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1 **Do we remember templates better so that we can reject distractors**
2 **better?**

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Abstract

Feature Integration Theory proposed that attention shifted between target-like representations in our visual field. However, the nature of the representations that determined what was target-like received less specification than the nature of the attention shifts. In recent years, visual search research has focused on the nature of the memory representations that we use to guide our shifts of attention. Sensitive measures of memory quality indicate that the template representations are remembered better than other, merely maintained, memories (Rajsic et al., 2017). Here we tested the hypothesis that we prepare for difficult search tasks by storing a higher fidelity target representation in working memory than we do when preparing for an easy search task. To test this hypothesis, we explicitly tested participants' memory of the target color they searched for (i.e., the attentional template) versus another memory that was not used to guide attention (i.e., an accessory representation) following blocks of searches with easy to find targets (i.e., distractors were homogeneously colored) to blocks of searches with hard to find targets (i.e., distractors were heterogeneously colored). Although homogeneous-distractor searches required minimal precision for distractor rejection, we found that templates were still remembered better than accessories, just like we found in heterogeneous-distractor search. As a consequence, we suggest that stronger memories for templates likely reflects the need to decide whether new perceptual inputs match the template, and not an attempt to create a better template representation in anticipation of difficult searches.

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Introduction

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While our world abounds with detailed visual information, successful behavior relies on our ability to focus on the task-relevant pieces of information. Research on how we find and focus on task-relevant objects in a cluttered visual field was revolutionized with the publication of Treisman's Feature Integration Theory of Attention (FIT: Treisman & Gelade, 1980). This theory made the bold claim that despite the wholly integrated subjective percepts we experience, "features come first in perception" (Treisman & Gelade, 1980, p. 98). While FIT was a theory of perception, broadly construed, it had an especially large influence on studies of visual search. Indeed, it was the results of visual search experiments (Nakayama & Silverman, 1986; Pashler, 1987; Wolfe, Cave, & Franzel, 1989) that led to a revision of FIT ten years later by Treisman and Sato (1990).

65 Treisman's revised account acknowledged that scanning through displays of un-bound
66 conjunctions was not strictly random. Although still fundamentally feature-based, our
67 scans can exclude stimuli with irrelevant features when we search a display for a target.

68 In the years since, a great deal of research has been devoted to understanding
69 the control processes that allow us to focus on task-relevant objects during search
70 (Carlisle & Woodman, 2011; Desimone & Duncan, 1995; Kiyonaga, Egner, & Soto,
71 2012; Olivers, Meijer, & Theeuwes, 2006; Woodman, Vogel, & Luck, 2001). Searching
72 for a stimulus for the first time requires representing its features in working memory
73 (Woodman, Carlisle, & Reinhart, 2013; van Moorselaar, Theeuwes, & Olivers, 2016).
74 However, representing stimulus features in working memory is not the same as
75 searching for a stimulus with these features. If we maintain multiple stimulus
76 representations in working memory, but only need to look for one of those stimuli, visual
77 attention can be effectively restricted to those stimuli matching just the sought after
78 stimulus representation (Downing & Dodds, 2004; Peters, Goebel, & Roelfsema, 2008).
79 Consequently, Olivers, Peters, Houtkamp, and Roelfsema (2011) proposed that the
80 memory representations we use to guide attention – often known as search templates –
81 are maintained in a special state in visual working memory, and that memories not used
82 to guide search are maintained as accessory items, in a state that cannot influence the
83 settings of current priority maps (Zelinsky & Bisley, 2015).

84 Recently, Rajsic, Ouslis, Wilson, and Pratt (2017) found that a consequence of
85 assigning template status to a representation in working memory is that this memory
86 can be reported with greater fidelity than an accessory memory. This was the case even
87 when neither remembered color was encountered during search, suggesting that

88 making a memory into a search template does not only prevent accessory items from
89 interacting with visual attention, but shapes the memories themselves. Furthermore,
90 templates were remembered better than accessories even on occasional trials where
91 the search did not occur, consistent with the idea that this memory re-weighting occurs
92 in preparation for search and not during the search itself. Given that memory fidelity
93 differed between templates and accessories, this measure could provide a behavioral
94 index of the mental representations that allow searchers to selectively scan target-like
95 items, as Treisman proposed (Treisman & Sato, 1990). However, it is not clear from this
96 previous work whether this improved memory for templates marks something special
97 about search templates per se, or whether it reflects a more generic selection of internal
98 information that is task-relevant (Souza & Oberauer, 2016; Myers, Stokes, & Nobre,
99 2017). If the memory advantage for templates is a consequence of shaping the
100 template memory representation to more efficiently reject distractors in anticipation of
101 performing search, then one can predict that its memory advantage over accessory
102 items will only be observed in the context of search tasks that create sufficient
103 competition for spatial attention.

104 As noted earlier, one hypothesized function of search templates is to guide
105 search to stimulus locations that are worth searching, given that the features at that
106 location are similar to the target templates (Wolfe et al., 1989; Duncan & Humphreys,
107 1989; Zelinsky, 2008). We know that target representations can be used like this
108 because search can be restricted to subsets of items in a display sharing a feature,
109 reducing the effective search size (Egeth, Virzi, & Garbart, 1984; Friedman-Hill & Wolfe,
110 1995; Zohary & Hochstein, 1989), and search is more efficient when targets share fewer

111 features with distractors (Wolfe et al., 1989). It follows that more precise templates
112 should enable a reduction in the effective set size of search.

113 Experiments that have manipulated the precision of search templates have
114 indeed found a relationship between template precision and guidance. Hout and
115 Goldinger (2015) had participants search for realistic objects and found that less precise
116 templates resulted in more inefficient search. Template precision was manipulated in
117 two ways: by including targets that matched a pictorial cue to varying extents (e.g., the
118 exact mug cued or another mug that was cued, but was still the only mug in the display)
119 and by comparing dual-target searches when the two sought-after targets were more or
120 less visually similar. Both manipulations of template precision affected scan-paths,
121 which were taken to indicate the strength of attentional guidance. Thus, increases in
122 template precision do appear to increase the efficiency of search. It is therefore
123 plausible that participants remember templates more precisely than accessory items
124 because this allows for guidance to fewer candidate items during search. We will refer
125 to this account as the *adaptive-weighting hypothesis*. This hypothesis states that
126 representations of templates are strategically weighted over accessory memories to
127 improve search efficiency. Specifically, this account predicts that when searchers know
128 that targets are harder to find, they intentionally weight the storage of the template more
129 heavily than the accessory in advance of each search, but do not weight the template
130 more than accessory items when the target can be found without a template (i.e.,
131 because the target pops out).

