforementioned pool of eight colors. At the outset of each block, participants

233   were instructed to report whether the chosen target letter was one of the two colors, or not, using

234   one of two keys (M and Z, on a standard keyboard) for each response. For example, if the target

235   letter on a given block was p, and the two selected colors were red and blue, the participant may

236   have seen the instruction, "For each search, respond as follows: Press Z if the p is this color

237   (blue), press M if the p is another color." The particular response mapping changed from block to

238   block, such that no key was constantly mapped to either type of response. Once participants had

239   read and memorized the search rule, they initiated a block of 30 searches by pressing the Enter

240   key. Each participant completed 16 different blocks.

241   For each search, the target letter was always present, accompanied by seven distractor

242   letters. The participant's task was to determine, for a given display, which of two possible colors

243   the target letter appeared in. Distractor letters were each colored with one of the two colors

244   selected for the block, which we will refer to as the template matching color and template

245   mismatching color, with the former referring to the color explicitly mentioned in the block's

246   search rule. Two factors were manipulated within search blocks: which color the target was

247   drawn in (template matching or template mismatching; each equally likely), and the proportion

248   of search stimuli of the template matching color (0.25 – two of eight letters, 0.5 – four of eight

249   letters, and 0.75 – six of eight letters; each equally likely). Each block contained an equal

250   number of trials from each condition, and their order was randomized so that participants' global

251   strategy could be measured. Distractor letters were randomly sampled with replacement from the

252   pool of non-target letters. Search stimuli remained on screen until a response was provided, after

253   which the word "Correct" or "Incorrect" was presented at fixation as feedback.

254   **Results and Discussion**

255   To determine which strategy was implemented by participants, we conducted a 3 X 2

256   repeated measures ANOVA on median response time (RT) for trials with a correct response,

257   with Color Proportion (0.25, 0.5, 0.75) and Match-Color (template match, template mismatch) as

258   factors. Unless otherwise noted, all RT analyses include only trials with a correct response.

259   Predicted results for the confirmatory search strategy are a monotonic effect of Color Proportion

260   and a main effect of Match-Color, whereas the minimal search strategy predicted a quadratic

261   (i.e., non-monotonic) effect of Color Proportion and an interaction between Match-Color and

262   Color Proportion, as searches should terminate with template matching targets and template

263   mismatching targets, respectively, when the template matching color is in the minority and

264   majority, respectively. Our results (Figure 2) showed that search indeed slowed when

265   proportionally more hypothesis-confirming stimuli were present in the display. Response times

266   increased as the proportion of template-matching colors increased, $F(2, 22) = 28.37$, $p < .001$,

267   partial $\eta^2 = .72$; a linear contrast proved statistically reliable, $F(1, 11) = 47.03$, $p < .001$, partial
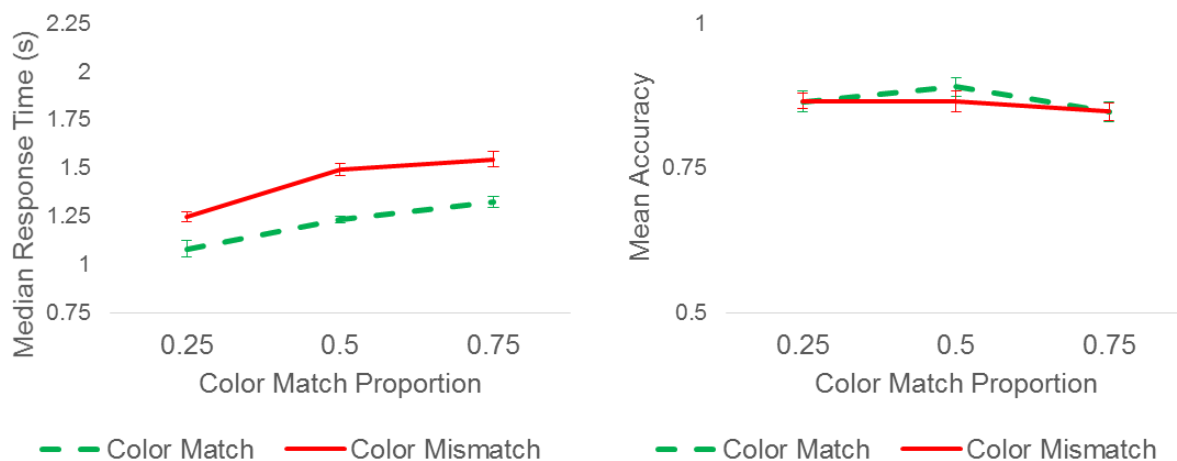
268

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

270   Experiment 1. Error bars in this and all other figures depict one within-subjects standard error

271   (Cousineau, 2005).

272

273    $\eta^2 = .81$, accompanied by a marginally significant quadratic contrast, $F(1, 11) = 4.33$, $p = .06$,

274   partial $\eta^2 = .28$. These results show that search time indeed increased as more template-matching

275   colors appeared in the search display, although the increase in search time was not completely

276   linear (we return to this point in Experiment 3).

277   Responses were also overall slower for template mismatching colors, $F(1, 11) = 58.39$, p

278    $< .001$, partial $\eta^2 = .84$, and, crucially, this effect did not interact with Color Proportion, $F(2, 22)$

279    $= 1.21$, $p = .32$, partial $\eta^2 = .10$. Although we observed a quadratic trend of Color Proportion on

280   search time, the lack of an interaction between Color Proportion and Color Match contradicts the

281   possibility that participants adaptively switched search strategies to minimize their searches

282   when the target-mismatching color was the smaller color subset, as in that case, the Color

283   Mismatch trials would now be those where the target *matched* the updated template, and

284   therefore ought to have exhibited a reduction in search time. We return to the issue of this

285   quadratic trend in the results section of Experiment 3. In addition to supporting the confirmatory

286   selection strategy, these results rule out a post-selection strategy, where stimuli are selected

287   randomly and color is only analysed after the target letter is identified.

288   We analysed overall accuracy using a similar repeated measures ANOVA to determine

289   whether results may have been due to a speed-accuracy trade-off. No main effects or interactions

290   were observed, Fs < 1.75, ps $> .20$, partial η^2s $< .14$, ruling out the possibility of a trade-off

291   between speed and accuracy.

