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Citation: Rajsic, Jason, Carlisle, Nancy B. and Woodman, Geoffrey F. (2020) What not to look for: Electrophysiological evidence that searchers prefer positive templates. *Neuropsychologia*, 140. p. 107376. ISSN 0028-3932

Published by: Elsevier

URL: <https://doi.org/10.1016/j.neuropsychologia.2020.10...>
<<https://doi.org/10.1016/j.neuropsychologia.2020.107376>>

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1 **What not to look for: electrophysiological evidence that**
2 **searchers prefer positive templates**

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30 Word Count:
31 Abstract: 237
32 Body: 10 123
33

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36

37 Formal publication available at:
38 <https://doi.org/10.1016/j.neuropsychologia.2020.107376>
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41

Abstract

42 To-be-attended information can be specified either with positive cues (I'll be
43 wearing a blue shirt) or with negative cues (I won't be wearing a red shirt).
44 Numerous experiments have found that positive cues help search more than
45 negative cues. Given that negative cues produce smaller benefits compared to
46 positive cues, it stands to reason that searchers may choose to use positive
47 templates instead of negative templates if given the opportunity. Here, we
48 evaluate this possibility with behavioral measures as well as by directly
49 measuring the formation of positive and negative templates with event-related
50 potentials. Analysis of the contralateral delay activity (CDA) elicited by cues
51 revealed that positive and negative templates relied on working memory to the
52 same extent, even when negative working memory templates could have been
53 circumvented by relying on long-term memories of target colors. Whereas the
54 CDA did not discriminate positive and negative templates, a CNV-like potential
55 did, suggesting cognitive differences between positive and negative templates
56 beyond visual working memory. However, when both positive and negative
57 information were presented in each cue, participants preferred to make use of
58 the positive cues, as indicated by a CDA contralateral to the positive color in
59 negative cue blocks, and a lack of search benefits for positive- and negative-
60 color cues relative to positive-color cues alone. Our results show that searchers
61 elect to selectively encode only positive information into visual working memory
62 when both positive and negative information are available.

63 Keywords: Visual search, attention, working memory, event-related potentials

64

65 **Highlights:**

66 Search is better with positive (find red) than negative (find non-red) templates

67 We tested whether people avoid storing negative templates in working memory

68 Neural measures of working memory were consistently found for both templates

69 Participants selectively stored positive templates when both cues were given

70

71

1. Introduction

72 Our visual system provides us with a wealth of potentially useful information, but
73 a key to successful behavior is selecting just the information that is useful in a
74 given moment. This selection has been variously explained as prioritization of
75 information we want to attend to (e.g., Wolfe, Cave, & Franzel, 1989; Wolfe &
76 Gray, 2007) and suppression of information we do not want to attend (Treisman
77 & Sato, 1990). In principle, foreknowledge of relevant and irrelevant information
78 should be equally helpful in selecting desired information, but research in visual
79 search shows that in fact there is an asymmetry: cues telling you what to attend
80 to (positive cues) are more helpful than cues telling you what not to attend to
81 (negative cues; Arita, Carlisle, & Woodman, 2012; Beck & Hollingworth, 2015;
82 Becker, Hemsteger, & Peltier, 2015; Beck, Luck, & Hollingworth, 2018). Because
83 negative cues provide smaller benefits, it stands to reason that searchers would
84 employ positive templates instead of negative templates when the opportunity
85 presents itself. In the present study, we used a combination of behavior and
86 event-related potentials elicited by positive and negative cues to directly measure
87 which cues participants use.

88

89 The question of how we process information about what not to do, think, or
90 believe has a long history in experimental psychology (Clark & Chase, 1972;
91 Logan, Schachar, & Tannock, 1997; Verbruggen & Logan, 2008; Wason, 1959;
92 Wegner, 1994). Across many tasks, receiving negative information presents
93 cognitive challenges compared to positive information. That is, information about

94 what is not true, or what will not occur is more difficult to represent or use than
95 information about what is true, or what will occur. For example, Clark and Chase
96 (1972) found that the time it takes to verify that a sentence accurately describes
97 a picture is slower overall when the sentence includes a negation (e.g., *the star is*
98 *not above the plus*). This was attributed to an additional cognitive step of
99 reversing judgments when the subjects of the statement otherwise matched the
100 picture.

101

102 More recently, research on visual search has addressed the question of how
103 negative information is used to control attention. These studies have presented
104 cues that tell participants what color, for example, a target will not be before
105 presenting a search array (Arita et al., 2012; Moher & Egeth, 2012). Two general
106 findings are worth emphasizing. First, positive cues generally lead to better
107 search performance than do negative cues. Second, negative cues can provide
108 benefits relative to conditions where no cues are provided (Arita, et al., 2012,
109 Carlisle & Nitka, 2019, Reeder, Olivers, & Pollman, 2017, Reeder, Olivers, &
110 Pollman, 2018), but some studies fail to find a negative cue benefit (see Beck &
111 Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2016), and sometimes
112 negative cues instead leads to costs (Moher & Egeth, 2012, Beck & Hollingworth,
113 2018).

114

115 Currently there is no consensus on how negative cues are used (Geng, Won, &
116 Carlisle, *in press*). One position is that negative templates cannot be directly

117 used, but that searchers must first attend to irrelevant information before they
118 can exclude it (Moher & Egeth, 2012) and subsequently attend to the remaining,
119 relevant information using either spatial (Beck & Hollingworth, 2015) or feature-
120 based (Becker, Hemsteger, & Peltier, 2016) recoding strategies. An alternative
121 position is that negative templates can be used to directly suppress irrelevant
122 information, but that attentional weights for ignored information are not set to
123 zero (Arita, et al., 2012, Carlisle & Nitka, 2019), which would account for the
124 relatively lower benefits of negative cues. While the former positions holds that
125 using negative information involves two cognitive steps, and the latter position
126 holds that negative information can be used in a single cognitive step, all sides
127 agree that negative cues do not provide the same performance advantages that
128 positive cues do.

129

130 While the debate regarding negative templates has largely focused on what
131 searchers are capable of, a complete account of how we implement control over
132 attention requires an understanding of what searchers choose to do when
133 multiple strategies are available (Irons & Leber, 2016; Pauszek & Gibson, 2018;
134 Rajsic, Wilson, & Pratt, 2015). Accounting for strategies and processing
135 preferences can reveal a capacity for cognitive control over seemingly automatic
136 processes that would otherwise go unnoticed (Bacon & Egeth, 1994; Carlisle &
137 Woodman, 2011; Kiyonaga, Enger, & Soto, 2012; Leber & Egeth, 2006;
138 Woodman & Luck, 2007). There is growing evidence that choice or strategy can
139 determine the pattern of results obtained in visual search tasks. For example,

140 spatially mixing relevant and irrelevant items in search discourages searchers
141 from relying on negative templates (Beck & Hollingworth, 2015). In contrast,
142 when the same non-effective spatially mixed arrays from Beck & Hollingworth
143 (2015) were randomly mixed into a block where the majority of trials contained
144 spatially separated arrays where negative cues are effective, a negative cue
145 benefit was found for both the spatially mixed and spatially separated arrays
146 (Carlisle and Nitka, 2019). Similarly, Conci, Deichsel, Müller, and Töllner (2019)
147 have shown that negative color cues do not lead to benefits during a search task
148 which can easily be performed based on target shape, but that benefits emerge
149 when the task cannot be completed based on simple shape features. This
150 suggests that searchers will only utilize negative cues when the task becomes
151 extremely demanding or impossible to complete without using the cues, even
152 though they are helpful in principle. This is consistent with the idea that they are
153 more difficult to use than positive cues (see also Beck & Hollingworth, 2015).

154

155 In the present study, we sought to address the question of whether positive
156 information is preferred to negative information in the guidance of attention by
157 directly measuring the maintenance of both positive and negative templates in
158 working memory using electrophysiology and examining the behavioral impact of
159 template choice. We reasoned that if negative templates are less useful than
160 positive templates, then opportunities to instead use positive templates should
161 lead to a reduction the frequency with which negative cues are encoded into
162 working memory as a search template. Although we are interested in the nature

163 of attentional dynamics during actual searching, our experiments here focus on
164 preparatory processes. That is, we measured the formation and maintenance of
165 templates based on cue displays in advance of search. Following Carlisle, et al.,
166 (2011; see also Woodman, Carlisle, & Reinhart, 2013; Reinhart & Woodman,
167 2015), we measured an event-related potential (ERP) known as the contralateral
168 delay activity (CDA) to cues that either showed colors that needed to be later
169 attended (positive cues) or ignored (negative cues). The CDA is a negative slow
170 wave measured at posterior electrodes contralateral to stimuli that are being
171 maintained in working memory. Previous experiments have established that this
172 component tracks the maintenance of positive search templates (Woodman &
173 Arita, 2011), decreases in amplitude when working memory templates can be
174 replaced by long-term memory templates (Carlisle, et al., 2011; Woodman,
175 Carlisle, & Reinhart, 2013), and increases when emphasis is placed on search
176 performance in an upcoming trial (Reinhart, McClenahan, & Woodman, 2016;
177 Reinhart & Woodman, 2014). This demonstrates that the CDA is sensitive to the
178 use cues to form positive search templates. As a result, we expected reliance on
179 negative templates would be captured by changes in amplitude of the CDA.

