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Out of sight, out of mind: Matching bias underlies confirmatory visual search

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Abstract

Confirmation bias has recently been reported in visual search, where observers who were given a perceptual rule to test (e.g. “Is the ‘p’ on a red circle?”) search stimuli that could confirm the rule stimuli preferentially (Rajic, Wilson, & Pratt, 2015). In the present study, we compared the ability of concrete and abstract visual templates to guide attention using the visual confirmation bias. Experiment 1 showed that confirmatory search tendencies do not result from simple low-level priming, as they occurred when color templates were verbally communicated. Experiment 2 showed that confirmation bias did not occur when targets needed to be reported as possessing or not possessing the absence of a feature (i.e., reporting whether a target was on a non-red circle). Experiment 3 showed that confirmatory search also did not occur when search prompts referred to a set of visually heterogeneous features (i.e., reporting whether a target on a colorful circle, regardless of the color), despite a clear ability to search for heterogeneous features when instructed (Experiment 4). Together, these results show that the confirmation bias likely results from a matching heuristic, such that visual codes involved in representing the search goal prioritize stimuli possessing these features.

48 As effortless as it seems, visual perception is not a passive process. The literature on visual
49 attention is rife with examples of how selection processes shape what visual information reaches
50 awareness and goes on to influence subsequent behavior (Simons & Chabris, 1999; Raymond,
51 Shapiro, & Arnell, 1992; Sligte, Scholte, & Lamme, 2008). What information is selected at any
52 given moment emerges from multiple sources of control (see Awh, Belopolsky, & Theewes,
53 2012), with selection not always being optimal for a specific task. Although failures of attention
54 often stem from stimulus-driven sources (Theeuwes, 1992; Lavie & Tsal, 1994), the ability to
55 selectively attend critical events or objects can also be affected by cognitive factors, such as the
56 number of targets one must look for (Menneer, Cave, & Donnelly, 2009; Cain, Adamo, &
57 Mitroff, 2013), the specificity of a target template (Vickery, King, & Jiang, 2005), and one's
58 working memory capacity (Fukuda & Vogel, 2009). A recent example of how cognitive states
59 can influence attention is the confirmation bias in visual search (Rajsic, Wilson, & Pratt, 2015).

60 Confirmation bias refers to the tendency to selectively process information in relation to a
61 focal hypothesis (Nickerson, 1998). The bias towards confirmation is most strongly associated
62 with Wason's research (1960; 1968) showing that thinkers tend not to sample information about
63 what would not happen if a rule were true. Noting similarities in the cognitive explanations of
64 the confirmation bias (Mynatt, Doherty, & Dragan, 1993) and theories of visual selection
65 (Wolfe, Cave, & Franzel, 1989; Olivers, Peters, Houtkamp, & Roelfsema, 2011), Rajsic et al.
66 found that visual selection would be biased towards one of two stimulus types, depending on
67 which type of stimulus the search was being framed as "for", even when this entailed processing
68 more information. This result establishes, and provides a method for studying the tendency to
69 prioritize a subset of all task-relevant information based on the mere framing of a search. As
70 well, it highlights a commonality between reasoning and our perception of the environment; both

71 exhibit biased information sampling. Indeed, confirmatory visual search patterns suggests that
72 people may be blind, or at least slow to notice, states of the environment that they do not expect
73 to be true under conditions of focused attention (Simons & Chabris, 1999).

74 To measure whether participants were biased towards one of two possible search targets,
75 Rajsic et al. (2015) adapted a subset search design (Bacon & Egeth, 1994; Sobel & Cave, 2002)
76 to include two different targets. Specifically, participants searched for a target letter that could
77 appear in one of two colors, and were instructed to press one key if the object appeared in the
78 first color, but to press another key if the target appeared in “another” color. We refer to the color
79 that was shown in the instructions as the “template”, and to the color that did not appear in the
80 instructions as the “non-template”. Indeed, confirmatory selection appeared to be the default
81 search heuristic; search was consistently biased towards the template-colored objects even when
82 it would have been more efficient to search through the non-template-colored objects. It is not,
83 however, known what sorts of templates lead to such confirmatory selection. Thus, the purpose
84 of this paper is to determine when task framing will bias search towards certain stimuli over
85 others, depending on how a search goal is phrased. In doing so, the source of this confirmation
86 bias can be better understood.

87 Like many other attentional heuristics – to items held in visual working memory (Soto,
88 Hodsoll, Rotschtein, & Humphreys, 2008), to stimuli with learned value (Anderson, Laurent, &
89 Yantis, 2011), to locations with statistical structure (Zhao, Al-Aidroos, & Turk-Browne, 2013),
90 and to stimuli with unique visual features (Theeuwes, 1992; Franconeri & Simons, 2003) – the
91 confirmation bias in search appears to be an unintentional bias towards some objects by virtue of
92 a non-perceptual property they possess. That property is their being framed as positive
93 information in the context of a prompt, and as such, the confirmation bias in search is an

94 attentional bias resulting from the mere framing of a search task. Rajsic et al. (2015) measured
95 confirmation bias in search using a task where search stimuli are presented in two different
96 colors, with the target stimulus (e.g., a p among d's, q's, and b's) being equally likely to appear
97 in either color. Orthogonally, the proportion of search stimuli of a given color varied while the
98 total search set size was held constant. Instructions were given to report whether the target letter
99 was a particular color or not, and given that either color may have been mentioned in the
100 instructions for a given participant, block, or trial, selection biases towards this color must have
101 come from these instructions. An unbiased observer would have preferentially searched the
102 smaller set of colored stimuli; because the target appeared on every trial, the rule can be
103 confirmed or falsified simply by having searched one color set exhaustively. If the target was not
104 among the smaller color set, it must have been on the other colour set. Instead, participants
105 exhibited a bias towards the confirmatory color set.

106 What is it about the instructions that leads to selection biases? One possibility is that the
107 instructions bias search because they present participants with a specific visual input that
108 matches one of the stimulus colors. In their experiments, Rajsic et al. (2015) consistently
109 instructed participants using a colored rectangle to depict the positive template. Thus, one
110 possibility is that confirmatory searching results from simple, bottom-up intra-trial priming of
111 the confirmatory color (e.g., Theeuwes, Reimann, & Mortier, 2007).