292   One possible source of perseveration on selection of the template-matching color is inter-

293   trial priming. Inter-trial priming refers to the facilitation of target selection when one of the

294   targets' features repeat across sequential trials. Such priming is known to occur when a target's

295   presence varies (Olivers & Meeter, 2006), and Experiment 1's design meets that criterion if we

296   consider template matching and template mismatching targets to be distinct target

297   representations.

298   To assess the possibility that inter-trial priming contributed to confirmatory selection, we

299   divided trials into those that were preceded by a template matching target trial, and those that

300   were preceded by a template mismatching target trial, which we will refer to as the Priming

301   condition. Prime X Match-Color X Color Proportion repeated measures ANOVA revealed a

302   main effect of Prime, $F(1, 11) = 14.96$, $p = .003$, but no interactions between Prime and other

303   factors, Fs < 1.92, ps $> .17$. It therefore appears that inter-trial priming did not greatly affect

304   selection performance, but that trials requiring falsification of the target template led to a small

305   overall reduction ($M = 59$ms, $SE = 11$ms) in search time on the subsequent trial.

306   **Experiment 2**

307   The results of Experiment 1 show a robust effect of confirmatory searching. Overall,

308   search tended to be biased by the target template provided in initial search instructions, despite

309   the fact that both bottom-up saliency and top-down strategy should have encouraged selection of

310   the smaller subset when the template matching stimuli were more numerous. In the present

311   experiment, we sought to determine whether search may have been confirmatory because it is

312   less cognitively demanding to retain a single template across a number of trials (Shiffrin &

313   Schneider, 1977), rather than switch templates based on the properties of any one search display.

314   To examine this, a new search target template was presented before each search trial in

315   Experiment 2. This allows us to test the possibility that maintaining a consistent mapping

316   between a given target letter and color as a search template was the source of confirmatory

317   search behavior in the previous experiment. If confirmatory searching occurs due to a resistance

318   to template-switching across trials, then we would expect a minimal search pattern of results (see

319   Figure 1c). However, if confirmatory searching is an automatic consequence of guiding search,

320   then the results of Experiment 2 will mirror those of Experiment 1.

321 **Methods**

322   **Participants**

323   Twelve new undergraduate students were recruited for the present experiment. All

324 participants provided informed consent and were compensated with course credit. We chose

325 twelve participants in order to match Experiment 1 for statistical power, and this general

326 approach was also adopted for all subsequent experiments.

327   **Stimuli and Procedure**

328   The stimuli and procedure for Experiment 2 were identical to those of Experiment 1, with

329 the exception that participants now completed 300 trials where search displays on every trial

330 were preceded by a new set of search instructions providing a new target template. With this

331 change, the two possible stimulus colors, the target letter, template color, and response mapping

332 were randomized before every trial.

333 **Results and Discussion**

334   We analysed median response time (Figure 3) and accuracy using separate 3 X 2 repeated

335 measures ANOVAs as in Experiment 1. Once again, a main effect of Color Proportion was

336 present, $F(2, 22) = 44.04$, $p < .001$, partial $\eta^2 = .80$. Consistent with confirmatory searching, we

337 observed a significant linear trend, $F(1, 11) = 59.78$, $p < .001$, partial $\eta^2 = .84$, but no reliable

338 quadratic trend, $F(1, 11) = 1.40$, $p = .26$, partial $\eta^2 = .11$. In addition, a main effect of Color-

339 Match was again observed, $F(1, 11) = 49.97$, $p < .001$, partial $\eta^2 = .82$, such that RT was faster

340 when the target matched the template color, and, critically, no interaction was present, $F(2, 22) =$

341 0.16, $p = .85$, partial $\eta^2 = .02$. These results suggest that template-color matching stimuli were

342 prioritized for search, and that searches terminated upon the detection of a template-color

343   matching target. Search template repetition, then, does not appear to be necessary for a

344   confirmatory search strategy to emerge.

345   Unlike Experiment 1, we observed an accuracy effect in Experiment 2. Color Proportion

346   did not reliably alter accuracy, $F(2, 22) = 1.21$, $p = .32$, partial $\eta^2 = .10$, nor did Color Proportion

347   interact with Color-Match, $F(2, 22) = 0.92$, $p = .41$, partial $\eta^2 = .08$, but Color-Match did, $F(1,$
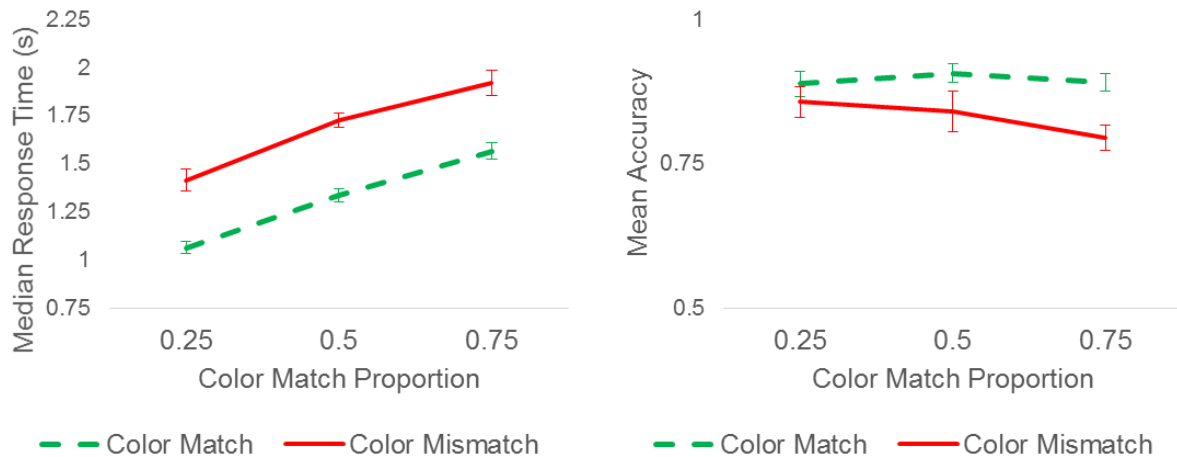
348

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

350   Experiment 2.

351

352    $11) = 5.03$, $p < .001$, partial $\eta^2 = .31$, such that more errors were made in reporting a template

353   mismatching target than in reporting a template matching target. Combined with the RT effects,

354   the overall picture is that template-color mismatching targets were associated with poorer

355   performance in general.