180

181 Here, we outline the purpose of each experiment and preview the results. In
182 Experiment 1, we compared ERPs of working memory storage elicited when
183 participants were shown what to attend (positive cues) to those elicited from cues
184 showing what to ignore (negative cues). In this experiment, no opportunities were
185 given for recoding of negative cues into positive templates prior to the onset of

186 the search array. With any given negative cue, participants could not predict what
187 color they would eventually attend, as it was selected at random from the
188 remaining set of colors. We found similar amplitude CDA effects for positive and
189 negative search templates. Experiment 1, then, establishes a baseline for how
190 negative cues are stored in working memory in comparison to positive cues. In
191 Experiment 2, we added an opportunity for participants to rely on their memory
192 for target features rather than negative templates: within short runs of trials, as
193 long as a given negative cue color repeated, so did the corresponding target
194 color for those searches. If guiding attention using knowledge of previous target
195 features is preferable to relying on negative cues, the CDA in the negative cue
196 condition should drop below that of the positive condition as cues repeat.
197 However, we found that participants still represented the negative templates in
198 working memory. This suggested that participants were still choosing to use
199 negative cues, even when positive templates could have been used instead. In
200 Experiment 3, we analyzed the CDA when both a positive and negative color cue
201 were available prior to the search array. Specifically, the two colors presented in
202 each lateralized cue array were the two colors that appeared in that trial's search,
203 with pre-cues and instructions specifying the cued color as positive or negative in
204 a given block. When given both cues in this manner, we found a CDA
205 contralateral to the cue indicating the target's color, regardless of instructions.
206 This suggests that while participants can prepare a negative cue in working
207 memory, when given the choice between using a negative and positive cue, they
208 have a strong tendency to use the positive cue information to guide attention to

209 search targets rather than negative cue information. Finally, to confirm that the
210 results of Experiment 3 reflect the use of the positive cue when both types of
211 cues are available, Experiment 4 compared the behavioral impact of receiving
212 positive, negative, and both cues compared to a neutral cue condition. By
213 measuring the size of response time benefits in the both cue condition to the
214 positive cue only condition, we could see whether adding negative cues
215 produced any extra search gains. The results showed that providing both
216 positive and negative colors in a cue produced no additional benefit when
217 compared to the positive cue alone, suggesting participants were largely
218 choosing to use the positive information alone even when a negative cue
219 provides additional information, confirming our interpretation of the CDA results
220 in Experiment 3.

221

222 **2. Experiment 1**

223

224 In Experiment 1, we used a simple conjunction search task that could be
225 completed with either positive or negative search templates. Subjects searched
226 for Landolt C's with a gap on their left or right side. Across different blocks of
227 trials the subjects were instructed that the cued object (i.e., to the left in Figure
228 1a) indicated the color in which the distractors would appear on negative-cue
229 condition. In the positive-template condition the cued object indicated the color
230 that the target would appear in. Following previous studies (Carlisle, et al., 2011;
231 Woodman, Carlisle, & Reinhart, 2013; Reinhart & Woodman, 2015), we expected

232 to see a CDA emerge for positive and negative cues, reflecting the creation of
233 positive and negative templates, respectively. Importantly, a horizontal Landolt-C
234 of both the cued color and another color was presented in each search, ensuring
235 that it was not possible to correctly report the target without knowing the cue's
236 color (Becker, Hemsteger, & Peltier, 2015). Without this addition, participants
237 could have ignored the cues entirely and simply looked for a horizontal Landolt-
238 C.

239

240 **2.1. Methods**

241

242 **2.1.1. Participants.**

243 Thirty-one volunteers from the Vanderbilt community participated in Experiment
244 1. Our goal for each ERP experiment was to collect at least 20 participants,
245 whose data passed inclusion criteria, to be consistent with the sample sizes of
246 previous studies measuring the CDA to cues in a visual search task (typically 15-
247 20 participants: Carlisle, Arita, Pardo, & Woodman, 2011; Grubert, Carlisle, &
248 Eimer, 2016; Reinhart & Woodman, 2013; Servant, Cassey, Woodman, & Logan,
249 2018). Participants' data were included for analysis if they met the following
250 criteria: fewer than 25% of trials lost to ocular artifacts in either the cue epoch or
251 the search epoch (mean of 10.9% trials rejected across remaining subjects), an
252 average error rate of less than 15% (mean of 93.5% correct across remaining
253 subjects), and less than 3.2 μ v of residual HEOG towards cues after rejecting
254 ocular artifacts. Blocking artifacts (Luck, 2005) were excluded on a trial and

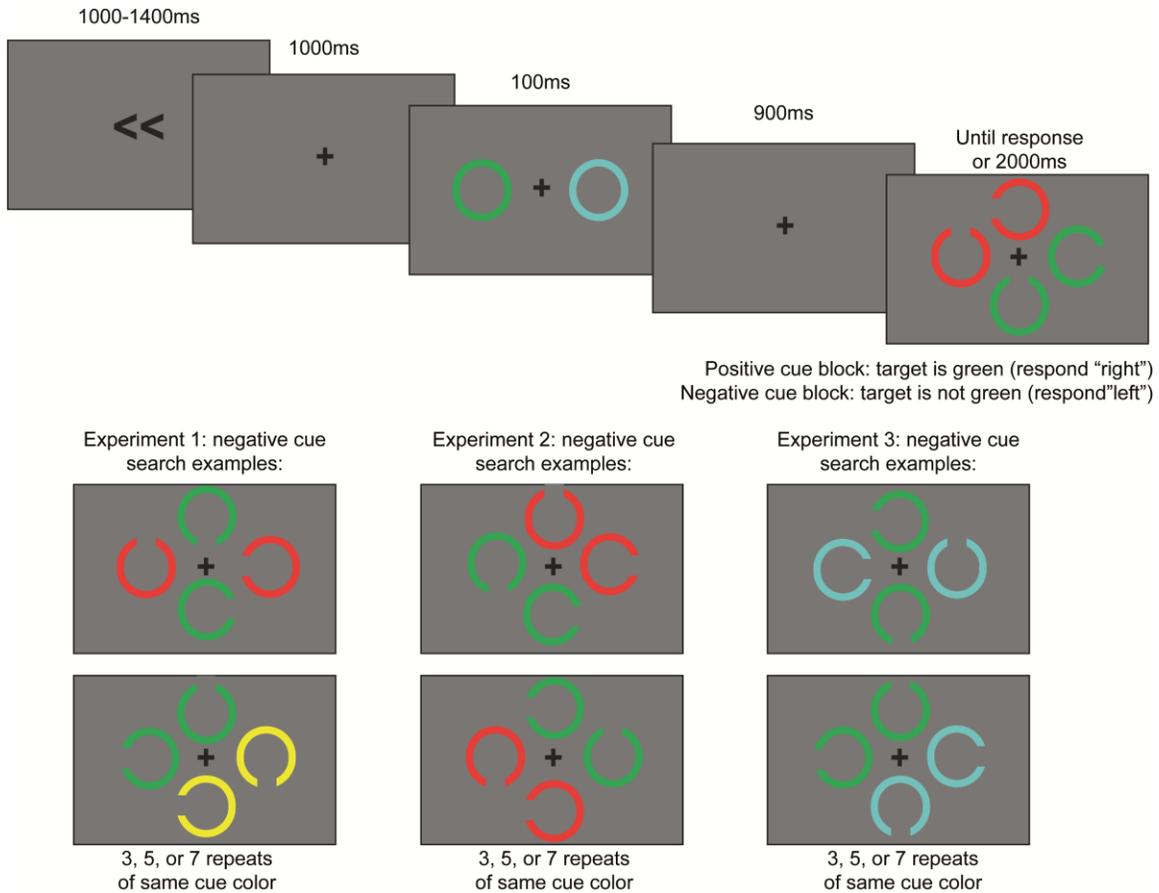
255 electrode-wise basis. One additional participant was excluded for excessive
256 blocking artifacts. Twenty-one participants remained after these criteria were
257 applied. All participants provided informed consent and were paid for their time.
258 Experimental procedures were approved by the Vanderbilt University Institutional
259 Review Board.

260

261 **2.1.2. Apparatus.**

262 Stimuli were presented on a CRT monitor in a soundproof, electrically shielded
263 booth. Participants viewed stimuli from approximately 150 cm. Stimuli were
264 generated with Matlab using the Psychophysics toolbox (Kleiner et al., 2007),
265 and responses were collected using a Logitech gamepad. Subjects' EEG was
266 recorded using an SA instrumentation isolated bioelectric amplifier from tin
267 electrodes embedded in a elastic cap (Electro-cap International Inc., Eaton, OH)
268 using the following locations from the International 10/20 system: F3, F4, Fz, C3,
269 C4, Cz, T3, T4, T5, T6, P3, P4, Pz, PO3, PO4, OL (PO7), OR (PO8), O1, O2,
270 along with bipolar HEOG (electrodes placed 2 cm from the outer canthi of both
271 eyes) and bipolar VEOG (electrodes placed 1cm below the lower right eyelid and
272 1cm above the right eyebrow). All electrodes were kept at 4k Ω or lower. The
273 voltages were amplified 20,000 times, digitally sampled at 250Hz, using the right
274 mastoid as an online-reference and re-referenced offline to the average of the left
275 and right mastoids.

276



277

278 Figure 1. A. Depiction of the task structure used in Experiments 1, 2, and 3.

279 Stimuli are not drawn to scale but drawn to maximize stimulus discriminability.

280 Stimuli on search displays were positioned at twice the eccentricity from fixation

281 of the cues. Examples in lower panels all provide two possible search displays in

282 a run of negative-cue repetitions, given a green cue (as pictured in the upper

283 panels).