112 Another possibility is that mentioning one of two possible target features in the
113 instructions primes categorical attentional guidance processes. Guided Search, for example,
114 proposes that the selection of relevant colored stimuli in a search array depends on broadly
115 tuned, categorical color channels (Wolfe, Cave, & Franzel, 1989; Wolfe, 2007). A categorically
116 tuned architecture is ideal for top-down control, given that goals of a search would often begin

117 with a linguistic code in everyday situations (e.g., saying to a friend “that blue car looks
118 expensive”), but especially in the context of psychology experiments where participants are
119 instructed with written or spoken guidelines. If the confirmation bias results from a heuristic
120 matching process between elements named in the instructions and this categorical guidance
121 apparatus, then the confirmation bias should be observed when templates are specified only
122 using words, not visual depictions. Experiment 1 tests this account against the possibility that
123 confirmatory search biases are due to bottom-up priming.

124 If visual attention is truly attracted to confirmatory stimuli, confirmation biases should
125 extend beyond situations in which stimuli match a particular template on a single, explicitly
126 mentioned, homogenous visual feature. Instead, stimuli should attract attention because of their
127 ability to verify a proposition per se, even when this proposition involves more abstract classes
128 of stimuli. Although searching for red stimuli when asked whether a target is red or not could
129 reflect a preference to find information that would yield an affirmative answer – a true
130 confirmation bias -- it could also be due to a heuristic of relevance, such that stimulus features
131 mentioned in the rule are heuristically deemed more important, or informative (Sperber, Cara, &
132 Girotto, 1995). Experiments 2 and 3 were conducted to distinguish true confirmatory search from
133 a relevance heuristic by measuring whether biases occur when confirmatory stimuli are defined
134 using negation (Experiment 2) and when confirmatory stimuli are visually heterogeneous
135 (Experiment 3).

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Experiment 1

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Experiment 1 was conducted to determine whether confirmation biases in visual search are mere instances of bottom-up priming of visual features or whether they can occur when a template is described verbally. To do so, we adapted the methods and stimuli from Rajsic et al. (2015). Participants were instructed that, on each trial, they should evaluate whether a particular question about the display should be answered in the affirmative or negative. Specifically, all trials asked whether a particular letter was on a circle of a particular color. Instead of using a colored square to communicate the particular color, as in Rajsic et al. (2015), the present study used a verbal label for each color (e.g., “red”). If participants search in a biased manner, they should preferentially search the template-matching (confirmatory) color, resulting in increased search times when the template-matching group is more numerous. If participants search in a strategic manner – ignoring confirmation bias – they should preferentially search the color with fewer circles on a trial-to-trial basis.

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Methods

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Participants

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

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Stimuli

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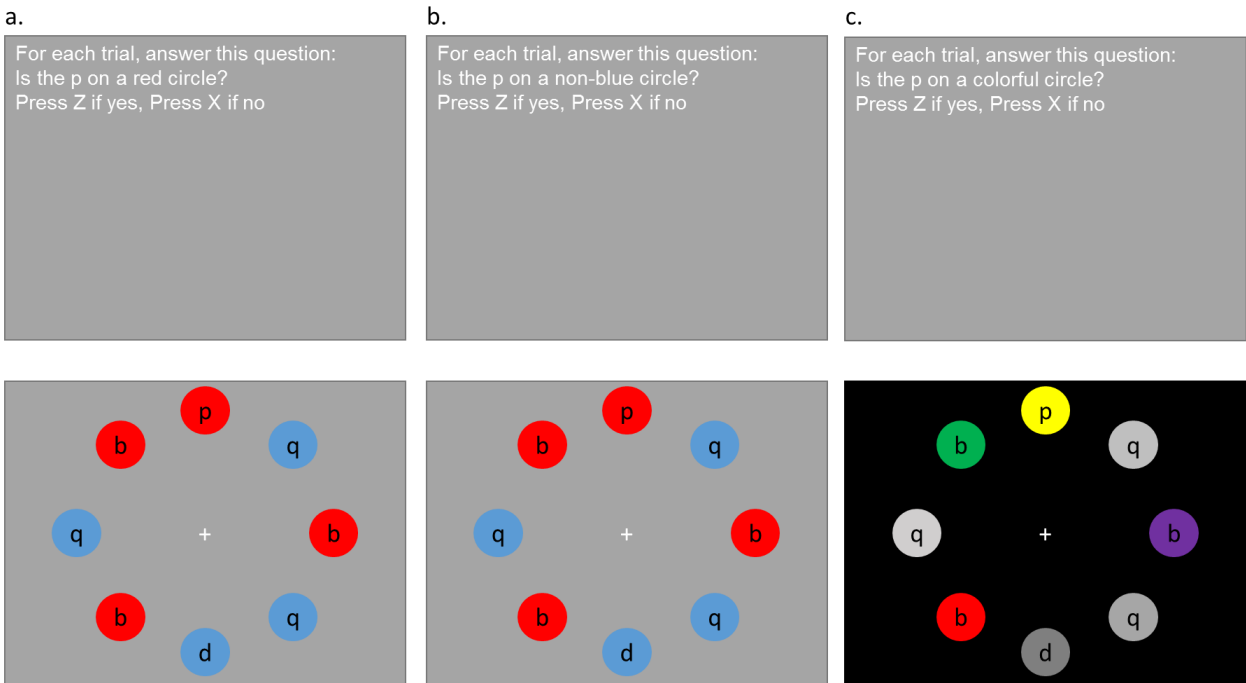
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Search displays consisted of eight letters, presented on the circumference of an imaginary circle centered on a central fixation cross. Each letter in a search display was a lowercase p, q, b, or d, approximately 2° in height and 1° in width, and was drawn approximately 8° from fixation using Arial font drawn in black (RGB: 0,0,0). These letters were placed on top of small discs (approximately 1° in radius) whose colors were selected from a pool of seven possible colors;