132 Although improving the fidelity of a memory when it becomes a search template
133 could serve the function of improving search efficiency, it could instead be a

134 consequence of having to use a representation to make a decision, regardless of the
135 perceptual load associated with the upcoming search. Preparing to make a decision
136 about whether or not a stimulus matches one, but not another, memory representation
137 requires some mechanism for focusing the decision on the correct stimulus-memory
138 pair (Summerfield & Koechlin, 2008). Simply preparing a memory to be compared with
139 incoming perceptual inputs may be sufficient to produce memory benefits for the
140 template memory, costs for the accessory memory, or both (Zokaei, Ning, Manohar,
141 Feredoes, & Husain, 2014; Myers et al., 2017; Reinhart & Woodman, 2014). We will
142 refer to this account as the *recognition-weighting hypothesis*. This hypothesis proposes
143 that preparatory weighting of the template over accessory memory representations
144 occurs because targets must be recognized based on a template, even if the target can
145 be localized via unique physical salience (i.e., popping out), such that the benefit of
146 weighting the template presumably lies in facilitating target recognition, once it has been
147 localized, rather than more efficient localization of the target during search.

148 Recent research by Geng, DiQuattro, & Helm (2017) has directly shown that
149 templates are indeed sharpened when distractors are more likely to be similar to the
150 target, lending some support to the hypothesis that the template memory benefit is
151 related to segregation of the target from concurrent distractors. One potentially
152 important factor, though, is the consistency of target colors. Electrophysiological
153 research has shown that repeatedly looking for the same target allows long-term
154 memory to participate in visual search (Woodman, Carlisle, & Reinhart, 2013). As such,
155 it is possible that this improvement in template precision reported by Geng and
156 colleagues resulted from repeated exposure to target and distractor color values such

157 that the sharpening that was observed was of a long-term memory representation of the
158 target. To rule out such an explanation in our experiments a new color was the target on
159 every trial, and so any change in template precision must be due to cognitive control
160 over the working memory representation of the target.

161 Experiment 1 was designed to test the hypothesis that templates are
162 remembered better so that distractors can be rejected more effectively. We ran two,
163 between-subjects conditions: a heterogeneous search and a homogeneous search.
164 Borrowing from the design of Rajsic et al. (2017), we had participants remember two
165 colors on each trial. One was the target, which we call the template in following text, and
166 the other was an item that they knew they would be tested as often, that we will call the
167 accessory item in the following text (see Figure 1). If templates are remembered better
168 than accessories so that search guidance can be improved, then we expect that
169 templates will be remembered better than accessory items in the heterogeneous
170 condition, but not the homogenous condition. This is because when distractors are
171 homogeneous, no guidance is necessary since the search target can be localized using
172 bottom-up contrast signals alone (Bacon & Egeth, 1994). On the other hand, if
173 templates are remembered better because making any target discrimination decision
174 entails a special cognitive state compared to just remembering an object, then both
175 heterogeneous and homogenous searches will lead to a difference in memory quality
176 between templates and accessories.

177 Experiment 1

178 Methods

179

180 Participants

181
182 Thirty participants volunteered for Experiment 1. All were recruited from
183 Vanderbilt's online experiment system, participated in exchange for course credit, and
184 provided informed consent before participating in procedures approved by the
185 Vanderbilt University Institutional Review Board. Six participants were excluded from
186 analysis for having either their search or their memory performance at chance (i.e.,
187 indistinguishable from chance in one or more conditions). Chance performance in the
188 search was defined as accuracy below 58% in any condition (i.e., the 95% cutoff for a
189 one-tailed binomial test with 100 observations and 50% probability of success). Chance
190 in the memory task was estimated using simulations. More specifically, we computed
191 the standard deviation between 50 pairs of randomly chosen angles (i.e., the number of
192 trials in a single condition) 10,000 times and chose the 5th percentile value as the cut-off
193 for above-chance performance (given that lower standard deviation indicates high
194 accuracy). Five participants in the heterogeneous search condition and one participant
195 in the homogeneous search condition were excluded using these criteria. The same
196 pattern of results was obtained with these participants included, but we preferred not to
197 analyze data from participants who could, or did, not reliably complete both the search
198 and memory components of the task. Data was collected until we obtained a sample of
199 twelve participants in each condition after exclusion criteria were applied.

200

201 Stimuli and Procedure

202

203 Stimuli were presented to participants on an ASUS monitor and were generated

204 using Matlab with the Psychophysics toolbox (Kleiner, Brainard, & Pelli, 2007).

205 Participants viewed the stimuli from a distance of approximately 80cm. Participants

206 entered responses using a standard USB keyboard.

207 Experimental stimuli on each trial comprised five kinds of displays, depicted in

208 Figure 1. The first display was a fixation display, consisting of a + in the middle of the

209 screen (0.8° in height and width) on a dark gray background for either 1000ms or

210 1500ms. Next was the memory sample display. This display presented the two to-be-

211 remembered colors for 500 ms, one to the 3° left of a fixation and one 3° to the right of

212 the fixation. Each was 1.1° in height and width, and colored by sampling along the

213 circumference of a circle in L*A*B space, using Matlab's lab2rgb function, centered on A

214 = 5 and B = 10, with a radius of 25, and a constant luminance value of 55%. On each

215 trial, 10 equidistant colors were sampled, two of which were used as the memory

216 stimuli, with the other eight reserved as potential distractor colors. Afterward the

217 memory sample array, a 500ms fixation display preceded the search array. Next,

218 participants were shown a cue that indicated which of the two memorized items to use