284

285 **2.1.3. Stimuli and procedure.**

286 Stimuli presented on each trial consisted of five displays, all with a uniform gray

287 background (27 cd/m²). The first display indicated which of the two upcoming,

288 lateralized stimuli would be the trial's cue color. This was indicated using two

289 arrowheads facing left (“<<”) or right (“>>”), centered on the screen, 0.5° width
290 and 0.15° height, lasting a variable interval between 1000ms and 1400ms.
291 Following the offset of this screen, a fixation display was presented for 1000ms
292 containing a central “+” symbol, 0.15° width and height. The cue display
293 appeared next for 100ms, which showed two line-drawn circles centered 1.5° to
294 the left and right of fixation. The color of these circles was randomly selected
295 from four colors: green ($x = .282, y = .586, Y = 44 \text{ cm/m}^2$), red, ($x = .631, y =$
296 $.328, Y = 17 \text{ cm/m}^2$), cyan ($x = .209, y = .310, Y = 41 \text{ cm/m}^2$), and yellow ($x =$
297 $.400, y = .500, Y = 44 \text{ cm/m}^2$), with the constraint that the two circles could never
298 be the same color. They had a diameter of 0.63° and a thickness of 0.1° . On
299 positive search blocks, participants were instructed that the target in the search
300 display would be the cued color. On negative search blocks, participants were
301 instructed that the target in the search display would be whichever color in the
302 search display was not the cued color. Following the cue display a fixation
303 display was again presented for 900ms. Lastly, participants were shown a search
304 display. Search displays were made up of four Landolt C stimuli, the same
305 dimensions as the cues, presented 3° to the left, right, top, and bottom of fixation,
306 with gaps of 0.2° . Two of these Landolt C’s had vertical gaps (distractors) and
307 two of the Landolt C’s had horizontal gaps (potential targets). One of each of
308 these Landolt stimuli appeared in two possible colors: the cued color and a non-
309 cued color, which could vary between all of the three non-cued colors. This
310 meant that participants needed to know the cued color in order to provide a
311 correct response. In this way, we ensured that any differences between positive

312 and negative search performance would not be due to a difference in the
313 strategic use of templates (Becker, Hemsteger, & Peltier, 2016; Carlisle & Nitka,
314 2019; Conci, et al, 2019), that is, the choice to simply look for a sole target (left or
315 right facing Landolt-C) irrespective of its color. Search displays were presented
316 for 2000ms or until a response was collected. Subjects responded by pressing
317 one of the two response buttons to signal their decision (the leftmost and
318 rightmost buttons on a Logitech gamepad, indicating left target gap and right
319 target gap, respectively). The next trial began immediately after the search trial
320 offset from the previous trial. Participants were instructed to maintain fixation at
321 the fixation cross at all times, and to blink only in the period between their
322 response and the onset of the following cue display.

323

324 Participants each completed six blocks of 360 trials within an experimental
325 session, which lasted approximately three hours, not including EEG setup. An
326 experimental session consisted of three positive cue (attend) blocks and three
327 negative cue (ignore) blocks, which were completed in an alternating fashion.
328 Half of participants completed a positive cue block first, and half completed a
329 negative cue block first. Following the design of Carlisle, Arita, Pardo, &
330 Woodman (2011)'s third experiment, trials were structured so, within a block, that
331 the same cue color would repeat for three, five, or seven trials before changing.
332 For each cue-repetition trial, the non-cued color could change on every trial, and
333 matched the non-cued search set at chance levels (33%, given that there were
334 always three potential non-target colors). Likewise, the non-cued search color

335 (i.e., the non-target color on positive cue blocks and the target color on negative
336 cue blocks) could change on any given trial. Participants were instructed verbally
337 with a visual aid depicting sample trials for each block type. Before beginning
338 their first recorded block, participants practiced trials of whichever block they
339 were to do first until they were comfortable with the task and were able to
340 maintain fixation and control their blinks, as indicated by experimenter
341 observation of the EOG during practice trials and by participant self-report.
342 During this time, verbal feedback on eye control was given by the experimenter
343 as deemed necessary to encourage fixation and proper blink timing (between
344 trials). Once eye control and trial completion became satisfactory, the participant
345 was invited to begin the first block, or to continue practicing. Experimental blocks
346 began when participants elected to start.

347

348 **2.1.4. EEG analysis.**

349 Continuous EEG data for each participant were sorted into epochs locked to the
350 onset of the cue on each trial, beginning 200ms before the onset of cue displays
351 until 1000ms following the onset of the cue display. EEG was baseline corrected
352 by subtracting the mean of 200ms period before each stimulus onset. Artifacts
353 were identified and rejected using a two-step procedure based on Woodman and
354 Luck (2003). Time windows with differences exceeding threshold values were
355 rejected (mean thresholds across subjects were $71\mu\text{v}$ for blinks and $25\mu\text{v}$ for
356 saccades, with thresholds set individually for each subject) as were individual
357 electrodes on trials with amplifier saturation or whose voltage exceeded $\pm 75\mu\text{v}$.

358 Averaging across participants and CDA electrode, the resulting number of trials
359 remaining after exclusions was 178, 180, 303, and 242 for the 4 repetition bins
360 (1, 2, 3:4, 5:7, respectively) in the positive cue condition, and 167, 171, 286, and
361 228 for the 4 repetition bins in the negative cue condition. Finally, EEG data were
362 algebraically re-referenced to the average of the left and right mastoids (Luck,
363 2005). Filtered ERPs were also calculated from the overall EEG time series, low-
364 pass filtered at 30hz, and we used these data to plot results. Mean amplitude
365 measurements were calculated using unfiltered data.

366

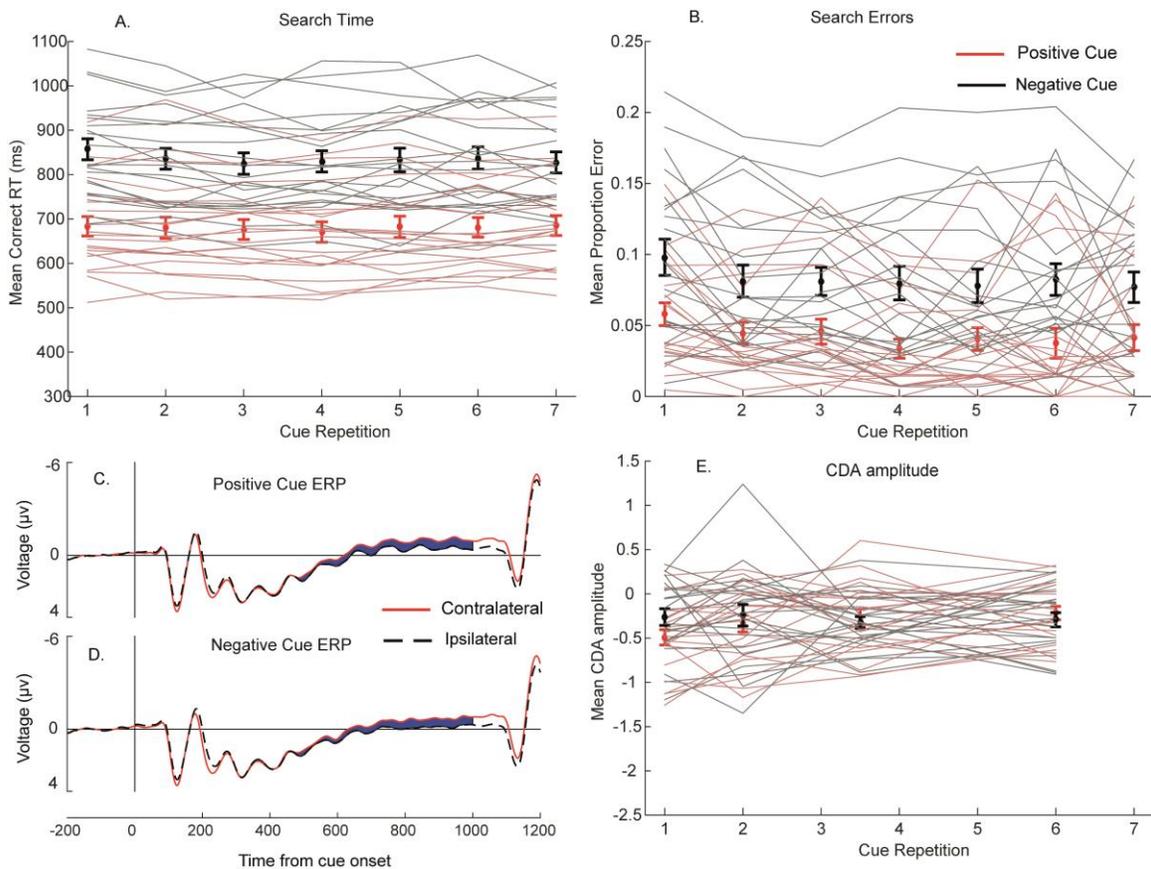
367 Our analysis focused on the contralateral delay activity, or CDA (Vogel &
368 Machizawa, 2004), elicited by the cue to measure the use of visual working
369 memory in representing the cue as a template. The CDA was measured as the
370 mean amplitude between 300 and 1000ms after cue onset (Vogel & Machizawa,
371 2004) at O1/O2, PO3/PO4, OL/OR, and T5/T6 (Carlisle, et al., 2011). ERPs were
372 calculated only for trials where a correct response was given, and on trials with
373 no identified saccades or blinks.