159 purple, yellow, green, orange, pink, blue, and red (RGB values, respectively: 200, 0, 255; 200,
160 200, 0; 0, 255, 0; 255, 128, 0; 255, 128, 255; 50, 50, 255; 255, 50, 50), with the background set
161 as mid-gray (RGB: 128, 128, 128). Before beginning a block of trials, participants were
162 presented with instructions written on the computer monitor in the following form: “For each
163 trial, answer this question: “Is the x on a y circle?” Press *key 1* if yes, press *key 2* if no.” For a
164 given instruction x would be the target letter (p, b, d, or q), y would be the categorical color
165 name, and *keys 1 and 2* would refer to either the Z or X key, which were alternately used as
166 either response. For example, as illustrated in Figure 1a, participants may have been prompted to
167 respond as to whether the “p” was on a red circle, using the Z key for yes and the X key for no.
168 Subsequent searches would include distractor letters on red and blue circles, with target p’s
169 appearing either on a red or blue circle from trial to trial. These instructions remained on screen
170 until participants chose to begin the corresponding block. Figure 1a depicts a sample instruction
171 and search display (at Template-Matching Subset Size 4, with a Matching Target Color).



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173 **Figure 1.** A sample search instruction (upper row) and sample search array (lower row) for

174 Experiments 1, 2, and 3 (columns a, b, and c). Stimuli are not drawn to scale.

175

176 **Procedure**

177 One experimental session consisted of 12 blocks of 24 trials, where each block consisted

178 of four repetitions of the six experimental conditions: Target Color (Template Matching or

179 Template Mismatching) X Template Matching Subset Size (2, 4, or 6). For a given block, two of

180 the seven possible colors were selected randomly as the two search colors to be used for the

181 subsequent 24 trials. Two conditions were manipulated: the Target Color, which was Template-

182 Matching if it matched the color mentioned in the instructions and Template-Mismatching if it

183 did not, and the Template-Matching Subset Size, which could be 2, 4, or 6 stimuli. The actual

184 target color on a given trial was equally likely to be Template-Matching and Template-

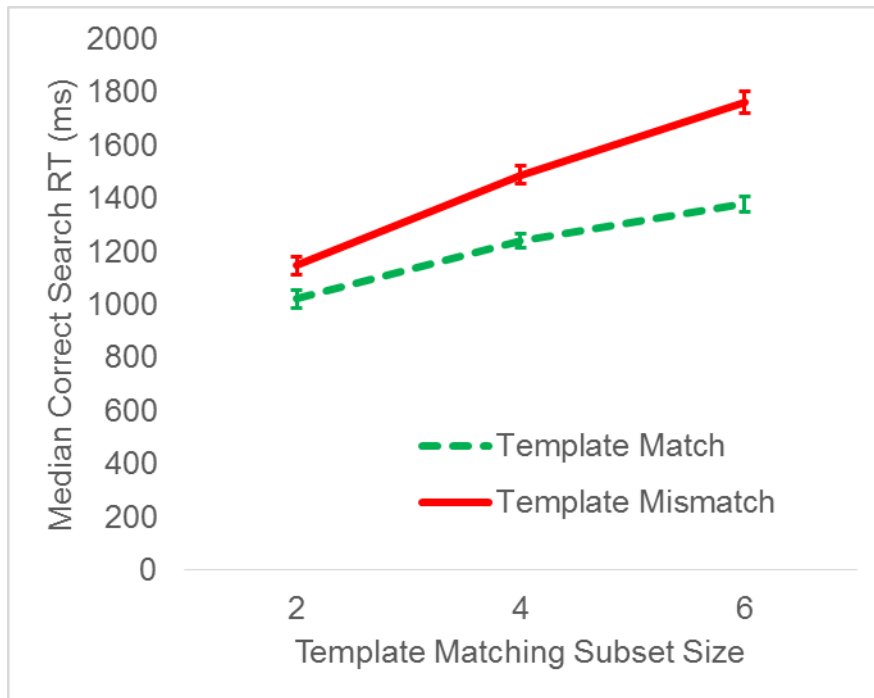
185 Mismatching, regardless of Template-Matching Subset Size, and participants were informed of

186 this overall pattern.

187 A given trial began with the presentation of a blank screen with a fixation cross for
188 2000ms. Following this period, the search display was presented until a response was given.
189 After a response was entered, using either the Z or X key, written feedback about response
190 accuracy (“Correct” or “Incorrect”) was displayed in the center of the screen for 2000ms. After
191 feedback offset, the next trial began.

192 **Results and Discussion**

193 To determine whether confirmation bias occurred with bottom-up priming concerns
194 removed, we analysed the effect of Template Matching Subset Size and Target Color on median
195 correct response times (RTs), where we expect a monotonic effect of Template Matching Subset
196 Size if selection is biased towards template-confirming stimuli. Two participants were excluded
197 for having either lower than 80% accuracy or average RT more than two standard deviations
198 from the group mean (i.e., greater than 2890 ms). Both Template Matching Subset Size, $F(2, 26)$
199 $= 73.46, p < .001, \eta^2_p = .85$, and Target Color, $F(1, 13) = 51.51, p < .001, \eta^2_p = .81$ affected RT,
200 as well as an interaction, $F(2, 26) = 10.60, p < .001, \eta^2_p = .45$. Follow up contrasts on Template
201 Matching Subset Size showed a linear trend, $F(1, 13) = 86.78, p < .001, \eta^2_p = .87$, but only a
202 marginally significant quadratic trend, $F(1, 13) = 3.71, p = .08, \eta^2_p = .22$. Median correct RT is
203 shown in Figure 2. An analysis of accuracy revealed only a main effect of Target Color, $F(1, 13)$
204 $= 7.66, p = .016, \eta^2_p = .37$, such that Template Mismatching Targets were reported more
205 accurately, $M = 95\%$. $SE = 1\%$, than Template Matching Targets, $M = 92\%$, $SE = 1\%$.



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207 **Figure 2.** Median Response Times in Experiment 1. Error bars in this and all other figures depict

208 one within-subjects standard error (Cousineau, 2005).