219 as a search template. The cue was a small arrow (0.8° by 0.4°) pointing to the left or

220 right, lasting 250, with the arrowhead pointed to the location that had just contained the

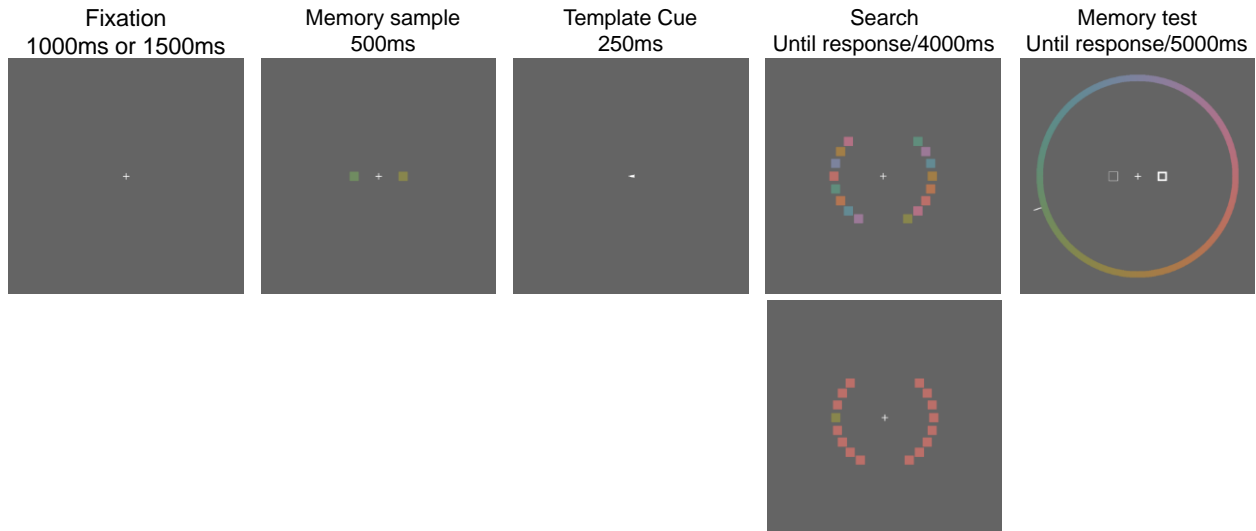
221 target color. We presented a fixation display for 1000 ms before the search display

222 onset. Search displays consisted of 16 squares ($1.1^\circ \times 1.1^\circ$), arranged along the

223 circumference of an imaginary circle, 6° in radius. Search stimuli were drawn in two

224 arcs, evenly spaced between 30° and 150° along the right half of the circle's

225 circumference and between 210° and 330° along the left half of the circle's
 226 circumference.



227

228 *Figure 1.* An example trial sequence used in Experiment 1, showing both
 229 heterogeneous and homogeneous search examples. Not pictured are two fixation
 230 displays before and after the cue display indicating the target participants should search
 231 for (lasting 500ms and 1000ms, respectively).

232

233 There were three types of search arrays: template-present arrays, accessory
 234 present arrays, and neither-present arrays. We created neither-present arrays first, and
 235 modified these arrays to create accessory-present arrays and template-present arrays
 236 by randomly replacing one of the 16 stimuli with the non-cued or the cued colors,
 237 respectively. Heterogeneous arrays were created by randomly placing the eight
 238 distractor colors on the left eight and right eight positions. Homogeneous search arrays
 239 were created by choosing just one of the eight available distractor colors and filling all

240 search stimuli with that color. In the neither present condition and the accessory present
241 condition, these arrays required a *no* response, which was signaled by the participant
242 using the m key. Template present arrays required a *yes* response, which was signaled
243 by the participant using the z key. Participants were given a maximum of 4 seconds to
244 produce a response. If participants entered an incorrect response, or no response,
245 feedback (i.e., a warning message) was displayed for two seconds.

246 After a response was given, the memory test display was shown immediately. In
247 this display, white, hollow squares appeared in the positions of the memory stimuli from
248 earlier in the trial. One of these squares was drawn with a 1-pixel width, and the other
249 was drawn with a 5-pixel width: the latter was the square whose color participants were
250 asked to recall. To report the remembered color, participants used the z and m keys to
251 move a pointer, 1° in length, clockwise or counter-clockwise, respectively, around the
252 outside of the color wheel (12° in radius and 0.4° thick), until the pointer was above the
253 color they thought best matched the color they remembered. Once participants were
254 satisfied with their response, they pressed the space bar to end the trial. Memory
255 responses were again required within five seconds to ensure the experiment could be
256 completed within the session. If no response was given, participants saw a warning
257 message for two seconds. Participants completed 300 of such trials, with a break every
258 50 trials. The entire experiment took between 45 and 60 minutes to complete.