374

375 **2.2. Results**

376 Consistent with previous reports, mean reaction time (RT, see Figure 2, panel A)
377 was faster following positive cues than negative cues, $F(1, 20) = 378.82$, $p <$
378 $.001$, $\eta^2_p = 0.95$. Response times declined over cue repetitions, $F(6, 120) = 3.54$,

379 $p = .003$, $\eta^2_p = .15$. Cue type and repetition did not interact, $F(3.72, 74.4)^1 = 2.18$,
 380 $p = .08$, $\eta^2_p = .10$. The same was true of error rate, with fewer errors for positive
 381 than negative cues, $F(1, 20) = 45.37$, $p < .001$, $\eta^2_p = 0.69$, and a decline in error
 382 rate over cue repetition, $F(3.46, 69.12) = 3.91$, $p = .009$, $\eta^2_p = .16$. Cue type and
 383 repetition did not interact, $F(3.69, 73.74) = 0.40$, $p = .80$, $\eta^2_p = .02$. As can be
 384 seen in Figure 2, however, the reduction in RT was modest.
 385



386

387 Figure 2. Results from Experiment 1. Panels A and B depict behavioral data
 388 (search time and error rate, respectively; error bars show one SEM; lines are
 389 individual participants), Panels C and D show contralateral and ipsilateral grand-

¹ Greenhouse-Geisser corrections are reported throughout where sphericity assumptions were violated.

390 average ERPs to the cues for positive and negative cues, respectively
391 (differences in the CDA epoch filled in blue), and panel E depicts averaged CDA
392 amplitude (error bars show one SEM; lines are individual participants).
393
394 Having verified that negative cues indeed led to poorer search performance in
395 our task, we asked whether both positive and negative cues were stored in
396 working memory in the same way. To assess whether participants prepare for
397 search differently when given a positive versus a negative cue, we analyzed cue-
398 locked CDAs. For both positive and negative cue trials, we observed a cue-
399 locked CDA, $F(1, 20) = 25.38$, $p < .001$, $\eta^2_p = 0.56$, with no differences in
400 amplitude due to cue type, $F(1, 20) = 0.92$, $p = .35$, $\eta^2_p = 0.04$. This shows that
401 participants simply stored the color of the cue in working memory regardless of
402 cue type (see Figure 2, panels C and D). We did not find a systematic change in
403 the CDA over cue repetitions, $F(3, 60) = 0.95$, $p = .42$, $\eta^2_p = 0.05$, suggesting
404 that participants tended to rely on working memory-based templates across
405 repetitions. Considering the type of cue (positive or negative) in this interaction
406 did not provide support for an effect of repetition on the CDA either, $F(2, 60) =$
407 2.14 , $p = .11$, $\eta^2_p = .10$. Thus, the results suggest that the cued object is held in
408 visual working memory regardless of whether the cue indicates an item to-be-
409 attended, or to-be-ignored.

410

411 **2.3. Discussion**

412 Experiment 1 demonstrated that both positive and negative cues were held in
413 working memory, as measured by the CDA. Although participants could have
414 recoded the negatively cued color into the remaining three colors, or even
415 suppressed the cued color (i.e., creating an inhibitory tag for the cued feature,
416 manifesting as a Pd; Sawaki, Geng, & Luck, 2012), their strategy was to simply
417 remember the single color they would either attend or ignore later.

418 Before we push the apparent tendency of participants to remember the
419 items they were supposed to ignore, we wanted to address some additional
420 analyses that we performed on the data from Experiment 1. Specifically,
421 informed readers may be aware of previous work suggesting that when the
422 searched for target remains the same across trials, that people exhibit faster RTs
423 when performing search, their CDA component appears to disappear, and frontal
424 components indexing long-term memory appear to systematically change (e.g.,
425 Reinhart & Woodman, 2015). Above we showed that in Experiment 1, we
426 observed a significant speeding in RTs across target repetitions, but did not see
427 the CDA component decrease in amplitude across these repetitions. The anterior
428 P1 (or P170) showed the same pattern as the CDA, in that it was insensitive to
429 the repetition of targets (Fz, 180ms – 220ms post-stimulus measurement
430 window), $F(3, 60) = 1.69, p = .18, \eta^2_p = .08$. And to preview our subsequent
431 experiments, we did not find significant effects of repetition on the anterior P1 in
432 Experiment 2, $F(3, 66) = 0.18, p = .91, \eta^2_p = .008$, or Experiment 3, $F(3, 57) =$
433 $1.55, p = .21, \eta^2_p = .08$, either. Although it is a tangent to the current question of
434 how negative and positive information is handled to guide attention, these

435 learning-related findings suggest that subjects may have control over whether
436 they use long-term memory or working memory to guide attention during visual
437 search (Reinhart, McClenahan, & Woodman, 2016).

438

439

3. Experiment 2

440 In Experiment 2, we pursued the question of whether participants would ignore
441 negative cues if the target color was largely predictable. In Experiment 1, only the
442 target color (in the positive cue condition) and the distractor color (in the negative
443 cue condition) would repeat for a short run of trials within each block. In
444 Experiment 2, each run of trials involved repetition of both the target and
445 distractor colors in every search display for both cue conditions. This meant that
446 participants could potentially learn to ignore negative cues and instead use their
447 memory of the previous trial's target color as a positive template once they had
448 completed the first trial of a given run. If participants elect to ignore negative cues
449 when they can predict a target's color, then we should observe equivalent search
450 performance and ERPs in the two cue conditions on later trials in a run, and a
451 large drop in the CDA in the negative cue condition over repetitions of cue colors,
452 as participants opt not to represent the to-be-ignored color in working memory.
453 Instead, if participants rely on negative cues instead of memory for the previous
454 trial's color, Experiment 2 should replicate the results of Experiment 1.
455

456 Experiment 2 was identical to Experiment 1 with one exception. In the negative-
457 cue condition, runs of trials where the cue color repeated also involved
458 repetitions of whatever target color was used (e.g., if the cue signaled a non-red
459 target and the target was blue on that trial, the same was true for the two, four, or
460 six cue repetition trials that followed). This is invited the potential for subjects to
461 not waste working memory capacity on representing the negative cues and rely
462 on target-color memory instead for search guidance. All other aspects of the
463 experiment were the same.

464

465 **3.1. Method**

466

467 **3.1.1. Participants.**

468 Thirty-one volunteers from the Vanderbilt participant pool participated in
469 Experiment 2. None of these participants had been in Experiment 1. Eight
470 participants' data were excluded, for the same reasons laid out in Experiment 1
471 (mean of 8.8% trials excluded for ocular artifacts and a mean of 94% accuracy in
472 remaining participants). All participants provided informed consent before
473 participating.

474

475 **3.1.2. Apparatus, stimuli, procedure, and EEG analysis.**

476 All methods were identical to Experiment 1 save for one difference. For each trial
477 in a run of repeated cues, both the target color and the non-target color repeated
478 in search displays. This ensured that the color of the object that participants

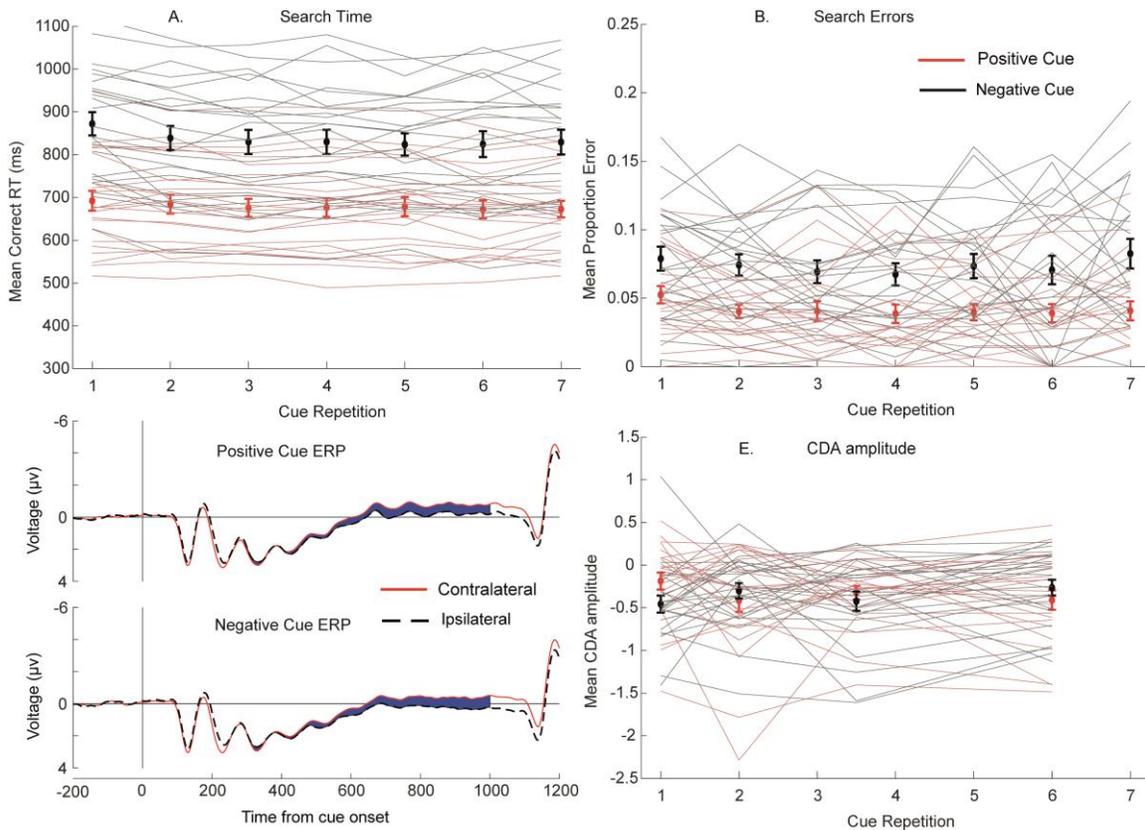
479 ultimately selected and responded to on each trial in a run repeated in both the
480 positive and negative search conditions, and allowed the target's color to be
481 largely predictable in negative-cue blocks. The mean VEOG threshold across
482 subjects was $62\mu\text{v}$ and mean HEOG threshold was $27\mu\text{v}$. Averaging across
483 participant and CDA electrode, the average number of trials remaining after
484 exclusions was 179, 182, 304, and 242 for each repetition bin (1, 2, 3:4, 5:7,
485 respectively) in the positive cue condition, and 172, 174, 290, and 233 for each
486 repetition bin in the negative cue condition.