                                    Experiment 3

357   The results of Experiment 2 shows that confirmatory selection still occurs when the target

358   template changed from trial to trial, meaning that confirmatory searching does not occur simply

359   as a result of an attempt to minimize cognitive effort. However, memorizing a new target

360   template on every trial would certainly tax working memory; for example, Carlisle and

361   Woodman (2011) have shown that new search targets are held in visual working memory, but the

362   working memory load decreases as searches continue with the same template. The lack of an

363   optimal selection strategy in Experiments 1 and 2, then, may have been due to the relatively high

364   working memory load associated with adopting new search targets. In Experiment 3, we reduced

365   cognitive load by having participants maintain the same search template for the entire

366   experiment. This allowed us to determine whether a flexible selection strategy could be adopted

367   when working memory demands were minimized. We anticipated two possibilities; that

368   confirmatory searching would again occur, showing that - while not necessary – template

369   repetition could be sufficient to encourage a confirmation bias, or that confirmatory searching

370   would cease, showing that it was the increased cognitive load associated with adopting new

371   target templates that prevented the use of an optimal search strategy.

372   **Methods**

373   **Participants**

374   Twelve undergraduate students were recruited for the third experiment. All participants

375   provided informed consent and were compensated with course credit.

376   **Stimuli and Procedure**

377   We used the same stimuli and procedure as Experiments 1 and 2, with the exception of

378   the number of trials and blocks, which were changed to 300 and 1, respectively. As a

379   consequence, each participant received a single pair of stimulus colors, target template

380   instruction, and response mapping that persisted for all searches in the experiment.

381   **Results and Discussion**

382   The results of a 3 X 2 repeated measures ANOVA again showed a main effect of Color

383   Proportion, $F(2, 22) = 8.20$, $p = .002$, partial $\eta^2 = .43$ on search times (Figure 4). Polynomial

384   contrasts revealed that the effect of Color Proportion was linear, $F(1, 11) = 11.12$, $p = .007$,

385   partial $\eta^2 = .50$, and not quadratic, $F(1, 11) = 1.06$, $p = .33$, partial $\eta^2 = .09$. In addition, a main

386   effect of Color Match was also evident, $F(1, 11) = 7.36$, $p = .02$, partial $\eta^2 = .40$, with no

387   interaction between the two factors, $F(2, 22) = 0.38$, $p = .69$, partial $\eta^2 = .03$. The results of the
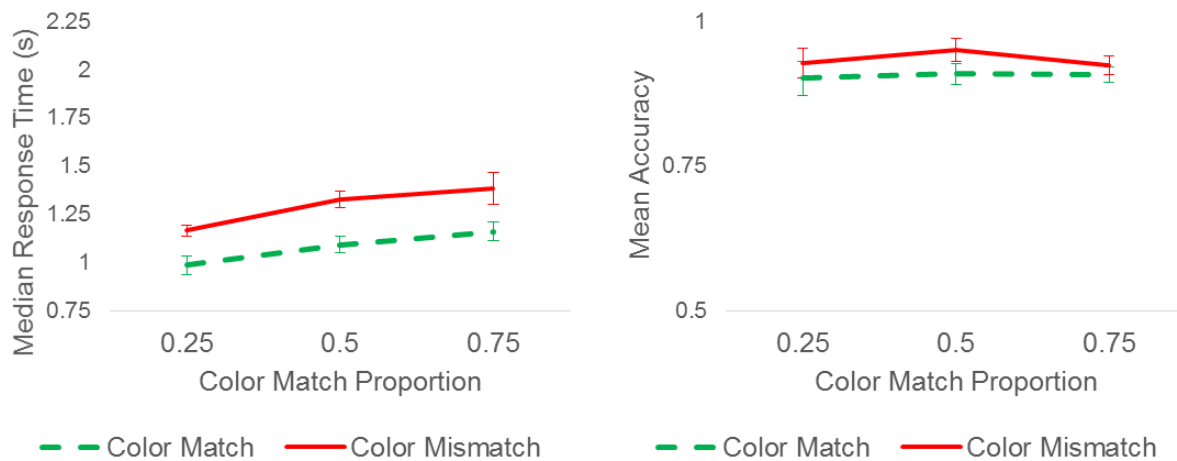
388

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

390   Experiment 3

391

392   search time analyses were quite clear: search time was consistently slower when more stimuli

393   matched the target template, and when the target did not match the template. Both of these main

394   effects showed that despite the reduced working memory load in Experiment 3, confirmatory

395   selection once again occurred.

396   A 3X2 repeated measures ANOVA on accuracy showed no main effects or interactions,

397     $Fs < 1.015$, $ps > .38$, partial $\eta^2s < .085$, thus ruling out the possibility of speed-accuracy trade-

398   offs. Furthermore, adding reported strategy as a between-subjects factor yielded no reliable

399   interactions with any factors for either RT or accuracy, Fs < 0.69, ps > .52, partial η^2s < .06,

400   suggesting that explicit search strategies did not substantially alter participant's searches.

401   Overall, the results of Experiment 3 suggest that repeated search does not reduce the

402   confirmatory nature of visual search. Thus, the results of Experiment 2 cannot be attributed

403   solely to the increased cognitive load of the switching search targets.

404   As can be seen from Figures 3 and 4, the Color Proportion X RT slopes were more

405   shallow in Experiment 3 than in Experiment 2; the average RT cost incurred for each additional

406   template-color matching stimulus in Experiment 2 was 151 ms, whereas in Experiment 3, this

407   cost was reduced to 56 ms, $t(11) = 2.68$, $p = .02$. Experiment 3, then, shows that experience with

408   a given template increases search efficiency, driven presumably by accumulated priming

409   (Kristjánsson, Wang, & Nakayama, 2002). Coupled with the results of Experiment 2, we

410   tentatively suggest that the quadratic trend in Experiment 1 reflects the contribution of

411   economical color selection – that is, selection of the Color Mismatching subset when it is smaller

412   – once sufficient experience has been acquired with a given template. This suggestion may seem

413   paradoxical given that in Experiment 3, where only one template is ever used, no quadratic trend

414   emerged, but this could reflect the fact that, as guidance is practiced, the costs of switching to the

415   Color Mismatching subset exceed the costs of searching through the larger, Color Matching

416   subset.