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210 To ensure that our effects were not due to speed-accuracy trade-offs, we calculated an
211 efficiency score, mean accuracy divided by median response time, for each participant in each
212 condition. Similarly to median correct RT, efficiency declined as Template Matching Subset Size
213 increased, $F(2, 26) = 61.52, p < .001, \eta^2_p = .83, M_{SS2} = 0.91, M_{SS4} = 0.72, M_{SS6} = 0.61$. Efficiency
214 was also lower for Template Matching Targets, $M = 0.80$, than Template Mismatching Targets,
215 $M = 0.70$. Thus, the confirmatory search bias we observed was not due to a speed-accuracy
216 trade-off.

217 Overall, these data show that confirmatory searching occurs even when template colors
218 are not visually presented, but instead conveyed through language. Therefore it is not the case
219 that confirmatory search biases are simply due to bottom-up visual priming from instructions.

220 Rather, confirmatory templates can be formed verbally, implying a level of non-perceptual,
221 semantic abstraction.

222 **Experiment 2**

223 Experiment 1 showed that search is biased towards information that could lead to an
224 affirmative endorsement of a visual hypothesis; when search was framed as being about the
225 presence of one target and not another, even though both targets were equally likely, stimuli
226 matching the color of the framed color attracted attention. Critically, this occurred in the absence
227 of any visual presentation of the target color in the instructions, leading to the conclusion that
228 confirmation bias in search is not due to visual priming, but may derive from categorical
229 guidance mechanisms (e.g., Wolfe, Cave, & Franzel, 1989).

230 In Experiment 2, we sought to determine whether the confirmatory search bias is due to a
231 more abstract coding of relevance. In Experiment 1, all stimuli that matched a template matched
232 by virtue of having the same feature. In research on reasoning using the Wason Selection Task, a
233 number of researchers have emphasized a distinction between truly confirmatory data selection,
234 where data is selected because it could be consistent with the proposition being evaluated, and a
235 relevance heuristic wherein the objects or classes mentioned in the proposition being evaluated
236 are rendered more salient (reviewed in Evans, 1998). A common technique for dissociating these
237 two possibilities is to introduce negation in to the proposition being evaluated, so that the
238 positive set is no longer explicitly mentioned (e.g., “If there is an A on the front of a card, there
239 is not a 7 on the back” does not mention a particular stimulus as a true consequent). Thus, in
240 Experiment 2 we pursued the question of whether confirmatory search patterns result from a
241 matching bias by including blocks where one stimulus color was referred to by negation (i.e., in
242 a block of red and blue stimuli, asking participants whether a target letter was on a “non-red”

243 circle in lieu of “blue” circle¹). Notably, the visual stimuli in this experiment are identical to
244 Experiment 1. Moreover, the information provided in the prompt is equivalent. The only
245 difference is the negative condition. Thus, the visual information and the logical information
246 available to observers in Experiments 1 and 2 are the same. The question is whether the negative
247 clause disrupts observers’ ability to use the template to guide search. If confirmatory selection is
248 based on the ability of stimuli to yield an affirmative response, then we should observe similar
249 search patterns between the Standard and Negation search conditions. However, if selection is
250 due to a matching-bias, the Negation search RT will not increase as the Template-Matching
251 Subset Size increases.

252 **Methods**

253 **Participants**

254 Nineteen undergraduate students were recruited for a second experiment. All participants
255 provided informed consent and were compensated with course credit. Participants were run until
256 the post-exclusion sample size of Experiment 1 (14) was reached after using the same exclusion
257 criteria.

258 **Stimuli and Procedure**

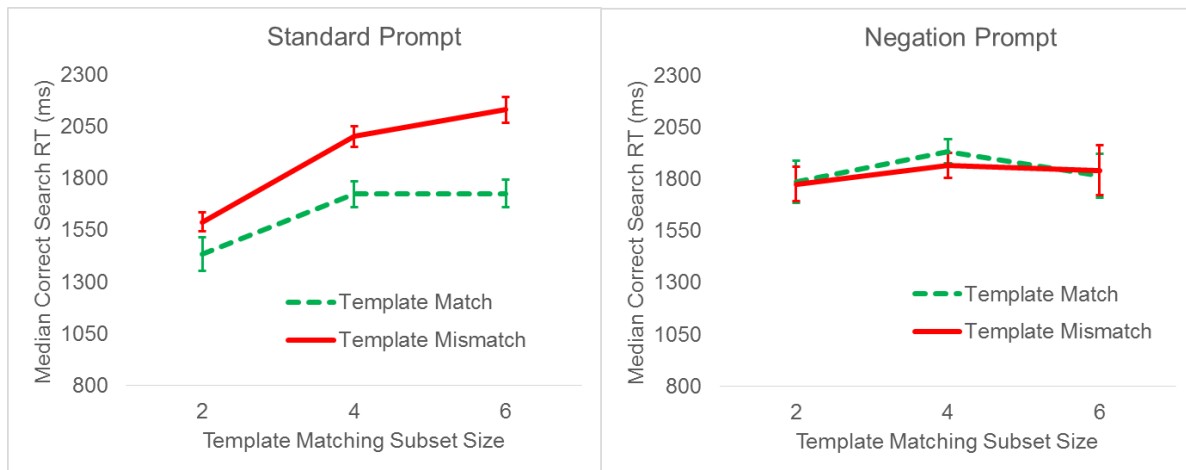
259 Stimuli and Procedure were identical to Experiment 1, with the following exception:
260 blocks were divided into two types. Standard blocks included instructions in the same format as
261 Experiment 1, whereas, in Negation blocks, participants answered questions of the form “Is the x
262 on a non- y circle?”. These blocks were presented in a random order, determined separately for
263 each participant. Figure 1b depicts a sample negated instruction and search display (at Template-
264 Matching Subset Size 4, with a Matching Target Color).

¹ We thank Todd Horowitz for suggesting this experiment.