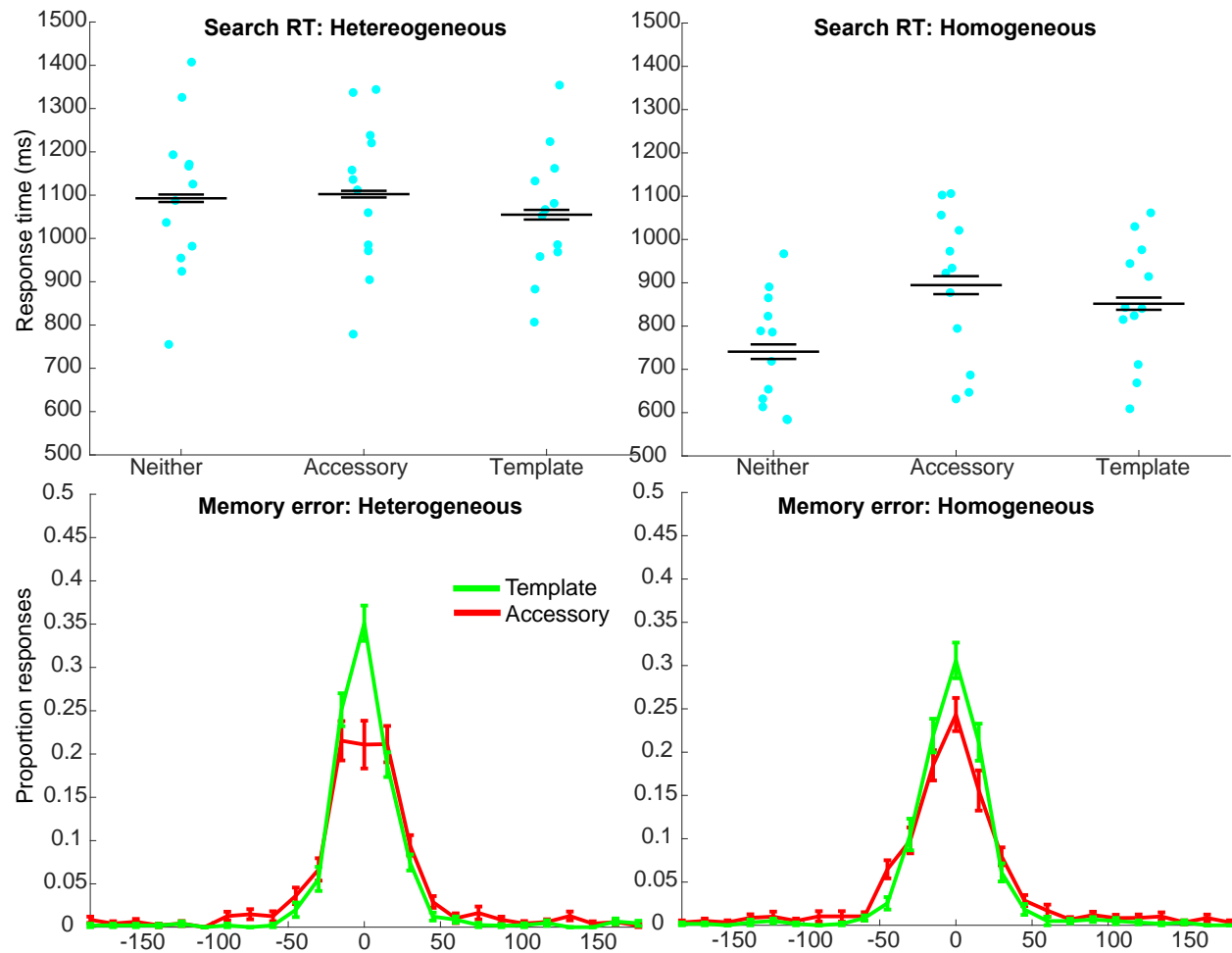
259 **Results**

260
261 As shown in Figure 2, search performance was worse in the heterogeneous
262 condition than the homogeneous condition, as expected. Responses on correct trials
263 were slower, $F(1, 22) = 17.07$, $p < .001$, and approximately 17% more errors were

264 made, $F(1, 22) = 110.2$, $p < .001$, when distractors were heterogeneous. Search
265 patterns differed for homogenous and heterogeneous search, $F(2, 44) = 12.20$, $p <$
266 $.001$, with search of heterogeneous arrays being quicker when the template was
267 present, $M = 1055\text{ms}$, $SE = 150\text{ms}$, than when neither memory color was present, $M =$
268 1093ms , $SE = 179\text{ms}$, or when the accessory was present, $M = 1102\text{ms}$, $SE = 172\text{ms}$,
269 trials. In contrast, homogeneous searches were fastest on neither-present trials, $M =$
270 741ms , $SE = 130\text{ms}$, compared to accessory-present trials, $M = 895\text{ms}$, $SE = 171\text{ms}$,
271 and template-present trials, $M = 852\text{ms}$, $SE = 141\text{ms}$, which suggests that deciding
272 whether the unique color matched the template or not incurred a search time cost.
273 Accuracy was also higher on neither-present trials than on both accessory-present trials
274 and target-present trials, $F(2, 44) = 12.57$, $p < .001$, meaning that participants
275 sometimes false alarmed to the accessory's presence (about 5% of trials).

276 The critical question was whether or not templates would be remembered better
277 than accessory memories in the homogeneous search condition, where guidance to the
278 target was trivially easy, and so template sharpening was not necessary. Our initial
279 analyses quantified memory errors as the reciprocal of the standard deviation ($1/\sigma$) of
280 individual color responses from the correct color on each trial following correct search
281 responses without using a modeling approach. We focused our analyses on only the
282 neither-present trials (plotted in Figure 2), since no priming of either memory
283 representation by stimuli presented in the search display could have occurred on these
284 trials (the same conclusions were reached from a full factorial analysis). Templates
285 were remembered better than accessories, $F(1, 22) = 22.65$, $p < .001$, but this did not
286 interact with search type, $F(1, 22) = 0.61$, $p = .45$. Preplanned comparisons showed that

287 memory for templates was better than memory for accessory items following both
 288 heterogeneous search, $t(11) = 3.36$, $p = .006$, and homogeneous search, $t(11) = 3.37$, p
 289 $= .006$. The fact that a memory difference occurred even when relevant items popped
 290 out suggests that improving distractor rejection is not the driving force behind the
 291 template memory advantage, and supported the recognition-weighting hypothesis.



292
 293 *Figure 2.* Upper panels: Search time with heterogeneous distractors (left) and
 294 homogeneous distractors (right) as a function of which remembered color was in the
 295 search array. Lower panels: Memory error histograms for the heterogeneous distractor
 296 (left) and homogeneous distractor (right) for accessories and templates for searches

297 where neither remembered color appeared during the search. Error bars depict one
298 standard error of the mean.

299 We also compared memory performance after modeling individual participants'
300 memory error distributions as a mixture of guesses and target responses (Bays,
301 Catalao, & Husain, 2009). The estimated standard deviation of recalled colors was
302 smaller (i.e., more precise) for templates than accessory memories, $F(1, 22) = 8.77$, $p =$
303 $.007$, and did not interact with search type, $F(1, 22) = 1.04$, $p = .32$. Similarly, the
304 estimated probability that the tested color was in memory (i.e., the height of the tails of
305 the response distribution) was higher for templates than accessory items, $F(1, 22) =$
306 8.46 , $p = .008$, with no modulation by search type, $F(1, 22) = 0.29$, $p = .60$. Separating
307 memory error into different error types did nothing to change the conclusions drawn
308 from un-modeled data.