417   **Experiment 4**

418   When the cognitive load of juggling multiple target templates was eliminated in

419   Experiment 3, confirmatory searching nonetheless persisted. In Experiment 4, we evaluated the

420   role of search strategy. In our previous experiments, the participants were simply instructed to

421   respond to searches as set out in the instructions, and we aimed to observe which strategy they

422   would adopt. Although the strategy evident in the search behavior appeared to be a confirmatory

423   strategy, it is possible that this strategy was adopted because participants did not recognize the

424   other strategies made available by task structure; namely, that if a target was not observed in a

425   given color set, one could infer that, on that trial, it appeared in the opposite color set. In

426   Experiment 4, we explicitly told this fact to participants at the outset of the experiment. In

427   addition, participants were informed that the fastest way to complete a search would be to

428   examine the stimuli in the smallest color subset to check for a target letter. We expected that, if

429   confirmatory search was the default, or preferred, strategy, these instructions would not affect

430   search behavior. However, if confirmatory searches were simply an artifact of participants' lack

431   of familiarity with the task and its idiosyncrasies, these instructions would eliminate

432   confirmatory searching. In the former case, a linear effect of Color Proportion on search time and

433   a main effect of Color Match on search time should again be found. However, if instructions are

434   able to curb the use of confirmatory selection, then a quadratic effect of Color Proportion on

435   search time, and an interaction between Color Proportion and Color Match should be found.

436   **Methods**

437   **Participants**

438   Twelve undergraduate students were again recruited for the present experiment. All participants

439   provided informed consent and were compensated with course credit.

440   **Stimuli and Procedure**

441   The stimuli and procedure for Experiment 4 were identical to those of Experiment 1. Only the

442   instructions given at the outset were modified. This consisted of the addition of the following

443   sentences:

444   "The fastest way to do these searches is to look through whichever colored

445   letters there are fewer of. If you see the target letter, you can respond

446   appropriately, but if you don't, you will know it must be in the other

447   group, and can make the opposite response."

448   Participants were then led through an example where the template mismatching

449   color was in the minority, and told that if the target letter was in that set, they could

450   immediately report the absence of the target-letter in the template-matching color.

451   In addition to verbally describing the strategy, participants were asked to identify

452   the stimulus that would be best to inspect first in the example mentioned above. If

453   the participant indicated that a template mismatching stimulus would be the best to

454   inspect first, this was taken to mean that the participant had understood the strategy.

455   However, if the participant failed to identify the mismatching stimulus, the optimal

456   strategy and illustrative example were reiterated until the participant chose a

457   template mismatching stimulus in the example.

458   **Results and Discussion**

459   Search behavior once again exhibited a confirmatory search pattern. A 3X2 repeated

460   measures ANOVA on search RT (Figure 5) showed a main effect of Color Proportion, $F(2, 22) =$

461   8.66, $p = .002$, partial $\eta^2 = .44$, which consisted of a linear trend, $F(1, 11) = 9.00$, $p = .012$,

462   partial $\eta^2 = .45$, and a marginally significant quadratic trend, $F(1, 11) = 4.74$, $p = .052$, partial η^2

463    $= .30$. In addition, a main effect of Color Match was again present, $F(1, 11) = 35.36$, $p < .001$,

464   partial $\eta^2 = .76$, and Color Match did not interact with Color Proportion, $F(2, 22) = 1.30$, $p = .29$,

465   partial $\eta^2 = .11$. A 3X2 repeated measures ANOVA on search accuracy showed no main effects

466   or interactions, Fs < 0.10, ps $> .91$, partial η^2s $< .01$.

467   These results of Experiment 4 were qualitatively identical to Experiment 1, supporting

468   the notion that confirmatory search was not an artifact of a lack of awareness of proper strategy.

469   Although the results suggest that a quadratic relationship between the number of template-color

470   matching stimuli and search time was present, the lack of an interaction between Color Match

471   and Color Proportion again indicates that participants were not consistently switching templates

472   when the template-color matching stimuli outnumbered the template-color matching stimuli. As

473   outlined in the discussion of Experiment 3, we suggest that this may reflect the contribution of

474   some economical searches, which become possible once the template becomes learned through

475   use.

476   Further supporting the conclusion that explicit strategy did not reduce confirmatory

477   searching is the observation that only five of twelve participants reported using the minimal

478   search strategy when debriefed, despite having been informed of it at the outset. Indeed, reported

479   search strategy did not reliably interact with any factors for either RT, Fs < 0.63, ps $> .55$, partial

480   η^2s $< .06$, or for accuracy, Fs < 0.71, ps $> .42$, partial η^2s $< .07$.

481

482
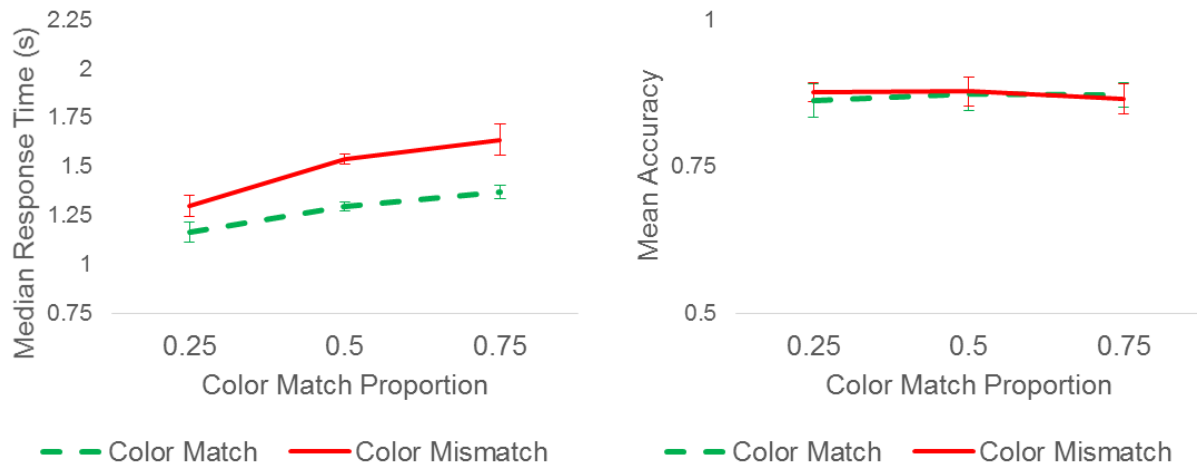
Figure 5. Median Response Times (left) and Mean Accuracy (right) for the search task in

Experiment 4.

485

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.