487

488 **3.2. Results**

489 Despite the opportunity for recoding during the runs in Experiment 2's design,
490 participants still performed better in the positive-cue condition (Figure 3, panel A).
491 Mean correct RTs were faster in the positive-cue condition, $F(1, 20) = 149.03$, p
492 $< .001$, $\eta^2_p = .87$, and declined over cue repetitions, $F(3.85, 84.76) = 9.44$, $p <$
493 $.001$, $\eta^2_p = .30$. The decline was more pronounced for the negative-cue condition,
494 as indicated by an interaction between cue type and repetition, $F(6, 132) = 2.47$,
495 $p = .027$, $\eta^2_p = .10$. Errors were also lower in the positive than negative-cue
496 condition, $F(1, 20) = 52.13$, $p < .001$, $\eta^2_p = .70$, but did not decline significantly
497 with cue repetition, $F(4.11, 90.48) = 1.77$, $p = .14$, $\eta^2_p = .075$. To behaviorally test
498 whether participants benefitted from target-color repetitions in the negative cue
499 condition, we compared negative-cue performance between Experiments 1 and
500 2. Neither RT, $F(4.50, 188.86) = 1.27$, $p = .28$, $\eta^2_p = .03$, nor error-rate, $F(4.13,$

501 173.30) = 1.04, $p = .39$, $\eta^2_p = .02$, provided any evidence for a benefit of target-
 502 color predictability.



503
 504 Figure 3. Results from Experiment 2. Panels A and B depict behavioral data
 505 (search time and error rate, respectively; error bars show one SEM; lines are
 506 individual participants), Panels C and D show contralateral and ipsilateral grand-
 507 average ERPs to the cues for positive and negative cues, respectively
 508 (differences in the CDA epoch filled in blue), and panel E depicts CDA amplitude
 509 in the four cue repetition bins (error bars show one SEM; lines are individual
 510 participants).

511

512

513 As in Experiment 1, we again found a CDA, $F(1, 22) = 18.27, p < .001, \eta^2_p =$
514 0.45 , that did not interact with cue type $F(1, 22) = 0.37, p = .55, \eta^2_p = 0.017$. This
515 provides strong evidence that even when the target color was predictable,
516 negative cue colors were simply maintained in working memory like positive cue
517 colors. While the CDA overall did not reduce as a function of repetitions, $F(3, 66)$
518 $= 0.39, p = .76, \eta^2_p = .017$, the cue-repetition effect on the CDA marginally
519 differed as a function of cue type, $F(3, 66) = 2.63, p = .057, \eta^2_p = .11$. As can be
520 seen in Figure 3, this interaction is driven by the smaller CDA in the positive cue
521 condition than the negative condition on the first cue repetition. While this could
522 be taken to indicate greater reliance on visual working memory for new, negative
523 templates, it instead appears that it is the positive-cue CDA that is unusually
524 small early on. Separate repeated-measures ANOVAs for positive and negative-
525 cue conditions that included only the early (repetition 1) and late (repetitions 5-7)
526 bins substantiated this impression: for the negative-cue CDA, the CDA was
527 larger early than late, $F(1, 22) = 4.55, p = .044, \eta^2_p = .17$, but the positive-cue
528 CDA was smaller early than late, $F(1, 22) = 5.42, p = .029, \eta^2_p = .20$. While an
529 unusual pattern, it is important to emphasize that it is entirely inconsistent with
530 the prediction that repeating target colors would allow strategic avoidance of
531 visual-working-memory-based negative templates later in a run of searches. In
532 sum, neither the CDA nor response times provided evidence that being able to
533 predict the target's color in the negative condition led participants to rely less on
534 visual-working-memory-based negative templates. Instead, both positive and
535 negative cue colors remained in working memory.

536 **3.3. Discussion**

537 The results of Experiment 2 showed that even when the target color could be
538 predicted on a majority of trials, participants held colors that they needed to
539 ignore in working memory, as evidenced by the CDA in the negative cue
540 condition. This predictability of target colors did not improve performance
541 following negative cues, consistent with a lack of relying on their memory of
542 target features. Although recoding was possible in Experiment 2, it would have
543 relied on an internal representation of the target's color, as well as recognition of
544 the cue repetition. Given that positive cues are more effective than negative
545 cues, it was surprising that participants did not adopt a strategy of relying on their
546 memory for recent target features. In Experiment 3, we provided participants both
547 negative and positive cues in advance of each search to test whether participants
548 would rely on positive and negative cues equally, or whether they would choose
549 to only rely on positive cues.

550

551 **4. Experiment 3**

552

553 In Experiment 3, we used the same task and instructions as Experiments 1 and
554 2, but provided both the target and distractor colors in each cue display. That is,
555 we fully equated visual presentation sequence of the positive-cue and negative-
556 cue conditions by using the same colors for all cue and search displays within a
557 given run of trials. We did this by reliably pairing target and non-target colors in
558 the search displays (as in Experiment 2) *and* in the cue displays as well. In other

559 words, the non-cued color in each negative cue display reliably predicted the
560 target color in that subsequent search display, and the non-cued color in each
561 positive display predicted the distractor color. This allowed us to test whether
562 participants preferentially form positive templates when both types of information
563 are available. Although we instructed participants that the cued color would show
564 them the to-be-ignored color on negative blocks, we anticipated that they could
565 learn that the non-cued color was always the target color. If it is the case that
566 positive search is a cognitively simpler process than negative search (Carlisle &
567 Nitka, 2018; Clark & Chase, 1972; Rajsic, Wilson, & Pratt, 2015) then
568 participants might instead encode the *non*-cued color in the negative-cue
569 condition, which would reverse the CDA's polarity. On the other hand, if
570 participants simply encode the cue they are informed about, Experiment 3's
571 results should look just like Experiments 1 and 2. Alternatively, if participants
572 encoded both positive and negative colors, the two CDAs would cancel out and
573 we would observe no CDA.

574

575 **4.1. Method**

576

577 **4.1.1. Participants.**

578 Twenty-five volunteers from the Vanderbilt community participated in Experiment
579 3. Three of the participants had participated in Experiment 1, but at least two
580 months elapsed between sessions, and participants did not recall the details of
581 the earlier session when asked. Five participants were excluded for exceeding

582 artifact criteria described in Experiment 1 (mean of 91% trials remaining after
583 rejecting ocular artifacts for included participants, mean of 94% accuracy in
584 included participants).