309 **Discussion**

310
311 The results of Experiment 1 strongly argue against the adaptive-weighting hypothesis,
312 which holds that participants strategically (or otherwise) prioritize the fidelity of template
313 representations to more efficiently separate targets from distractors. Templates were
314 consistently remembered better than accessory items both when target localization was
315 difficult, because distractors were heterogeneous (Duncan & Humphreys, 1989), and
316 when target localization was trivially easy, because distractors were homogenous. As
317 such, it seems that the difference in memory fidelity that results when one memory is
318 assigned template status serves some other function than augmenting search guidance.

319 One limitation of Experiment 1 is that the critical contrast of heterogeneous and
320 homogeneous search was run between-subjects. In Experiment 2 we sought to make a
321 more direct, within-subjects comparison of the difference between template and
322 accessory memory fidelity following difficult and easy search.

323 **Experiment 2**

324 The goal of Experiment 2 was to compare template and accessory memory fidelity
325 within-subjects following different types of search tasks. To collect sufficient data for
326 both search conditions and test memory for the different types of objects, we modified
327 the search task from Experiment 1. Whereas the search task in Experiment 1 required
328 participants to report the presence or absence of the cued object, Experiment 2 used a
329 compound search task (Olivers & Meeter, 2006), wherein each stimulus in a search
330 array contained a left- or right-tilted line. Participants were told that they needed to find
331 the single colored square that matched the cued item they had stored in memory, and
332 report the orientation of the line inside that square. Every trial contained a single item
333 whose color exactly matched the template color (i.e., the target), and a single item
334 whose color exactly matched the accessory color (i.e., a memory-matching non-target).
335 The rest of the search items were either homogeneously colored, during easy search
336 blocks, or heterogeneously colored, during difficult search blocks. In addition to
337 providing a more sensitive within-subjects' measurement of the template advantage,
338 Experiment 2 ensured that all participants experienced both the easy and hard search
339 condition. If experience with a more difficult search is necessary to realize that template
340 sharpening is unnecessary during easy search, then we might see the template
341 advantage disappear here following easy searches.

342 **Method**

343 Participants

344 Twenty-eight participants, none of whom were in Experiment 1, volunteered for
345 Experiment 2. All provided informed consent before participating and were awarded
346 partial course credit as compensation. Data were collected until 24 participants
347 remained after exclusion criteria were applied.

348 Four participants were excluded for performance that was not statistically
349 distinguishable from chance in one or more conditions for either the search or memory
350 task. One participant performed the search task at chance levels, two participants had
351 chance-level memory in either the homogeneous or heterogeneous search blocks, and
352 one participant produced chance-level responses in all conditions for both search and
353 memory.

354 Stimulus and Procedure

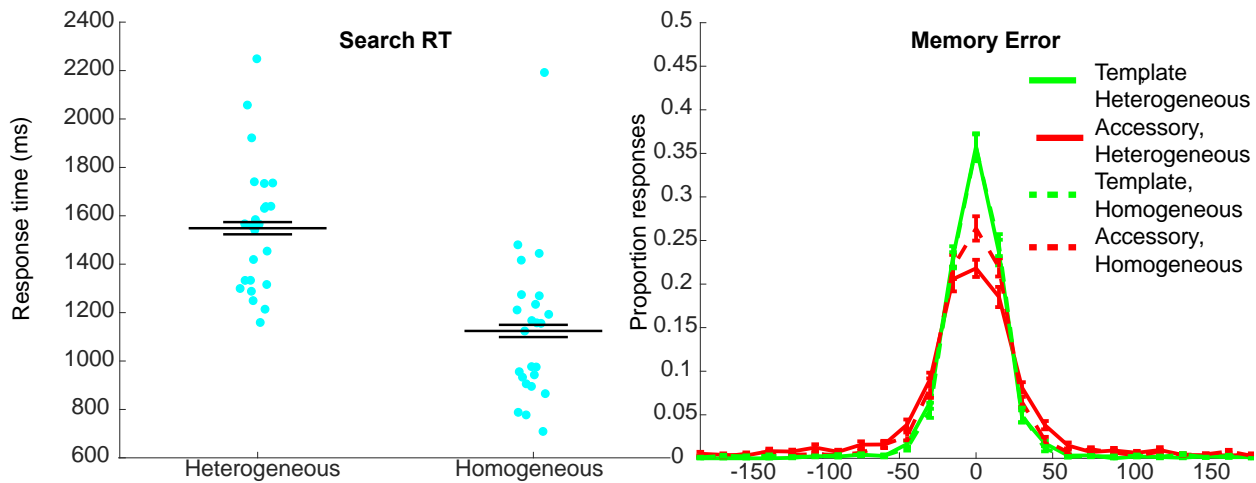
355 Stimuli and procedure were the same as in Experiment 1 with the following exceptions.
356 Search arrays were constructed the same way as in Experiment 1 with two exceptions.
357 First, both the cued and uncued color on each trial replaced a randomly positioned
358 distractor on all trials. Second, all search stimuli were overlaid with black lines tilted 45
359 degrees leftwards or rightwards. Participants pressed the z key to indicate that the
360 target square had a left-tilted line, and pressed the m key to indicate that the target
361 square had a right-tilted line. Search and memory display timeouts were extended to six
362 seconds so as not to truncate reaction time distributions. All participants completed 6
363 pseudorandomly presented blocks of 50 trials, half of which required search for targets

364 embedded in arrays of homogeneous distractors (with the exception of the non-cued
365 stimulus), and half of which required search for targets embedded in arrays of
366 heterogeneous distractors. Block order was randomized by appending pairs of
367 heterogeneous and homogeneous blocks whose order was randomized, ensuring that
368 no more than two sequential blocks of the same type could be presented. Participants
369 completed 300 blocks in total, allowing for 75 trials in each of the four cells in the
370 design. The experiment took approximately one hour to complete.