265 **Results and Discussion**

266 Median correct RTs were analysed, with Target Color, Template-Matching Subset Size,
 267 and Negation as factors. Five participants were excluded for having accuracy lower than 80% or
 268 average RT more than two standard deviations above the group mean (i.e., greater than 3520ms).
 269 Overall, both Target Color, $F(1, 13) = 9.73, p = .008, \eta^2_p = .43$, and Template-Matching Subset
 270 Size, $F(1, 13) = 9.30, p = .001, \eta^2_p = .42$, affected search time. Critically, Negation interacted
 271 with both Target Color, $F(1, 13) = 7.66, p = .016, \eta^2_p = .37$, and Template-Matching Subset Size,
 272 $F(2, 26) = 3.93, p = .032, \eta^2_p = .23$ (see Figure 3). As such, we analysed search performance
 273 separately for the Standard and Negation. Accuracy was not affected by any factors or their
 274 interaction, and so was not analysed further, $F_s < 1.93, p_s > .17, \eta^2_p < .13$.

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277 **Figure 3.** Median Response Times Experiment 2 for Standard Prompts (left) and Negation
 278 Prompts (right).

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280 For Standard trials, Target Color affected correct search times, $F(1, 13) = 17.30, p = .001$,
 281 $\eta^2_p = .57$, as did Template-Matching Subset Size, $F(2, 26) = 23.23, p < .001, \eta^2_p = .64$,
 282 accompanied by an interaction, $F(2, 26) = 3.51, p = .045, \eta^2_p = .21$. Template Matching Subset

283 Size showed significant linear, $F(1, 13) = 35.19, p < .001, \eta^2_p = .73$, and quadratic trends, $F(1,$
284 $13) = 7.30, p = .018, \eta^2_p = .36$. Follow-up paired t -tests, while search RT increased as Template-
285 Matching Subset Size increased for 2 to 4 for both Template-Matching, $t(13) = 3.60, p = .003$,
286 and Template-Mismatching Targets, $t(13) = 8.22, p < .001$, increases from Subset Size 4 to 6 did
287 not lead to a significant increase in search RT for Template-Matching, $t(13) = 0.04, p = .97$, or
288 Template-Mismatching Targets, $t(13) = 1.83, p = .09$. However, given that the search RT was
289 faster for Template Matching Targets than Template Mismatching targets at Subset Size 6,
290 participants showed an overall confirmatory search tendency.

291 For Negation trials, neither factor, nor their interaction, affected search RT, $F_s < 1.02, p_s$
292 $> .37, \eta^2_p = .07$. At the end of each experimental session, participants reported their search
293 strategies. Those who reported that, when shown a Template-Matching Subset Size 6 display,
294 they would choose to first inspect a Template-Mismatching Target were classified as “strategic”
295 searchers, whereas those who reported that they would choose to first inspect a Template-
296 Matching Target (despite the larger Subset Size) were classified as “confirmatory” searchers.
297 Overall, seven participants were classified as confirmatory searchers, and seven were classified
298 as strategic searchers. However, an analysis of Negation trials showed that Search Strategy did
299 not interact with Template-Matching Subset Size, $F(2, 24) = 0.06, p = .94, \eta^2_p = .005$, Target
300 Color, $F(1, 12) = 2.40, p = .15, \eta^2_p = .17$, nor their combination, $F(1, 12) = 0.04, p = .96, \eta^2_p =$
301 $.003$. The same was true for Standard trials, $F_s < 0.35, p_s > .63$; reported search strategy did not
302 modulate the search strategy indicated by search RT.

303 One reason that the Negation condition may not have shown confirmatory searching is
304 due to an asymmetry in information between these conditions. In the Standard condition, the
305 color of the implied template was mentioned in the rule, whereas in the Negation condition, only

306 the color of the implied non-template was mentioned. As such, participants may have searched in
307 a confirmatory manner once they knew the implied template's color; that is, later in a given
308 block. To assess this possibility, we analysed search performance for both Standard and
309 Negation trials with the additional factor of Block Half (first vs. last). For Standard trials, Block
310 Half showed no main effect, $F(1, 13) = 3.13, p = .10, \eta^2_p = .19$, nor interactions, $F_s < 1.68, p_s <$
311 $.21, \eta^2_{ps} < .12$, with Template Matching Subset Size or Target Color. On the other hand, in
312 Negation trials, the interaction between Block Half and Template Matching Subset Size affected
313 RT, $F(2, 26) = 3.77, p = .037, \eta^2_p = .23$, and Accuracy, $F(2, 26) = 4.86, p = .016, \eta^2_p = .27$. In
314 the first half, search RTs were notably longer for Matching Subset Size 4 and 6, $M_s = [1977\text{ms},$
315 $1937\text{ms}]$, $SE_s = [183\text{ms}, 176\text{ms}]$, compared to 2, $M = 1779\text{ms}, SE = 151\text{ms}$. In the second half,
316 however, RTs were very similar across all Matching Subset Sizes, $M_{[2, 4, 6]} = [1844\text{ms}, 1839\text{ms},$
317 $1799\text{ms}]$, $SE_{[2, 4, 6]} = [150\text{ms}, 135\text{ms}, 117\text{ms}]$. As such, there is a suggestion of confirmatory
318 searching with Negation instructions, but certainly it is not as clear or consistent as Standard
319 instructions.

320 Overall, the results of Experiment 2 show that confirmatory search biases disappear when
321 the goals of search are framed using negation. Indeed, neither Template-Matching Subset Size
322 nor Target Color affected search patterns when the target question included a negation. This
323 suggests that no color-based selection occurred in this case. It is, however, difficult to
324 distinguish this possibility from the alternative that search strategies differed across participants.
325 What we can conclude is that instructions that refer to a negated feature do not reliably produce
326 confirmatory search.

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Experiment 3

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The results of Experiment 2 demonstrate that visual confirmation biases do not occur when search goals are communicated using negation (i.e., when looking for a target *without* a particular property). Despite the search stimuli being identical across negation and standard blocks, search strategy differed markedly. However, it possible that search is biased to stimuli that are confirmatory in an abstract sense when negation is removed. Our previous demonstrations of confirmatory search have all relied on situations in which a tested proposition refers to the presence or absence of a single, visual feature, meaning that participants could create a single visual template, or expectation, in advance of a search for stimuli possessing that feature. In Experiment 3, we ask whether confirmatory search biases rely on this ability – to prepare a single visual template in advance – or whether a set of stimuli that are visually heterogenous might all attract attention solely because they could affirm a proposition. This provides a strong test of the possibility that participants select information because of its abstract ability to verify a proposition. The guidance of attention can be diluted when multiple potential target types are searched for (Menneer, Cave, & Donnelly, 2009; van Moorselaar, Theeuwes, & Olivers, 2014; but see Beck, Hollingworth, & Luck, 2012), suggesting that a confirmatory template for a visually heterogenous set of target types is unlikely unless stimuli are able to be rapidly perceived as confirmatory, and subsequently selected.