585

586 **4.1.2. Apparatus, stimuli, procedure, and EEG analysis.**

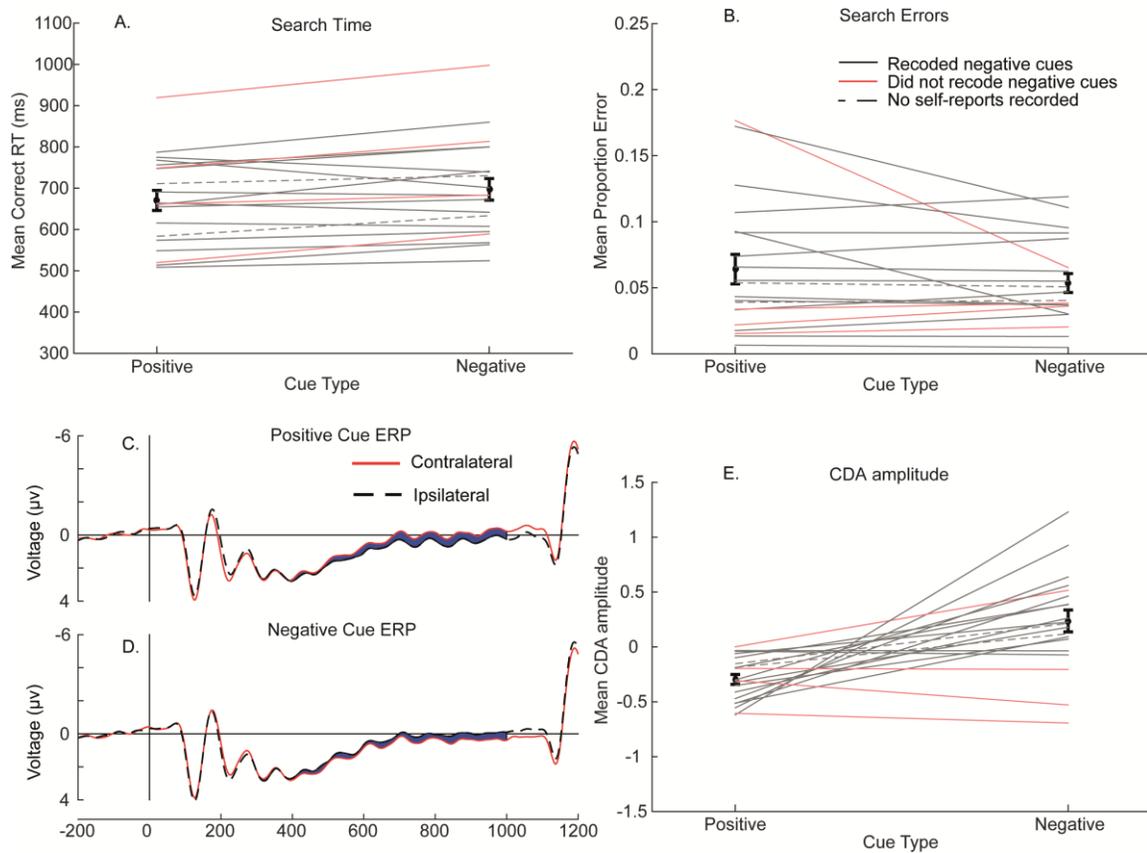
587 All apparatus, stimuli, procedure, and analysis were identical to Experiment 2
588 except as follows. On each trial, in both positive and negative cue blocks, search
589 displays were constrained to include the same two colors shown in the cue
590 display for that trial. Specifically, on positive cue trials, the cued color would be
591 the target color on that trial and the uncued color (in the hemifield the central
592 arrows pointed away from) would be the distractor color. The opposite was true
593 on negative trials. The cued color was used for the distractor objects, and the
594 uncued color was used for the target objects. The mean VEOG threshold across
595 participants was $65\mu\text{v}$ and the mean HEOG threshold was $26\mu\text{v}$. Averaging
596 across participant and CDA electrode, the number of trials remaining after
597 exclusions was 175, 178, 297, and 240 for each repetition bin (1, 2, 3:4, 5:7,
598 respectively) in the positive cue condition and 180, 184, 302, and 243 for each
599 repetition bin in the negative cue condition.

600

601 **4.2. Results**

602 Showing both the target and non-target color almost completely equated the
603 positive and negative cue conditions. Mean response time (see Figure 4A) for the
604 positive cue condition were still faster, than for the negative cue condition, $F(1,$

605 19) = 7.85, $p = .01$, $\eta^2_p = .29$. While different, the magnitude of the difference is
606 considerably smaller than Experiment 1 and 2, as shown by an experiment X cue
607 type interaction, $F(2, 61) = 50.23$, $p < .001$, $\eta^2_p = .62$. For perspective, the
608 negative cue condition was 155ms slower than the positive cue condition in
609 Experiment 1, 157ms slower than the positive cue condition in Experiment 2, but
610 only 26ms slower than the positive cue condition in Experiment 3. Response time
611 did not reduce as a function of cue repetitions, $F(6, 114) = 0.46$, $p = .83$, $\eta^2_p =$
612 0.02. No difference in error rate was found between the positive cue and
613 negative cue conditions, $F(1, 19) = 1.54$, $p = .23$, $\eta^2_p = 0.08$, but error rate did
614 reduce with cue repetition, $F(3.28, 62.22) = 7.23$, $p < .001$, $\eta^2_p = .28$.
615



616

617 Figure 4. Results from Experiment 3. Panels A and B depict behavioral data
 618 (search time and error rate, respectively; error bars show one SEM; lines are
 619 individual participants), Panels C. and D. show contralateral and ipsilateral
 620 grand-average ERPs to the cues for positive and negative cues, respectively
 621 (differences in the CDA epoch filled in blue), and panel E depicts averaged CDA
 622 amplitude (error bars show one SEM; lines are individual participants). For
 623 panels A, B, and E, participant data are visually coded according to their reported
 624 strategy (see legend in panel B).

625

626 Most dramatically, the polarity of the CDA reversed in the negative cue condition,
627 such that we observed an interaction between cue condition and laterality, $F(1,$
628 $19) = 21.07, p < .001, \eta^2_p = 0.53$, with no main effect of laterality, $F(1, 19) = 0.56,$
629 $p = .46, \eta^2_p = 0.029$. To be sure, the positive cue CDA was different from zero,
630 $F(1, 19) = 47.61, p < .001, \eta^2_p = 0.72$, and so was the polarity-reversed, negative
631 cue CDA, $F(1, 19) = 5.02, p = .037, \eta^2_p = 0.21$. To check whether the positive
632 cue and negative cue CDAs were of similar amplitudes, we multiplied the
633 negative-cue amplitudes by -1 and checked for an interaction with laterality. No
634 such interaction was present, $F(1, 19) = 0.56, p = .46, \eta^2_p = 0.03$, suggesting that
635 participants nearly fully relied on the non-cued color in the negative cue
636 condition. Consistent with response times, the CDA amplitude did not change as
637 a function of cue repetitions, $F(3, 57) = 1.35, p = .27, \eta^2_p = .07$. The CDA was
638 largest at OL/OR, $F(1.72, 32.66) = 3.25, p = .028, \eta^2_p = .15$, but was larger at
639 T5/T6 for negative compared to positive cues, $F(2.15, 40.93) = 7.79, p = .001, \eta^2_p$
640 $= .29$.

641 The CDA reversal (Figures 4C, D, E) shows that when participants were
642 always shown what they would later attend opposite what they were cued to
643 ignore, they preferred to instead encode what color they would later attend into
644 working memory. Informal conversations following the experiment confirmed this
645 result, with the clear majority of those participants asked about strategy (14 out of
646 18) verbally reporting that they chose to remember the uncued color in negative
647 cue blocks. As can be seen in Figure 4E, the CDA for the participants who
648 reported no strategic selection of positive cues on negative cue blocks (plotted in
649 red) tended to be negative in the negative-cue condition, supporting this
650 distinction. Indeed, when only the participants reporting recoding are included in
651 the analysis, the small difference between positive and negative cues in RT is no
652 longer evident, $F(1, 13) = 1.69$, $p = .22$, $\eta^2_p = 0.12$.

653

654 **4.3. Discussion**

655 In Experiment 3, we found that when participants were given access to both
656 target and distractor color information prior to search, most chose to encode only
657 the positive cue information, even when they were told to use the negative cue in
658 negative cue blocks. This suggests that, when equally available, searchers
659 prefer to rely only on positive information instead of negative information, or both
660 kinds of information. However, since Experiment 3 did not have a condition in
661 which only positive or negative cues were provided, it is not possible to be sure
662 that negative information was not also used, but to a lesser extent than positive
663 information.

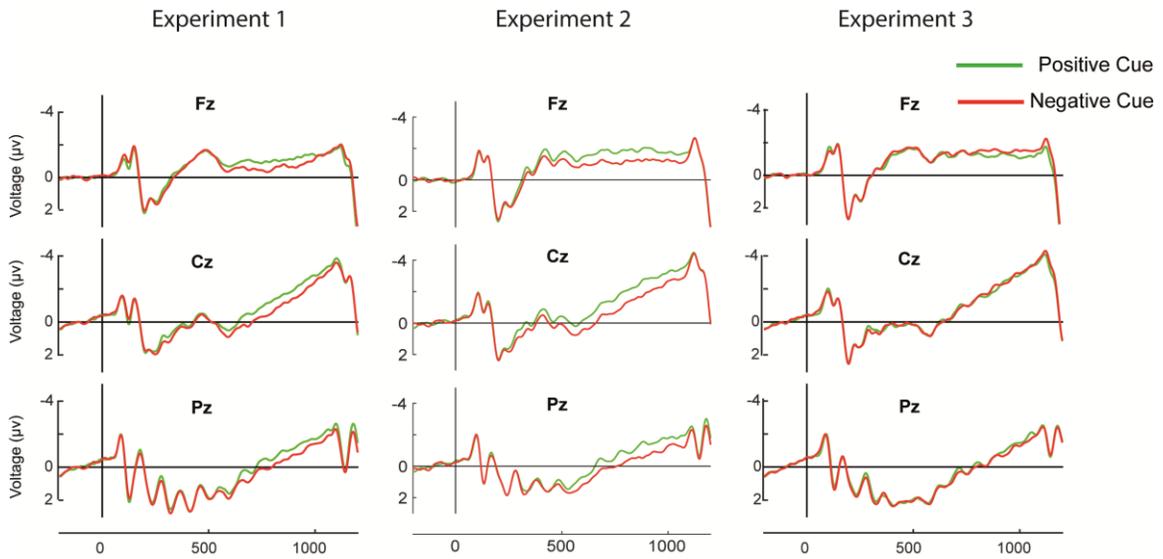
664 **5. Midline ERPs discriminate positive from negative cues**

665 As a brief summary, Experiments 1 and 2 showed that our ERP measure
666 of visual working memory storage (the CDA) did not discriminate between
667 positive and negative cues despite the rather large difference evident in response
668 times and error rates. Only when participants were given the opportunity to
669 selectively encode cues (Experiment 3) did we observe a difference in how visual
670 working memory was used to store these cues. Although we designed our
671 experiment to look at this established marker of template preparation (Carlisle, et
672 al., 2011), the experimental design also provided an opportunity to look for other
673 possible electrophysiological markers of the negative-cue disadvantage (or
674 positive-cue advantage).