371 **Results**

372 As shown in Figure 3, search was over 400 ms faster in the homogeneous than
373 heterogeneous condition, $F(1, 23) = 70.74$, $p < .001$, and led to a 10% difference in
374 error rate in favor of the homogeneous search condition, $F(1, 23) = 83.12$, $p < .001$.
375 Participants' error ($1/\sigma$) in the memory task once again showed a template fidelity
376 benefit, $F(1, 23) = 56.21$, $p < .001$, with marginal evidence for a larger benefit after
377 heterogeneous search, $F(1, 23) = 3.84$, $p = .06$. Analyzing modeled memory SD
378 provided additional statistical support for this interaction, $F(1, 23) = 22.78$, $p < .001$, with
379 poorer precision following heterogeneous distractors (though this was largely driven by
380 accessory memory precision differences between the search conditions), $F(1, 23) =$
381 18.94 , $p < .001$, and the familiar template advantage, $F(1, 23) = 51.44$, $p < .001$.
382 Estimating the probability of memory based on the height of the tails of the response
383 distributions in color space showed a similar pattern. That is, an ANOVA with the factors
384 of memory type (template versus accessory item) and search condition (heterogeneous
385 versus homogeneous) was run on the participants' estimates of P_{mem} . This yielded a
386 memory type x search condition interaction: $F(1, 23) = 5.16$, $p = .033$, a benefit for

387 templates: $F(1, 23) = 19.10, p < .001$, but no memory cost due to the type of distractors,
 388 $F(1, 23) = 0.79, p = .38$. Thus, there was some indication that the template-accessory
 389 difference was larger during heterogeneous search blocks. However, it was still the
 390 case that templates were remembered better than accessories when distractors were
 391 homogeneous, $t(23) = 4.25, p < .001$, in a planned comparison.



392

393 *Figure 3.* Left panel: search time in Experiment 2 when distractors were heterogeneous
 394 and homogeneous. Right panel: memory error histogram for templates and accessories
 395 for both distractor types.

396

397 Discussion

398 Experiment 2 replicated the evidence from Experiment 1 that target representations are
399 remembered better than other memory representations regardless of the difficulty of the
400 visual search task. Experiment 2 also suggests that heterogeneous distractors impair
401 the precise retention of colors in working memory. Searching through a heterogeneous
402 display of colors seems to have led to a larger difference between the memory for
403 templates and accessories. One possible explanation for this finding is that
404 heterogeneous distractors lead to more memory interference. However, it could also be
405 due to accessories being sharpened more frequently through resampling during
406 homogeneous searches (Woodman & Luck, 2007). Although both the template and
407 accessory colors were always presented in search, the accessory color more likely
408 attracted attention in the context of homogeneous distractors, which should increase its
409 feature contrast, compared to heterogeneous distractors, which make the accessory
410 color non-unique. To address this possibility, we conducted Experiment 3, which used
411 a present versus absent search task, more similar to that used in Experiment 1.
412 Comparing template and accessory memory on target absent trials, where neither color
413 is present in the array, allowed us to measure memory fidelity without the opportunity for
414 resampling.

415 Experiment 3

416 Experiment 3, like Experiment 2, tested participants on both easy (homogeneous
417 distractors) and hard (heterogeneous distractor) blocks of search. However, to measure
418 the quality of memory for accessories and templates in the absence of perceptual

419 resampling, we returned to a target present versus absent search task, like that used in
420 Experiment 1. To obtain an adequate number of trials, we dropped the accessory-
421 present trials, such that target absent searches contained neither of the colors being
422 remembered, and target present searches always contained the template color and not
423 the accessory color. We focused our analyses on the target absent condition as in
424 Experiment 1, as it should allow us to measure the precision of participants' memories
425 when there is no opportunity to resample the colors being remembered.

426 **Method**

427 Participants

428 Twenty-four undergraduates from Vanderbilt University participated in Experiment 3. All
429 participants provided informed consent before participating, and none of the participants
430 had already taken part in Experiments 1 or 2.

431 Of the twenty-four participants who completed Experiment 3, eight performed the
432 task with chance-level performance in at least one condition. Clearly intermixing the
433 easy and hard search tasks in the context of a target present versus absent search
434 caused participants some difficulty. Chance performance either occurred in the
435 heterogeneous search condition ($n = 2$), in accessory memory recall ($n = 3$), or both of
436 these two conditions ($n = 3$). This indicates that the excluded participants could not, or
437 did not, successfully manage to simultaneously remember accessory items and
438 successfully pick out the template from search arrays with multiple, often similar, colors.

439 Stimuli and Procedure

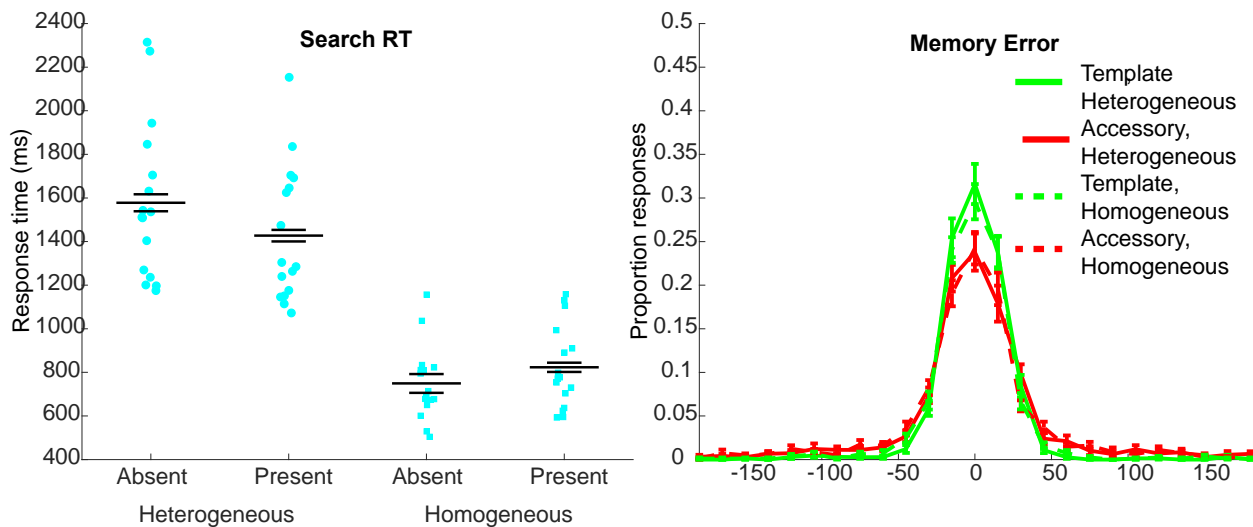
440 Experiment 3 was identical to Experiment 2, with the exception of the search displays
441 used. The task was a target present versus absent search task, and participants were
442 asked to report that the cued color was present, using the z key, or that it was absent,
443 using the m key. We increased the total number of trials in the Experiment to 384, so
444 that each of the eight possible conditions (distractor type X memory type X and target
445 presence) contained 48 trials.