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To test for attention biases towards visually heterogenous, but confirmatory, stimuli, Experiment 3 used instructions that referred not to individual colors, but instead the presence or absence of color (i.e., saturation). Here, we expect that visual grouping processes involved with guidance (Duncan & Humphreys, 1989) will not contribute to salience, leaving only the categorical match between stimuli and the representation of search goals.

350 **Methods**

351 **Participants**

352 Seventeen undergraduates volunteered to participate in Experiment 3. All participants
353 provided informed consent and were compensated with course credit. Participants were run until
354 the included sample size of Experiment 1 (14) was matched after performance-based exclusions,
355 using the same criteria as Experiment 1.

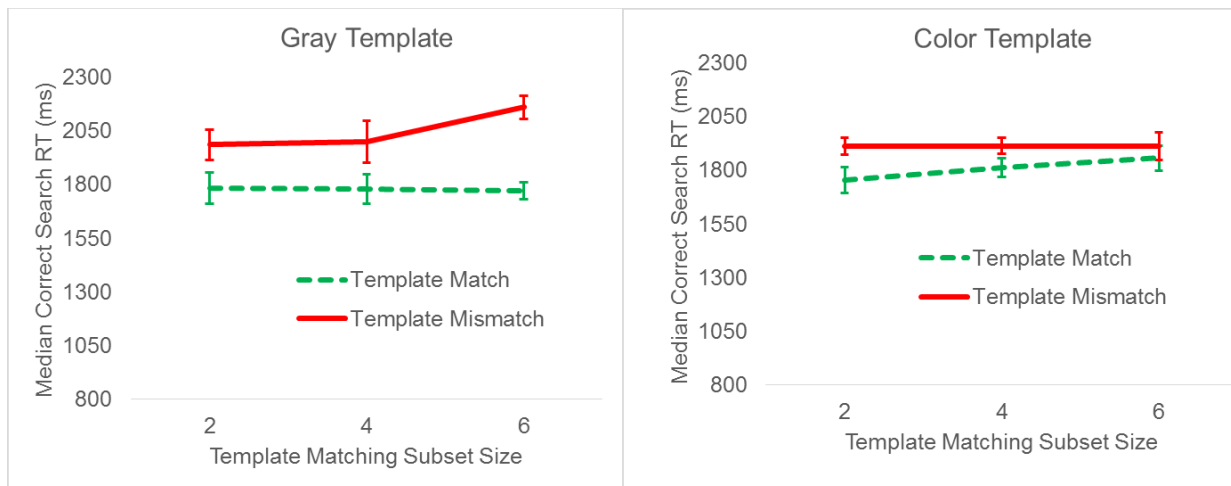
356 **Stimuli and Procedure**

357 The stimuli and procedure for Experiment 3 were identical to those of Experiment 1, with
358 two exceptions. First, instead of using subsets of two different colors, one stimulus subset was
359 now composed of random samples from the colors used in Experiment 1, whereas the other was
360 composed of seven shades of gray (RGB values: 77, 77, 77; 102, 102, 102; 128, 128, 128; 153,
361 153, 153; 179, 179, 179; 204, 204, 204; 230, 230, 230). To ensure that all search stimuli were
362 luminance increments relative to the background, we set the background screen color to black
363 (RGB: 0, 0, 0).

364 Second, the instructions were changed such that, instead of participants answering a
365 question about whether a target letter was on a specifically colored circle, participants were
366 instructed in one of two ways. The question posed to participants was either “Is the x on a
367 colorful circle” or “Is the x on a gray circle.” Participants completed an equal number of both
368 block types (six). Block order was again determined randomly for each participant. Figure 1c
369 depicts a sample colorful-search instruction and search display (at Template-Matching Subset
370 Size 4, with a Matching Target Color).

371 **Results and Discussion**

372 Median correct RTs were again analysed, with the additional factor of Color Category,
 373 that is, whether participants answered a questions about whether the target letter was on a gray
 374 circle or on a colorful circle. Three participants were excluded from analysis for either accuracy
 375 lower than 80% or average RT more than two standard deviations above the group mean (i.e.,
 376 greater than 2830ms). Overall, only Target Color, $F(1, 13) = 11.36, p = .005, \eta^2_p = .47$, affected
 377 correct search RT, such that trials that led to a “yes” response were overall faster, $M = 1793\text{ms}$,
 378 $SE = 100\text{ms}$, than trials where a “no” response was given, $M = 1981\text{ms}, SE = 97\text{ms}$ (see Figure 4.
 379 Critically, no effect of Template-Matching Subset Size was found, $F(2, 26) = 1.10, p = .38, \eta^2_p =$
 380 $.07$, indicating participants did not select stimuli on the basis of their color category.



381
 382 **Figure 4.** Median correct Response Times in Experiment 3 for Gray Templates (left) and
 383 Colorful Templates (right).

384
 385 Furthermore, Template-Matching Subset Size did not statistically interact with Color
 386 Category, $F(2, 26) = 0.27, p = .77, \eta^2_p = .02$, Target Color, $F(2, 26) = 0.31, p = .73, \eta^2_p = .02$, nor

387 their combination, $F(2, 26) = 2.26, p = .13, \eta^2_p = .15$. Finally, no factors or interactions affected
388 search accuracy, $F_s < 1.70, p_s > .20, \eta^2_p < .12$.

389 To summarize, while a post-perceptual confirmation bias was present in this task, such
390 that affirmation of the question being evaluated was faster than rejection, we did not find
391 evidence that stimuli were prioritized for search on the basis of their template-matching features.
392 This result indicates that dimension-level perceptual frames do not spontaneously guide search.
393 In both Experiments 2 and 3, participants appear to have searched for target letters using a “brute
394 force”, or random, search, making a decision about the target’s properties after having found it,
395 rather than using target properties to guide attention to subsets of potential targets. At no point
396 did the data suggest that guidance was used strategically (i.e., to search smaller subsets), despite
397 this possible strategy. Feature-based subset searching, then, seems not to be a function of the
398 environment, but rather of the participants’ task set. While this is clearly evident in the contrast
399 between Experiment 1 and 2, where the same search stimuli were used, it is not clear whether
400 grouping of subsets (by the presence or absence of hue) in Experiment 3 is even possible.
401 Experiment 4 addressed this uncertainty.