675 Previous investigations have found that midline ERPs can distinguish
676 between how different search tasks employ identical cues. Gunseli, Olivers, &
677 Meeter (2014; Gunseli, Meeter, & Olivers, 2014) have found that more difficult
678 target discriminations lead to more positive, sustained voltage shifts over central
679 and parietal electrodes (the LPC), which they have interpreted as the amount of
680 effort devoted to maintaining a representation in visual working memory. More
681 closely related to the present experiment, Kawashima and Matsumoto (2016)
682 found that the P3b elicited by a to-be-remembered cue was larger when it reliably
683 predicted the colour of the search target in an intervening search.

684 To see whether these components might provide a clue as to whether
685 differences in positive and negative search might be partially explained by
686 differences in cue processing, we computed midline ERPs time-locked to the cue
687 for Experiment 1 – 3. Based on previous reports we computed average amplitude
688 for Fz, Cz, and Pz in the 275-375ms time range (P3: Kawashima and
689 Matsumoto, 2016) and in the 475-700ms time range (LPC: Gunseli, Olivers, &
690 Meeter, 2014; Gunseli, Meeter, and Olivers, 2014). In both Experiments 1 and 2,
691 where negative information needed to be stored on negative blocks, a sustained
692 midline ERP can be seen (see Figure 5). In Experiment 1, there were no cue-
693 related effects in the P3 range, $F_s < 2.06$, $p_s > .11$, $\eta^2_p s < .10$, but a marginally
694 different LPC, $F(1, 20) = 3.26$, $p = .09$, $\eta^2_p = .14$. In Experiment 2, both the P3,
695 $F(1, 22) = 6.73$, $p = .017$, $\eta^2_p = .23$, and the LPC, $F(1, 22) = 12.39$, $p = .002$, η^2_p
696 $= .36$, were more positive in the negative cue condition overall². Importantly, in
697 Experiment 3, when the CDA results suggested that only positive information
698 was stored, these ERP differences vanished. $F_s(1, 57) < 0.10$, $p_s > .76$, $\eta^2_p s \leq$
699 0.005.

² There were also sporadic interactions, but we are wary to over-interpret them. While we use the time-windows from previous studies for consistency, it is important to note that the midline ERP difference is both spatially and temporally broad in both our ERPs and in previously published ERPs. Indeed, computing mean amplitude over a broader, 400-1000ms time window supported the simple, consistent finding of a main effect of cue type and electrode, but nothing else, for Experiments 1 and 2.



700

701 Figure 5. Grand average, midline ERPs for Experiments 1 – 3, time-locked to the
702 appearance of the cue.

703 While we observed a LPC difference between the positive and negative
704 cue conditions, it is not yet clear what cognitive process is indexed by this ERP.
705 Günseli and colleagues (2014) have tended to interpret the LPC as a marker of
706 the amount of effort invested in maintaining a template, given the differences
707 they observed when search difficulty was varied. Intuitively, our findings would fit
708 this explanation. Given that participants chose to use positive cues over negative
709 ones, one could infer that negative templates are more effortful, and therefore
710 aversive (Kool et al., 2010). However, this side steps the question of what
711 cognitive process is marked by the LPC. It may also be that this ERP reflects a
712 change in the contingent negative variation (CNV), which reflects preparatory
713 processes in the period leading up to a target. Indeed, spatial cuing studies have
714 found a similar sustained, central potential that is more negative when cues are
715 spatially informative (Talsma, Slagter, Nieuwenhuis, Hage, & Kok, 2005; Wright,
716 Geffen, & Geffen, 1995) and more negative for spatial cues when targets must
717 be identified rather than localized (Eimer, 1993).

718 Given the breadth of potential interpretations of this component, it is
719 premature to draw conclusions about what it may tell us about positive and
720 negative templates. Nonetheless, it does provide evidence that the cognitive
721 representation of positive and negative templates does differ beyond visual
722 working memory, as measured by the CDA. As such, it may not be simply the
723 case that the difference between positive and negative search can be solely
724 explained as the result of memory-driven attention (see the General Discussion).
725

726

6. Experiment 4

727

728 The electrophysiological results of Experiment 3 suggest that participants largely
729 chose to use positive cues instead of negative cues when both positive and
730 negative information were provided before search. While the CDA results imply
731 that the positive, but not the negative, colors were encoded, it is difficult to rule
732 out the possibility that negative colors were encoded, but to a lesser extent. To
733 do so, we would need to compare search with both positive and negative cues to
734 search with only positive cues, to see if the additional negative information
735 produces any extra benefits. Fortunately, N.B.C had independently conducted a
736 behavioral experiment with this pair of conditions. If cues with both positive and
737 negative information improve search time compared to cues with only positive
738 information, then negative information is clearly being incorporated into the
739 template, but if they do not, then one can conclude that only positive information
740 is stored as a template.

741

6.1. Method

743

6.1.1. Participants.

745 Twenty-five participants were recruited from Lehigh University's Participant pool.
746 Five participants were replaced for search accuracy in one or more conditions
747 that was 2 standard deviations below the mean. The mean age of the final

748 sample was 19, and there were 12 females in the sample. All participants gave
749 informed consent, and the procedures were approved by Lehigh University's IRB.

750

751 **6.1.2. Stimuli.**

752 Stimuli were presented using Matlab (Kleiner et al., 2007) and viewed from
753 approximately 105 cm. Trials began with a central fixation dot (0.3°) on a gray
754 background. After 500 ms, a color cue (1.2°) was presented via a filled circle for
755 150ms. Positive cues indicated the color of the upcoming target and were
756 presented 1.2° below the fixation dot. Negative cues indicated the color of the
757 upcoming distractors and were presented 1.2° above the fixation dot. Neutral
758 cues were presented surrounding the fixation dot. A 500ms fixation screen was
759 presented before the 12- item visual search array of Landolt-Cs (1.2°) was
760 presented on an imaginary circle (5.2° radius) centered on the fixation dot (see
761 Figure 1). On each trial, two colors were randomly selected for the search array
762 from red, green, blue, magenta, orange, and cyan. All items in one hemifield
763 shared one color. The target Landolt-C had a gap ($.2^\circ$) opening facing the top
764 (0°) or bottom (180°). Each distractor had a gap facing 45° , 90° , 135° , 225° ,
765 270° , or 315° . The search array remained on the screen until response (or for a
766 maximum of 3500 ms).

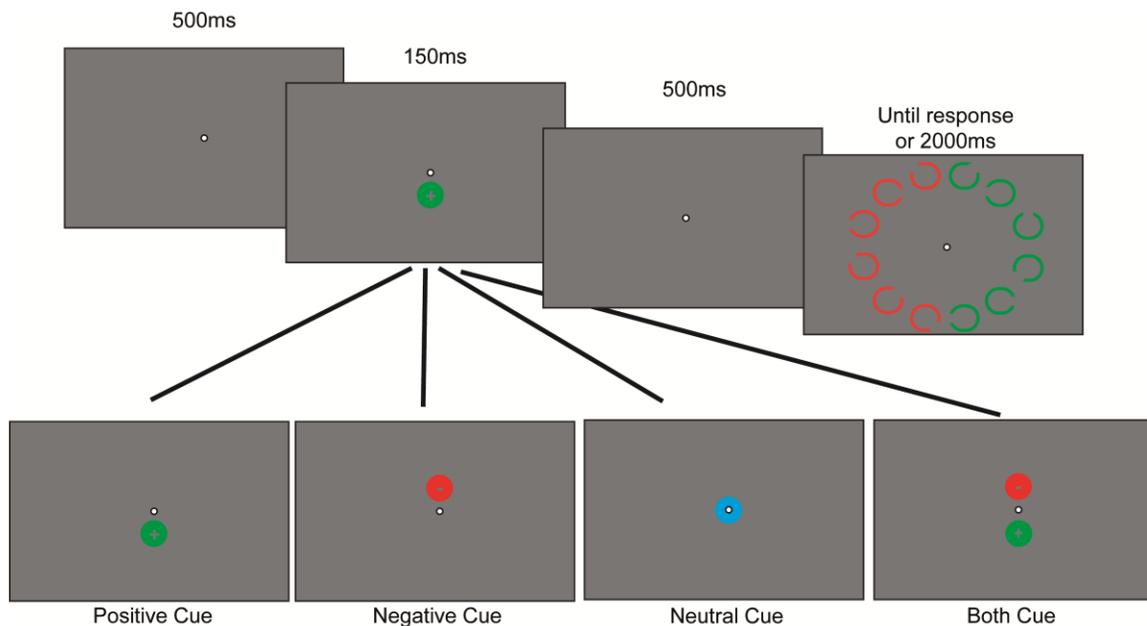
767

768 **6.1.3. Procedure.**

769 All participants completed four blocks of trials, where the meaning of the cue was
770 held the same throughout a block. In positive cue blocks, the cue indicated the

771 color of the upcoming target. In negative cue blocks, the cue indicated the color
772 of the upcoming distractor. In neutral cue blocks, the cued color would not
773 appear in the search array. Finally, in both cue blocks, participants received both
774 a positive and a negative cue. They were instructed to use both cues to aid in
775 performance in finding the target. For each condition, participants received
776 verbal and visual instructions and performed a practice block of 8 trials.
777 Participants could repeat the practice trials if they were not comfortable with the
778 task. Then participants completed the experimental block of 72 trials with breaks
779 including feedback on performance every 18 trials. The instructions, practice and
780 experimental blocks were then repeated for the other conditions. An illustration of
781 a sample trial is presented in Figure 6.