498   **Experiment 5**

499   Thus far, our results have consistently provided evidence for a confirmatory search bias.

500   The effect is largely insensitive to the presence or lack of repetitions of template use, as well as

501   knowledge of the task. In Experiment 5, we tested whether the confirmatory search bias could be

502   reduced by presenting a preview of the color of search stimuli in advance of the search. Given

503   the robustness of confirmatory selection observed thus far, it is tempting to conclude that

504   confirmatory selection of stimuli matching a template is a relatively automatic process. In

505   previous experiments, participants often did report using a minimal selection strategy, even

506   though their search times told a different story. It may be the case that the strategic guidance of

507   search lags behind the more automatic orienting towards template matching stimuli. An

508   alternative to automatic guidance to template matching stimuli that one could reasonably expect

509   is for automatic orienting to be towards the fewest, and therefore most perceptually salient

510   stimuli. However, at least for our search task, confirmation bias seems to be the default tendency

511   that must be overcome.

512   To test this possibility, we presented a color preview in advance of the search stimuli on

513   every trial. Our reasoning is that, if given the chance to observe the statistics of the colors while

514   not having the ability to begin searching, participants might more appropriately plan their search

515   in advance. If strategic control of selection is simply slower than template-guided selection, we

516   predict a quadratic trend between search time and the proportion of Color Proportion, and an

517   interaction between Color Match and Color Proportion.

518 **Methods**

519   **Participants**

520   Twelve undergraduate students were recruited for the present experiment. All participants

521 provided informed consent and were compensated with course credit.

522   **Stimuli and Procedure**

523   The stimuli and procedure were very similar to Experiment 1; 16 blocks of 30 trials were

524 again implemented, and a search template was provided prior to each search block, but search

525 stimuli themselves were slightly changed. For each search, a color preview display was

526 presented for 1000 ms in which colored squares, approximately 1.2° x 1.2º, appeared centered on

527 the positions of their respectively colored search stimuli. After 1000 ms had elapsed, the letters

528 used as search stimuli onset in front of the colored squares. These letters were uniformly colored

529 in white. Instructions were changed accordingly, such that participants were now asked to

530 respond regarding whether the target letter was *on* a particular color.

Results and Discussion

531

532   Preliminary RT analyses showed a number of outlying trials, consisting of both

533   suspiciously long search times (>10s, 0.013% of all trials), and anticipatory responses (<100ms,

534   0.06% of all trials). Trials with search times falling outside of either of the aforementioned

535   bounds were excluded before conducting the following analyses. The extended color preview

536   display led to a change in the pattern of search RT (Figure 6), but this change was also

537   accompanied by changes in search accuracy. A 3X2 repeated measures ANOVA on RT revealed

538   a main effect of Color Proportion, $F(2, 22) = 17.05$, $p < .001$, partial $\eta^2 = .61$, which was

539   comprised of a linear, $F(1, 11) = 8.70$, $p = .013$, partial $\eta^2 = .44$, and quadratic, $F(1, 11) = 46.97$,

540    $p < .001$, partial $\eta^2 = .81$, trend. The effect of Color Proportion was accompanied by a main

541   effect of Color Match, $F(1, 11) = 15.62$, $p = .002$, partial $\eta^2 = .59$, but no interaction was

542   observed, $F(2, 22) = 2.34$, $p = .12$, partial $\eta^2 = .18$.

543   The RT data alone is suggestive of a flexible selection strategy, but a repeated measures

544   ANOVA on accuracy revealed speed-accuracy trade-offs. A main effect of Color Match, with

545   template-color matching targets being reported with lower accuracy, approached significance,

546    $F(1, 11) = 4.41$, $p = .06$, partial $\eta^2 = .29$. In addition, Color Proportion decreased search

547   accuracy, $F(2, 2) = 13.88$, $p < .001$, partial $\eta^2 = .56$, in a monotonic fashion, $F(1, 11) = 37.38$, p

548
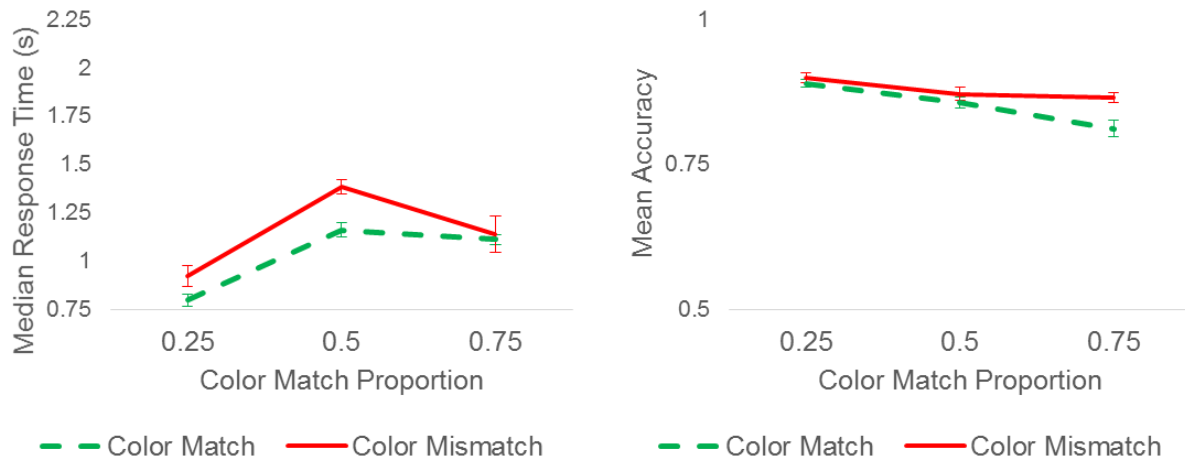
Figure 6. Median Response Times (left) and Mean Accuracy (right) for the search task in

Experiment 5.