402 **Experiment 4**

403 Although Experiment 3 did not reveal a confirmatory search tendency when stimuli are
404 heterogenous, this may reflect an inability to guide attention to stimuli sharing a more abstract
405 feature, like hue, or its absence. To determine whether the lack of guidance in Experiment 3 was
406 due to an inability to select a heterogenous group of stimuli or due to a lack of a bias, we
407 conducted a fourth experiment where the target letter could be in the template-matching subset or
408 not present at all. In this situation, selecting the template-matching subset is an ideal strategy.
409 Thus, if heterogeneously colored stimuli can be selectively searched when selection would

410 improve performance, search times will increase in proportion to the size of the template-
411 matching subset.

412 **Methods**

413 **Participants**

414 Fourteen participants, none of whom participated in any of the previous experiments,
415 participated in Experiment 4. All of the participants were enrolled in a first-year undergraduate
416 Psychology course at the University of Toronto, and were compensated with course credit for
417 their participation. Participants all gave informed consent before participating.

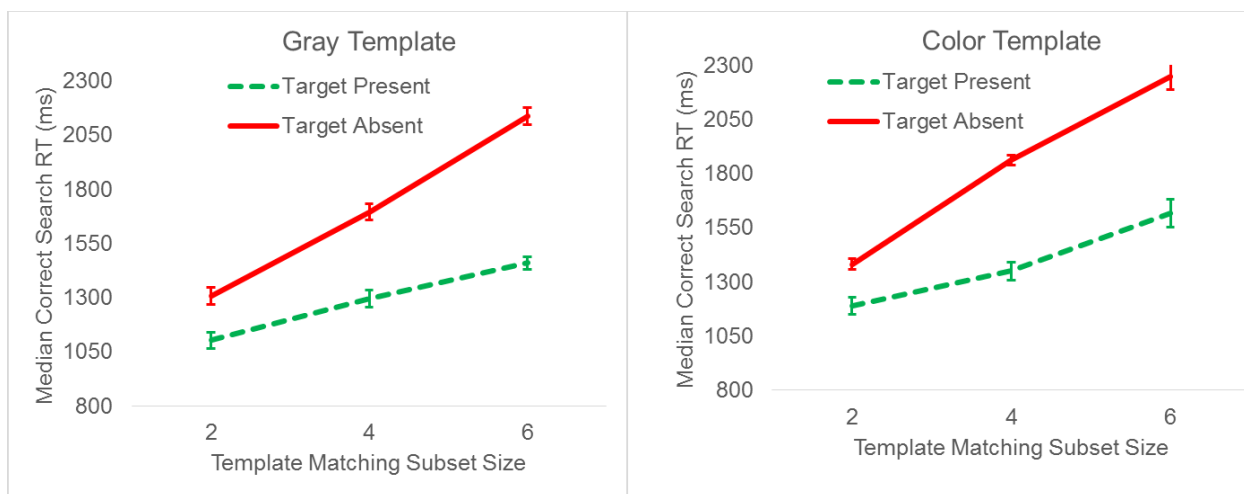
418 **Stimuli and Procedure**

419 Stimuli and procedure were identical to those of Experiment 3, with two exceptions.
420 First, target letters appeared on one of the template-matching search stimuli on half the trials, but
421 on the other half of the trials, all letter stimuli were non-targets. Second, the instructions at the
422 beginning of each block were changed to reflect this modification. The prompt for Experiment 4
423 was “For each trial, answer this question: Is the <target letter> on a <colourful/gray> circle?
424 Press <key1> if yes, Press <key2> if no,” where angular brackets depict variable contents (i.e.,
425 the target letter could be p, d, b, or q).

426 **Results**

427 One participant was excluded from analysis for having an average RT greater than two
428 standard deviations from the group mean (i.e., greater than 3038 ms). Median search RTs can be
429 seen in Figure 5. Template Matching Subset Size, $F(2, 12) = 127.32, p < .001, \eta^2_p = .91$, Target
430 Presence, $F(2, 12) = 172.16, p < .001, \eta^2_p = .94$, and Color Category, $F(2, 24) = 14.37, p = .003,$
431 $\eta^2_p = .55$, all affected search RTs, with an interaction between Target Presence and Template
432 Matching Subset Size, $F(2, 12) = 35.02, p < .001, \eta^2_p = .74$. As can be seen in Figure 5, for both

433 Colour Categories, search slopes were linear, with Target Absent searches being notably slower.
 434 A linear contrast for Template Matching Subset Size, $F(1, 12) = 151.52, p < .001, \eta^2_p = .93$, with
 435 no quadratic contrast, $F(1, 12) = 0.07, p = .80, \eta^2_p = .006$, showed that searches were restricted to
 436 appropriate category set. Searches were faster when the target was present, $M_{\text{present}} = 1335\text{ms}$,
 437 $SE_{\text{present}} = 63\text{ms}$, $M_{\text{absent}} = 1772\text{ms}$, $SE_{\text{absent}} = 88\text{ms}$. An analysis of accuracy also showed higher
 438 accuracy for Target Absent, $M = 94.8\%$, $SE = 1.2\%$ than Target Present, $M = 90.1\%$, $SE = 2.0\%$,
 439 searches, suggesting that miss errors were more common than false alarms, $F(1, 12) = 12.34, p =$
 440 $.004, \eta^2_p = .51$. Target Matching Subset Size, also affected accuracy, $F(2, 12) = 6.46, p = .006$,
 441 $\eta^2_p = .35$, such that accuracy declined as Subset Size increased, $M_{2,4,6} = [93.7\%, 92.9\%, 90.8\%]$,
 442 $SE_{2,4,6} = [1.6\%, 1.6\%, 1.6\%]$, suggesting that both misses and false alarms occurred more often
 443 when more stimuli matched the search template, a trend that was present in the confirmatory
 444 searches found in Experiments 1 and 2. Overall, however, these data show that searches can be
 445 guided towards a heterogeneous color category (the presence or absence of hue), which, in
 446 combination with the findings of Experiment 3, show that the confirmation bias does not occur
 447 for visually heterogeneous templates.