446 **Results**

447 As shown in Figure 4, target presence had opposite effects on search time for
448 heterogeneous and homogeneous search, $F(1, 15) = 25.96, p < .001$. Target present
449 responses were faster than target absent responses for heterogeneous search, $t(15) =$
450 $4.92, p < .001$, but target absent responses were faster during homogeneous search,
451 $t(15) = 2.20, p = .044$. Accuracy was also higher for homogeneous search, $F(1, 15) =$
452 $177.45, p < .001$, by almost 20%, and response times were faster, $F(1, 15) = 146.67, p$
453 $< .001$.

454 As in Experiments 1 and 2, we again found that templates were generally
455 remembered better than accessories, both when distractors were heterogeneous and
456 when they were homogeneous (see Figure 4). Looking at trials where neither
457 remembered color was shown during search, raw memory accuracy (calculated as $1/\sigma$
458 of color error) was better for templates than accessories overall, $F(1, 15) = 28.85, p <$
459 $.001$, and memory accuracy was also better overall following search through
460 heterogeneous distractors, $F(1, 15) = 4.64, p = .05$. However, this was driven by an
461 interaction, $F(1, 15) = 5.79, p = .029$, such that template memory was better when

462 distractors were heterogeneous than when they were homogeneous. However, recalling
 463 that errors were made often following heterogeneous distractors than homogeneous
 464 distractors, it is possible that excluding trials with search errors also excludes trials
 465 where the template color happened to be encoded poorly before the cue even
 466 appeared, given that imprecise templates would be expected to cause search errors.
 467 Running the same analysis with search error trials included eliminated the interaction,
 468 $F(1, 15) = 1.53, p = .24$. Interesting as this may be, the more important point is that
 469 templates were still remembered better than accessories when distractors were
 470 homogeneous, $t(15) = 2.84, p = .012$, contrary to the predictions of the adaptive-
 471 weighting hypothesis but consistent with the recognition-weighting hypothesis. As in
 472 Experiments 1 and 2, an overall benefit for templates was observed as well in modeled
 473 memory $SD, F(1, 15) = 12.20, p = .003$, as well as in probability of memory, $F(1, 15) =$
 474 $15.17, p = .001$, with no other main effects or interactions.



475

476 *Figure 4.* Left panel: search time in Experiment 3 as a function of target presence and
 477 distractor type (Homogeneous and Heterogeneous). Right panel: memory error

478 histograms for accessories and templates for both distractor types following target
479 absent trials.

480 **Discussion**

481 When the opportunity for resampling was removed, the difference in memory
482 between templates and accessory items between heterogeneous search and
483 homogeneous search was less convincing. Therefore, it seems reasonable to suggest
484 that the differences observed in Experiment 2 stemmed from the fact that participants
485 re-encoded (intentionally or otherwise) accessory colors more often in the
486 homogeneous search condition. Any difference in interference between heterogeneous
487 and homogeneous displays should have been larger in Experiment 3 than in
488 Experiment 2, given that the target absent displays we analyzed from Experiment 3
489 contained only one color. Despite this, the template benefit (or accessory cost) was
490 about the same in both distractor conditions, so the differences observed in Experiment
491 2 are most reasonably attributed to resampling (Woodman & Luck, 2007). As such,
492 Experiment 3 provides further evidence that template memories are not sharpened in
493 response to difficult-to-reject distractors.

494 The presence of a template-accessory memory difference in the homogeneous
495 search condition is even more surprising in light of the fact that these search displays
496 only ever contained the template color as a singleton, or contained a homogeneous
497 array of distractors. That is, participants could have learned to respond present
498 whenever there was a singleton, regardless of its color, and still made the correct
499 decision (Bacon & Egeth, 1994), obviating the need to assign distinct template and

500 accessory statuses to the colors at all. Given that participants weren't informed of this
501 regularity, it may be that they were simply being strategically conservative by following
502 instructions.

503 **General Discussion**

504 When we look for one of two things we are remembering, our memory for what
505 we looked for is better than our memory for what we did not look for (Rajsic et al.,
506 2017). Here, we asked whether this is because we sharpen template memories so that
507 we can later filter out distractors more effectively during search (the adaptive-weighting
508 hypothesis) or because we need to respond affirmatively to a specific feature, once
509 attended, and not others (the recognition-weighting hypothesis). The results of these
510 experiments argue against this possibility. When we made finding the target trivially
511 easy by presenting the target alongside completely homogeneous distractors, templates
512 were still reported with higher fidelity than accessory memories. While the difference
513 between template and accessory memories was larger following heterogeneous
514 searches in Experiment 2, Experiment 3 demonstrated that this was likely caused by
515 differences in the opportunities for perceptual resampling. On the basis of these results,
516 it seems most sensible to conclude that the template memory advantage we have
517 observed in this task before (Rajsic et al., 2017) reflects the need to make a decision
518 about the template color during search rather than an effort to improve the guidance of
519 attention toward target-defining features and away from distractors during search. We
520 should note as well that template memories could have, in principle, been sharpened
521 during the difficult search as distractors were being rejected, and not in advance of

522 search. Given that this predicts the same results as the adaptive-weighting hypothesis,
523 it is also inconsistent with our data.