< .001, partial η^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 η^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 η^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

565   correct and incorrect trials). Efficiency was greatest with 2 of 8 stimuli matching the template

566   color ($M_{Color\ Match} = 1.23$, $SE = 0.10$; $M_{Color\ Mismatch} = 1.10$, $SE = 0.09$), worst with 4/8 matching

567   the template color ($M_{Color\ Match} = 0.79$, $SE = 0.06$; $M_{Color\ Mismatch} = 0.68$, $SE = 0.04$), and slightly

568   better with 6/8 matching the template color ($M_{Color\ Match} = 0.81$, $SE = 0.08$; $M_{Color\ Mismatch} = 0.88$,

569    $SE = 0.10$). Estimates of efficiency were affected by Color Proportion, $F(2, 22) = 74.95$, $p <$

570    $.001$, partial $\eta^2 = .51$, with both linear, $F(1, 11) = 27.31$, $p < .001$, partial $\eta^2 = .71$, and quadratic,

571    $F(1, 11) = 40.97$, $p < .001$, partial $\eta^2 = .79$, components. Although Color Match was only

572   marginally significant, $F(1, 11) = 4.23$, $p = .062$, partial $\eta^2 = .28$, it critically interacted with

573   Color Proportion, $F(2, 22) = 7.98$, $p = .002$, partial $\eta^2 = .42$. This interaction was such that, when

574   the number of template-matching colors was greater than the number of template-mismatching

575   colors, template-color matching targets were *less* efficiently detected than template-color

576   mismatching targets, suggesting that participants indeed did adapt their search strategy to the

577   proportion of colors in a search display. However, that this effect was accompanied by a linear

578   effect of Color Proportion suggests that the strategic search strategy coexisted with a

579   confirmatory tendency. Searches where confirmatory searching was strategically optimal were

580   overall more efficient than trials where it was not, as indicated by a pairwise comparison

581   between 25% template-matching color trials and 75% template-matching color trials, $F(1, 11) =$

582   27.31, $p < .001$, partial $\eta^2 = .71$. Nonetheless, the previews did alter the extent of confirmatory

583   searching; a Mixed Model ANOVA comparing efficiency scores between Experiments 1 and 5

584   showed that Experiment interacted with the effect of Color Proportion, $F(2, 44) = 15.88$, $p <$

585    $.001$, partial $\eta^2 = .42$, as well as with the interaction between Color Proportion and Color Match,

586    $F(2, 44) = 4.12$, $p = .023$, partial $\eta^2 = .16$. Overall, these results show that color preview displays

587   can attenuate confirmatory searching, but not completely.

588   **General Discussion**

589   Across five experiments, we measured visual search performance in a novel task

590   designed to examine the use of confirmatory search strategies. Participants were asked to report

591   whether a target letter was a target color or not, and across searches we varied the proportion of

592   stimuli in search displays that were the target color or non-target color. Despite the fact that this

593   search task allowed participants to adopt a strategy of target disconfirmation – that is, they could

594   examine the stimuli in a non-target color – the target confirmation strategy dominated

595   performance. We conclude, therefore, that a confirmation bias exists even in simple visual search

596   tasks. This conclusion is supported by the conjunction of two general findings; first, that

597   participants were slower to report the target identity when proportionally more search stimuli

598   matched the target template, as defined in search instructions, even though a more economical

599   selection strategy was available, and second, that participants were faster to report the target

600   identity when the target was the color of the template than when the target was another color.

601   The first finding is reminiscent of studies of subset search (e.g., Bacon & Egeth, 1997;

602   Sobel & Cave, 2002), where participants perseverate in selecting stimuli possessing a particular

603   guiding feature if instructed, even when this feature is present in the larger of two equally useful

604   search subsets. While subset search research speaks to the strength of instructions in dictating

605   top-down selection, these results cannot, by themselves, demonstrate confirmatory searching, as

606   no other search strategy (i.e., disconfirmation of target presence) is available in these tasks as a

607   viable alternative to confirmatory searching. Similarly, the finding of slower search times for

608   targets not matching the template may be considered to be an instantiation of the classic finding

609   of slower searches for targets defined by the absence of a feature (Wolfe, 2001). If this

610   comparison is valid, then our results provide a demonstration that feature absence may be

611   relative to task set. That is, the particular stimulus that would be considered "feature-present"

612   and "feature-absent" in our task was a consequence of an arbitrary assignment of one of two

613   colors in the search instructions.

614   The results of these experiments converge on the conclusion that the default, or preferred,

615   search strategy is one in which searcher prioritizes stimuli that share features with a target

616   template, and opts to determine the status of a target by matching it to the template rather than by

617   switching to a disconfirmation strategy of searching for stimuli that would provide evidence

618   against the presence of a template-matching target. Our results therefore rule out the possibility

619   that confirmatory searching is task-contingent selection strategy. In our search task, matching

620   search stimuli to a single color-letter conjunction entailed conducting more analysis than strictly

621   necessary to complete a search. However, search times indicated that this is how participants

622   opted to search. It is important to note that, because our data rely only on overall response time,

623   increases in response time caused by increases in the proportion of template-matching stimuli

624   may not simply reflect increases in the total number of stimuli inspected in search, but may also

625   reflect increases in time spent processing the color statistics in the display to plan searches,

626   updating templates, processing individual stimuli, or selecting responses. While additional

627   stimulus manipulations, or within-trial search metrics (e.g., eye tracking) are needed to resolve

628   this uncertainty, from a purely performance based perspective, we may still conclude that visual

629   search is successfully terminated faster when a target's presence is confirmed, not disconfirmed.

630   Confirmatory search may stem from a number of underlying sources. The first possibility

631   is, as has been suggested before, that visual search can only be guided by one template at a time.

632   A number of studies investigating the control of visual search guidance by representations in

633   visual working memory have demonstrated that only one representation appears to be prioritized

634   to guide search at a time (reviewed in Olivers et al., 2011). Although contrary findings exist

635   (Beck, Hollingworth, & Luck, 2013; Irons, Folk, & Remington, 2012), a sufficiently

636   sophisticated notion of search templates, such as the Boolean Map Theory of Visual Selection

637   (BMTVS) can accommodate guidance by multiple *features*, but via a single template. In the

638   BMTVS, multiple features may be combined using Boolean (conjunctive and disjunctive)

639   operations, with the critical consequence that any stimuli selected using a given Boolean setting

640   cannot be distinguished from each other on the selection dimension (e.g., color); further template

641   adjustments would need to be made in order to distinguish these selected stimuli from each other

642   on any a particular dimension. In our selection task, because color is a dimension that is

643   necessary to select the appropriate response, BMTVS predicts that only a single color can be

644   used to guide selection and analysis, because color is necessary for deciding between responses

645   in addition to selecting potential target stimuli. A single template architecture introduces costs

646   associated with updating the target template to the appropriate template for a particular display.

647   The costs associated with calculating and updating to the appropriate template to use may simply

648   outweigh the benefits of updating in terms of overall search time. Thus, capacity limitations in

649   search template guidance from working memory are a potential culprit in the source of

650   confirmatory searching. As suggested earlier, a similar limitation has been suggested in

651   reasoning (Mynatt, Doherty, & Dragan, 1993), which requires search for information through a

652   possibility space.