448

449 **Figure 5.** Median search times for Experiment 4. Error bars reflect one, within-subjects standard
450 deviation of the mean.

451 **General Discussion**

452 The goal of the present study was to determine the level of representation at which biases
453 in attention induced by the framing of a search goal occur. Previous research has shown that, in a
454 search for two possible target conjunctions, simply phrasing the instructions such that one target
455 is the absence of another target will lead to preferential selection of the latter target possibility
456 (Rajsic et al., 2015). However, these results are attributable to a range of possible
457 representational sources, ranging from simple visual priming to an abstract, logical target code.
458 The present results demonstrate that confirmatory biases, as they exist in visual search, occur
459 when one possible target type is defined by the presence of a visual feature (i.e., the color “red”),
460 but not when positive templates consist of a set of visual features (i.e., any colored stimulus) or
461 the absence of a visual feature (i.e., not red). This suggests that confirmation bias results from a
462 sort of conceptual priming, such that propositions that can be translated into a single, categorical
463 visual template can produce search biases for instances of this visual template. This is consistent
464 with the finding that the presentation of verbal labels of objects speeds their entry in to
465 awareness (Lupyan & Ward, 2013) and orients attention (Spivey, Tyler, Eberhard, & Tanenhaus,
466 2001), as well as findings that visually specific templates guide attention better than more
467 abstract templates (Vickery, King, & Jiang, 2005; Maxfield & Zelinsky, 2012; Hout &
468 Goldinger, 2014). Furthermore, it is consistent with findings that negative information tends not
469 to guide attention in visual search (Moher & Egeth, 2012; Beck & Hollingworth, 2015; Becker,
470 Hemsteger, & Peltier, 2016).

471 Given the contrast between the results of Experiment 4, which demonstrate an ability to
472 attend to a heterogeneous subset, and the results of Experiment 3, which show no bias towards
473 heterogeneous subsets due to the task framing, we must emphasize that the confirmation bias in
474 visual search appears to be just that: a bias. Following Rajsic et al. (2015), we interpret data from
475 these experiments as indicating the presence of cognitive heuristics in search that can, in certain
476 circumstances, be overcome. Indeed, we have found that searches in which information is
477 obtained more slowly shows a reduced confirmation bias (Rajsic, Wilson, & Pratt, under
478 review). Furthermore, Walenchok, Goldinger, & Hout (2016) have shown that confirmatory
479 searching patterns are reversed when Template-Matching targets are less common than
480 Template-Mismatching targets, suggesting search efficiency takes precedent over cognitive
481 framing. Overall, the available evidence suggests that cognitive economy is an important factor
482 in the presence of cognitive heuristics in attention (see also: Irons & Leber, 2016).

483 Another important conclusion of this study is that merely framing one class of stimuli as
484 positive instances of a hypothesis does not guarantee that they will be prioritized. What appears
485 to be necessary for this bias to emerge is for positive instances to share a common visual feature,
486 and for that feature to be explicitly stated in advance. As such, we speculate that the mechanism
487 underlying this bias may be the visual representations that are constructed to encode and store
488 the question being evaluated. This is consistent with the notion that attention is often
489 involuntarily driven to stimuli with features that match information held in visual working
490 memory (Soto, Hodson, Rotshtein, & Humphreys, 2008; Olivers, 2009). In Experiments 2 and 3,
491 since targets were defined by the absence of a feature, or by a visually heterogeneous set of
492 features, we suspect that the search instructions could not be stored as a visual code. We note,

493 however, that in Experiment 3, we did observe an overall RT cost for template-mismatching
494 targets, suggesting an additional, post-perceptual confirmation bias.

495 The finding that confirmatory search exists only for non-negative templates is consistent
496 with research on confirmation bias using Wason's selection task (Wason, 1968; Evans & Lynch,
497 1973; Evans, 1998). Although participants often neglect to select the not-q card in their
498 evaluation of an arbitrary rule (i.e., to use modus tollens), when participants evaluate the
499 expression "if p then not-q", their selection of the negated consequent (in this case, simply q)
500 improves. Indeed, negation reduces card selections for both antecedent cases and consequent
501 cases. These findings are consistent with the notion that evaluation performance in the standard
502 task is a mixture of tendencies towards logical evaluation and tendencies, or heuristics, to select
503 those cards with features that are mentioned by the rule (i.e., the p and q cards). Most theories of
504 the matching bias explain it by appealing some sort of relevance heuristic; at the first stage of
505 reasoning, information must be sorted by its relevance to the evaluation of a proposition
506 (Sperber, Cara, & Girotto, 1995). Stimuli that possess features contained in the to-be-evaluated
507 proposition are rapidly seen as relevant, whereas stimuli that may be relevant, but are not
508 mentioned in the proposition (i.e., a false consequent when evaluating an "if p then q"
509 proposition) must be recognized as relevant by mentally unpacking the proposition's
510 implications. In this light, the visual confirmation bias does seem to be an instance of a matching
511 bias heuristic, which is consistent with our previous work showing that it persists despite
512 instructions to attend the smaller subset (Rajsic, Wilson, & Pratt, 2015). Research on the
513 matching bias has uncovered one salient limitation, however: the use of realistic materials and
514 scenarios (Griggs & Cox, 1983; Oaksford & Stenning, 1992). In such situations, the richer
515 knowledge base available to guide information selection and store the proposition in memory

516 seems to reduce the effect of matching biases in data selection. As such, future research on the
517 confirmation bias in search ought to consider using realistic materials and prompts to assess
518 whether the matching-heuristic will still apply and lead to confirmatory search patterns,
519 especially given the ability of object category knowledge to guide attention (Maxfield &
520 Zelinsky, 2012; Yu, Maxfield, Zelinsky, 2016).

521

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525

526

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