524 Preparing to use a mental representation for a particular task is not a trivial
525 process. Numerous experiments have now shown that cuing a particular item in a set of
526 already encoded items can improve memory for the cued item compared to other items
527 (Griffin & Nobre, 2003; see Souza & Oberauer, 2016 for a review). Our experiments,
528 along with others (Zokaei et al., 2014) help to show that simply using a mental
529 representation can lead to similar differences when a sensitive task (i.e., continuous
530 feature recall) is used to probe the memories themselves. Indeed, instructions to simply
531 think about an item can shift memory performance in favor of those items proportionally
532 to the number of times an item is thought about (Souza, Rerko, & Oberauer, 2015).

533 Cued items – those ready to be used – appear to be maintained in a qualitatively
534 different neural state. Lewis-Peacock and colleagues (Lewis-Peacock, Drysdale,
535 Oberauer, & Postle, 2012; LaRocque, Lewis-Peacock, Drysdale, Oberauer, & Postle,
536 2013) have found that the most recently cued item is uniquely decodable from fMRI and
537 EEG. de Vries, van Driel, and Olivers (2017) have also shown that lateralized EEG
538 elicited by items about to be used for search shows stronger alpha suppression
539 contralateral to items that are to be searched for immediately than to items to be
540 searched for later, with no differences in contralateral voltage that reflects visual
541 working memory storage (Vogel & Machizawa, 2004). These results have been taken to
542 indicate that memory representations currently being used are in a more active state.
543 However, another noteworthy proposal is that cuing a memory for use does more than
544 change the activation state of the memory: it binds the memory to a particular task set in

545 order to prepare for upcoming memory-driven decisions and responses (Myers et al.,
546 2017). This account suggests that benefits for templates could instead result from their
547 being already coupled the relevant decision circuitry for judging whether inputs match
548 that mental representation, as opposed to differences in states of activation.

549 It is important to stress that the dual memory-search task that we used here was
550 quite difficult. Across each experiment, more participants performed at chance levels
551 than we expected. We take this to indicate that some participants could not encode the
552 two-color memory set with enough precision to reliably distinguish distractors from
553 targets during heterogeneous search. Indeed, some excluded participants showed
554 chance memory of the accessory item only, despite instructions that emphasized the
555 fact that both items could be tested. This may indicate that they dropped the accessory
556 memory in an attempt to remember the template precisely enough to distinguish targets
557 from distractors, as distractors in the heterogeneous condition could often occur from
558 the same color category as the template.

559 Our results provide an interesting complement to Geng, Diquattro, and Helm's
560 (2017) recent demonstration of an improvement in the precision of distractor filtering
561 during search. In contrast, we found almost no role of distractor differences in
562 determining the precision of the attentional template relative to the accessory memory.
563 As noted in the introduction, a major difference between these experiments is whether
564 the target color varied between trials. In our task, template colors changed on every
565 trial, and so participants' only recourse to improving distractor rejection would have
566 been to tune their template using top-down control. In this context, no such special
567 tuning occurred in anticipation of more heterogeneous distractors. On the other hand,

568 experience with irrelevant information does seem to be necessary for improving the
569 allocation of attention away from distractors within a given search array (Cunningham &
570 Egeth, 2016; Geng et al., 2017; Vatterott & Vecera, 2012). Taken together, these
571 results suggest that more precise distractor rejection requires repeated exposure to
572 relevant and irrelevant visual features, implying that this improved tuning of attention
573 could involve perceptual learning instead of, or in addition to, better cognitive control.

574 Throughout her iconic work on FIT, Treisman was very sensitive to the possible
575 contribution of feature-based selection strategies to search efficiency (Treisman &
576 Gelade, 1980; Treisman & Sato, 1990). For example, in noting the incompatibility
577 between her search efficiency estimates and the convincing demonstration of subset
578 search by Egeth, Virzi, & Garbart (1984), she concluded that searchers may choose to
579 use feature-based strategies only when they provide frequent enough opportunities for
580 search benefits, anticipating the classic demonstrations of search modes (Bacon &
581 Egeth, 1994). Although we agree with Treisman that such selection strategies are
582 possible, the results of the experiments we report here provide no evidence that the
583 difference in memory quality between templates and accessory memory representations
584 is a result of such a strategy. Templates were still remembered better than accessories
585 when targets were color singletons, a condition which does not require a feature-based
586 template to separate the target from distractors. We take these results to mean that
587 memory advantages for templates likely do not result from a need to sharpen template
588 memories to improve selection within the search array. Instead, we believe the
589 template memory difference measured in this task reflects the operation of a
590 mechanism that enables decision making – specifically, deciding that an attended object

591 is the object being searched for -- rather than the signature of a representation that
592 works to shift attention toward target-like objects and away from distractor-like objects.

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Competing interests statement

The authors declare no competing financial interests.

Open Practices Statement

None of the data or materials for the experiments reported here is available, and none of the experiments were preregistered.

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766 **Figure Legends**

767

768 **Figure 1.** A sample trial sequence for Experiment 1, showing both heterogeneous and
769 homogeneous search examples. Not pictured are two fixation displays before and after
770 the template cue display (lasting 500ms and 1000ms, respectively).

771

772 **Figure 2.** Upper panels: Search time with heterogeneous distractors (left) and
773 homogeneous distractors (right) as a function of which remembered color was in the
774 search array. Lower panels: Memory error (root mean squared error) for the
775 heterogeneous distractor (left) and homogeneous distractor (right) for accessories and
776 templates for searches where neither remembered color appeared during the search.

777

778 **Figure 3.** Left panel: search time in Experiment 2 when distractors were heterogeneous
779 (Het.) and homogeneous (Hom.). Right panel: average memory error (root mean
780 squared error) for templates and accessories for both distractor types.

781

782 **Figure 4.** Left panel: search time in Experiment 3 as a function of target presence and
783 distractor type (Homogeneous and Heterogeneous). Right panel: memory error (root
784 mean squared error) for accessories and templates for both distractor types.