653   On the other hand, confirmatory searching in our task may be due to difficulties in

654   guiding search with negative information. In the instructions, we framed the search such that the

655   target could either be one particular color, or not that particular color. While the search

656   performance appears to reflect a confirmatory, template matching stimulus prioritization, it may

657   be that search cannot be strategically guided by negative information (e.g., "not blue"). As noted

658   earlier, search for absent features is well-known to be difficult. If it is the case that our mere

659   framing of the non-template color as the absence of the template color was sufficient to recode

660   the non-template color as an absent feature, this may account for why selection was

661   preferentially guided towards the template color. In this case, the template color would have been

662   treated as a "present" feature, and therefore would lead to easier selection, making the

663   perseveration of selection on this color optimal for participants. While plausible, this account

664   would require an additional interpretation of feature-absent effects: until now, these effects have

665   been taken to reflect a property of the visual system's coding, as opposed to task demands. The

666   nearest approximation of a cognitive, rather than perceptual, interpretation of feature-absent

667   effects that we are aware of stems from work on familiarity as a feature in visual search (e.g.,

668   Wang, Cavanagh, & Green, 1994; Shen & Reingold, 2001). These studies have shown that

669   stimuli whose low-level visual properties are otherwise identical interact with search efficiency

670   depending on whether they are meaningful stimuli: finding an unfamiliar stimulus (a rotated

671   letter) among familiar stimuli (un-rotated stimuli) is easier than finding a familiar stimulus

672   amongst many unfamiliar stimuli. If the negative-framing of the search task in our instructions is

673   indeed the reason for confirmatory searching, then we will have incidentally provided a

674   demonstration of the top-down construction of what defines a feature in visual search.

675   Although in this task, participants performed in a way that was not strategically optimal,

676   confirmatory searching is likely a globally optimal strategy for visual search. For falsification to

677   be an economical strategy requires some features or stimuli exist that are negatively correlated

678   with the presence of whatever is being searched for. When target presence and absence is

679   independent of other environmental features, only confirmation of the target's presence can

680   reduce search times compared to an exhaustive search. In light of arguments that visual search

681   may be optimized for foraging (Klein & MacInnes, 1998; Cain, Vul, Clark, & Mitroff, 2012),

682   confirmatory searching would prove beneficial, in that the analysis of the environment would be

683   tailored towards the goal of finding any extant resources, and promote the sustained pursuit of a

684   goal even in situations where positive evidence is scant. Friedrich (1993) has argued for a related

685   basis of confirmation bias in reasoning, noting that different types of errors produce more or less

686   costs in the context of particular goals, and that it is more pragmatic to minimize costly errors

687   than to simply minimize all errors, irrespective of their consequences. In the context of our visual

688   search, additional covert costs – such as switching templates in working memory – may simply

689   be more costly than the additional time spent searching in those cases where more stimuli match

690   target templates. More broadly, expending cognitive (and motoric, in the case of saccades)

691   resources to sustain a purely visual search for signs of prey is a relatively low cost investment,

692   given the potential payoffs. Mechanisms in visual search, therefore, may be tuned to allow

693   perseveration on the possibility that a real resource is indeed present, so that visual inspections

694   can be sufficiently thorough. Cognition in general may be seen as a (relatively) biologically

695   cheap way of tuning our actions in advance so as to acquire proportionally greater survival gains.

696   While we have shown that visual search tends to prioritize the confirmation of the

697   presence of a target stimulus, even when suboptimal, it is not yet clear whether the confirmatory

698   tendencies of top-down visual attention are related to confirmation bias as it exists in more

699   cognitively complex social behavior and problem solving. A surface relationship between visual

700   search and reasoning has been suggested by Mercier (2012), who noted the utility of using visual

701   search as an analogy for how individuals seek arguments in order to persuade another person. In

702   principle, both vision and reasoning are subject to the problem of combinatorial explosion

703   (Tsotsos, 1995; Evans, 2006) where the number of possible interpretations of observations

704   exceeds any reasonable estimate of computability. In both cases, selection is necessary in order

705   to arrive at any conclusion, and goal-driven selection is a sensible implementation for motivated

706   agents. Despite the differences in complexities, visual selection and complex cognition may be

707   related on the basis of shared executive processes or working memory, as suggested by Mynatt,

708   Doherty, and colleagues (1990, 1991, 1993). Indeed, Hills and colleagues (2006; 2014) argue

709   that goal directed cognition may find its evolutionary roots in foraging behavior, and has shown

710   that search styles can be primed across domains – for example, between a visual foraging task

711   and a lexical search task (Hills, Todd, & Goldstone, 2008) – suggesting shared cognitive control

712   mechanisms. Clearly, goal-driven selection is a broad feature of the human mind, and while

713   globally beneficial, it can lead us to flawed beliefs or behaviors when the assumptions borne by

714   particular goal-driven attentional settings are themselves flawed, irrespective of the domain of

715   analysis. Of course, all is not lost; flawed beliefs and interpretations can be corrected by a

716   sufficient amount of inconsistent evidence. The effect of selection is merely a bias towards

717   certain conclusions, not utter hegemony of beliefs and expectations in the face of all available

718   evidence. Our primary proposal is that the effects of selection on evaluation of information will

719   occur regardless of the domain in question.

720   **Conclusions**

721   By using a modified visual search task, we measured whether stimuli that could confirm

722   the presence of a target are prioritized over those that could disconfirm the presence of a target.

723   Our results provide support for the notion that top-down attention prioritizes stimuli that match a

724   template, even when this strategy is not optimal for the task at hand. This constitutes a

725   confirmatory search tendency, and given the similarities between features of theories of limits in

726   both visual search and reasoning, we take these results as suggesting that mechanisms of top-

727   down, selective attention, to the extent that they are shared across cognitive domains, may

728   contribute to confirmation bias beyond visual search.

References

Bacon, W. F., & Egeth, H. E. (1997). Goal-directed guidance of attention: evidence from conjunctive visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(4), 948.

Beck, V. M., Hollingworth, A., & Luck, S. J. (2012). Simultaneous control of attention by multiple working memory representations. *Psychological science*, *23*(8), 887-898.

Bundesen, C. (1990). A theory of visual attention. *Psychological review*, *97*(4), 523.

Cain, M. S., Vul, E., Clark, K., & Mitroff, S. R. (2012). A Bayesian optimal foraging model of human visual search. *Psychological science*, *23*(9), 1047-1054.

Carlisle, N. B., Arita, J. T., Pardo, D., & Woodman, G. F. (2011). Attentional templates in visual working memory. *The Journal of Neuroscience*, *31*(25), 9315-9322.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision research*, *51*(13), 1484-1525.

Cousineau, D. (2005). Confidence intervals in within-subject designs: A simpler solution to Loftus and Masson's method. *Tutorials in Quantitative Methods for Psychology*, *1*(1), 42-45.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual review of neuroscience*, *18*(1), 193-222.

Doherty, M. E., & Mynatt, C. R. (1990). Inattention to P (H) and to P (D $\backslash \sim$ H): A converging operation. *Acta Psychologica*, *75*(1), 1-11.

Evans, J. S. B. (2006). The heuristic-analytics theory of reasoning: Extension and evaluation. *Psychonomic Bulletin & Review, 13(3)*, 378-395.

Friedrich, J. (1993) Primary error detection and minimization (PEDMIN) strategies in social cognition: A reinterpretation of confirmation bias phenomena. *Psychological Review, 100(2)*, 298-319.

Fugelsang, J. A., Stein, C. B., Green, A. E., & Dunbar, K. N. (2004). Theory and data interactions of the scientific mind: Evidence from the molecular and the cognitive laboratory. *Canadian Journal of Experimental Psychology, 58(2)*, 86-95.

Hills, T. T. (2006). Animal Foraging and the Evolution of Goal-Directed Cognition. Cognitive Science, 30(1), 3-41.

Hills, T. T., Todd, P. M., & Goldstone, R. L. (2008). Search in external and internal spaces evidence for generalized cognitive search processes. Psychological Science, 19(8), 802-808.

Hills, T. T., Todd, P. M., Lazer, D., Redish, A. D., Couzin, I. D., & Cognitive Search Research Group (2014). Exploration versus exploitation in space, mind, and society. *Trends in Cognitive Sciences,* doi: http://dx.doi.org/10.1016/j.tics.2014.10.004

Huang, L., & Pashler, H. (2007). A Boolean map theory of visual attention. *Psychological review*, *114*(3), 599.

Irons, J. L., Folk, C. L., & Remington, R. W. (2012). All set! Evidence of simultaneous attentional control settings for multiple target colors. *Journal of Experimental Psychology: Human Perception and Performance*, 38(3), 758.

Kassin, S. M., Dror, I. E., & Kukucka, J. (2013). The forensic confirmation bias: Problems, perspectives, and proposed solutions. *Journal of Applied Research in Memory and Cognition*, *2*(1), 42-52.

Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological science*, *10*(4), 346-352.

Koehler, D. J. (1991). Explanation, imagination, and confidence in judgment. *Psychological Bulletin, 110(3)*, 499-519.

Kristjánsson, A., Wang, D., & Nakayama, K. (2002). The role of priming in conjunctive visual search. *Cognition*, 85(1), 37-52.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. The MIT Press.

Mercier, H. (2011). Looking for arguments. *Argumentation, 26(3)*, 305-324.

Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005). What you see is what you set: sustained inattentional blindness and the capture of awareness. *Psychological review*, *112*(1), 217.

Mynatt, C. R., Doherty, M. E., & Dragan, W. (1993). Information relevance, working memory, and the consideration of alternatives. *The Quarterly Journal of Experimental Psychology*, *46*(4), 759-778.

Mynatt, C. R., Doherty, M. E., & Sullivan, J. A. (1991). Data selection in a minimal hypothesis testing task. *Acta Psychologica*, *76*(3), 293-305.

Neuberg, S. L. (1994). Expectancy-confirmation processes in stereotype-tinged social encounters: The moderating role of social goals. In The psychology of prejudice: The Ontario symposium (Vol. 7, pp. 103-130).

Nickerson, R. S. (1998). Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology, 2(2)*, 175-220.

Olivers, C. N., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in cognitive sciences*, *15*(7), 327-334.

Pines, J. M. (2006). Profiles in patient safety: confirmation bias in emergency medicine. *Academic Emergency Medicine*, *13*(1), 90-94.

Sanbonmatsu, D. M., Posavac, S. S., Kardes, F. R., & Mantel, S. P. (1998). Selective hypothesis testing. *Psychonomic Bulletin & Review, 1998, 5(2)*, 197-220.

807 Shen, J., & Reingold, E. M. (2001). Visual search asymmetry: The influence of stimulus
808   familiarity and low-level features. *Perception & Psychophysics*, *63*(3), 464-475.

809 Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information
810   processing: II. Perceptual learning, automatic attending and a general theory.
811   *Psychological review*, *84*(2), 127.

812 Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness
813   for dynamic events. *Perception-London*, *28*(9), 1059-1074.

814 Sobel, K. V., & Cave, K. R. (2002). Roles of salience and strategy in conjunction search. *Journal
815   of Experimental Psychology: Human Perception and Performance*, *28*(5), 1055.

816 Treisman, Anne, and Sharon Sato. "Conjunction search revisited." *Journal of Experimental
817   Psychology: Human Perception and Performance* 16.3 (1990): 459.

818 Tsotsos, J. K. (1995). Toward a computational model of visual attention. In Papathomas, T. V.,
819   Chubb, C., Gorea, A., & Kowler, E. (Eds), *Early vision and beyond*, 207-218. Cambridge,
820   MA: The MIT Press.

821 Tversky, A. & Kahneman, D. (1981). The framing of decisions and the psychology of choice.
822   *Science, 211*, 453-458.

823 Wang, Q., Cavanagh, P., & Green, M. (1994). Familiarity and pop-out in visual search.
824   *Perception & psychophysics*, *56*(5), 495-500.

825 Wason, P. C. (1960). On the failure to eliminate hypotheses in a conceptual task. *Quarterly
826   journal of experimental psychology*, *12*(3), 129-140.

827 Wason, P. C. (1966). Reasoning. In B. Foss (Ed.), *New horizons in psychology* (pp. 135–151).
828   Harmondsworth: Penguin Books.

829 Wolfe, J. M. (2007). Guided search 4.0. *Integrated models of cognitive systems*, 99-119.
830
831 Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided search: an alternative to the feature
832   integration model for visual search. *Journal of Experimental Psychology: Human
833   perception and performance*, *15*(3), 419.