782



783

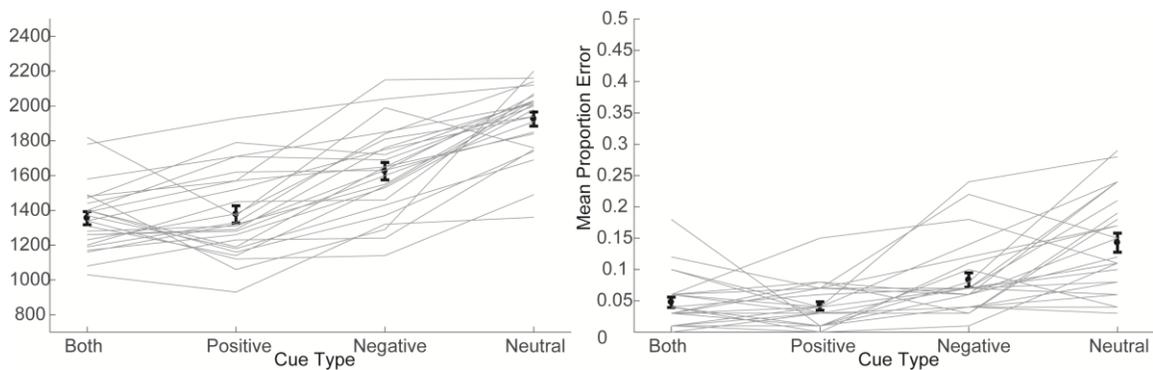
784 Figure 6. A sample trial from Experiment 4 (not drawn to scale). The bottom
 785 panels depict the potential cues that could have been shown in the sample trial,
 786 depending on block.

787

788 6.2. Results

789 As can be seen in Figure 7, providing positive and negative information in cues
 790 before search noticeably improved search performance (RT: $F(3, 72) = 72.34$, p
 791 $< .001$, $\eta^2_p = 0.75$; accuracy: $F(3, 72) = 22.22$, $p < .001$, $\eta^2_p = .48$). Importantly,
 792 although search was again faster, $t(24) = 6.26$, $p < .001$, and more accurate,
 793 $t(24) = 3.71$, $p = .001$, for positive than negative cues, it was no faster or more
 794 accurate ($ps > .61$) with both cues compared to positive cues. This suggests that
 795 participants only rely on positive cues when both positive and negative
 796 information are presented.

797



798

799 Figure 7. Response time (panel A) and error rate (panel B) for each cue type in
 800 Experiment 4. Error bars depict one standard error of the mean, individual lines
 801 depict participant means.

802

803 6.3. Discussion

804 The results of Experiment 4 provide a direct comparison of RT benefits for
805 positive cues, negative cues, and both cues. We replicated the pattern of faster
806 RTs for positive than negative cues shown in our previous experiments, and
807 additionally found that the RT benefits and accuracy benefits for the both
808 condition were not significantly different than the benefits for the positive cue
809 condition. This demonstrates that when both positive and negative information
810 are available, participants prefer to guide their search using only the positive
811 information, and substantiates our interpretation of the CDA results in Experiment
812 3.

835 search condition). Participants were markedly slower at reporting a target in the
836 negative search condition than in the positive search condition (Arita, et al., 2012;
837 Beck & Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2015). Scalp potentials
838 showed that in both cases participants stored the cued colors in working
839 memory, as indicated by a cue-locked CDA. This occurred as well in Experiment
840 2, where the target's color was predictable over short runs of trials and
841 participants could have relied on memory for the previous target's color to create
842 a positive template. However, when cue displays presented both the to-be-
843 attended and to-be-ignored color, participants preferred to rely on the positive
844 cue information in Experiments 3 and 4. Moreover, subjects' brain activity
845 suggests that they elect to encode the to-be-attended color, as demonstrated by
846 a reversal in the CDA's polarity in Experiment 3. This is despite the fact that
847 instructions only communicated to participants that, in negative cue blocks, the
848 cued color would *not* be the target's color. Clearly, the relationship between the
849 non-cued color and the target's color was learned and strategically exploited by
850 most participants. Thus, our final experiments demonstrate that participants will
851 choose to use the more potent positive cue than the negative cue when given the
852 opportunity.

853

854 By providing a direct measure of template formation, our experiments
855 demonstrate that the contents of working memory for positive and negative
856 templates are simply the color shown in the cue. Although selection and inhibition
857 in ERPs of visual attention have been associated with different polarities (Luck &

858 Hillyard, 1994; Sawaki, Geng, & Luck, 2012), the CDA clearly does not code the
859 attentional valence (attend versus ignore) of the information being stored.
860 Recently, de Vries, Savran, van Driel, & Olivers (2019) found that lateralized
861 alpha oscillations likewise do not differentiate between positive and negative
862 templates, implying similar activations of the to-be-attended and to-be-ignored
863 features. Thus, it is simplest to assume that when shown cues that predict either
864 the target or the non-target color, participants simply remember this color and
865 some other process uses information this to compute the attentional valence of
866 the color. The notion that attentional templates consist of separate
867 representations for features and task rules is consistent with broader accounts of
868 working memory that propose separate systems for declarative and procedural
869 aspects of cognitive components of actions (Oberauer, 2002; Oberauer, Souza,
870 Druey, & Gade, 2013; Myers, Stokes, & Nobre, 2017). However, it is nonetheless
871 possible that positive and negative templates rely on distinct populations of
872 neurons within the same cortical areas (e.g., Wallis, Anderson, & Miller, 2001,
873 Reeder, et al., 2017, 2018). Our findings also cast doubt on the possibility that
874 negative templates are less helpful because participants re-code them into the
875 remaining positive set (Becker, Hemsteger, & Peltier, 2016; Beck, Luck, &
876 Hollingworth, 2018). For example, when told not to look for red, one could opt to
877 instead prepare to look for a green, blue, or yellow target. This sort of search
878 would be less efficient due to the multiplicity of potential target colors (Stroud,
879 Menneer, Cave, & Donnelly, 2012). Insofar as the CDA tracks the number of
880 active representations used to guide attention (Carlisle, et al., 2011; Grubert,

881 Carlisle, & Eimer, 2016), our results do not support this possibility. Either the
882 positive, recoded representations rely on a different format than visual working
883 memory, or no such recoding of negative templates occurs. However, this is not
884 to say that recoding could not occur following the onset of the search array,
885 rather than in advance of it (Becker, Hemsteger, & Peltier, 2016). Currently
886 evidence for this possibility is mixed, with ERP findings failing to support a
887 biphasic, seek-and-destroy process (Carlisle, & Nitka, 2019), but eye-tracking
888 findings suggesting early selection of negatively cued features followed by later
889 suppression (Beck, Luck, & Hollingworth, 2018).

890

891 Because negative templates involve active maintenance of the non-target color,
892 a simple explanation of their reduced benefit is memory-driven attentional
893 capture. Previous research has found that while memory-driven capture is
894 reduced or prevented when the contents of memory reliably match distracting
895 information (Carlisle & Woodman, 2011a; Carlisle & Woodman, 2011b;
896 Kiyonaga, Egner, & Soto, 2012), some attentional capture may still occur
897 (Carlisle & Woodman, 2013; Carlisle & Woodman, in press; van Loon, Olmos-
898 Solis, & Olivers, 2017) So while there is more to attentional guidance than the
899 contents of working memory (Downing & Dodds, 2004; Olivers, Peters,
900 Houtkamp, & Roelfsema, 2011; Dube & Al-Aidroos, 2019), having recently stored
901 a feature makes it more difficult to ignore that feature in the future. This bias
902 would help performance for positive cues, but hurt it for negative cues, providing
903 a simple explanation of the positive cue benefit.

904

905 Another factor that may contribute to the positive cue benefit is that, in our task,
906 the negative cue must be actively maintained, because the correct response
907 cannot be given without knowing which color to avoid. In many other negative
908 search studies, negative cues are provided as *hints*, but nothing about the tasks
909 prevented participants from finding the search target without using the cue (Beck
910 & Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2016), as the target has
911 another unique feature (albeit one that is usually less salient, such as Landolt
912 rotation or letter identity). As noted in the introduction, recent research has
913 demonstrated that negative cues are more likely to be used in search tasks
914 where they are strategically beneficial (Carlisle & Nikta, 2019) or that are difficult
915 to complete without guidance from the negative cue (Conci et al. 2019). The
916 same argument holds for memory-driven capture experiments; since search
917 targets are necessarily defined by some other unique feature than the
918 remembered feature, differences in the magnitude of memory-driven capture
919 could be due to strategic changes in whether or not the remembered feature is
920 maintained as part of the search task set. Thus, tasks where the negative cue is
921 necessary for discriminating targets from non-targets may measure a different
922 kind of positive template advantage (or negative template cost) that reflects the
923 cognitive demand of needing to monitor for the presence of a feature that should
924 be avoided (Wegner, 1994; Moher & Egeth, 2012; Huffman, Rajsic, & Pratt,
925 2016). Directly comparing search performance between tasks that require
926 negative templates and tasks that simply provide negative cues would provide a

927 good test of this hypothesis. Indeed, comparing the CDA findings between these
928 conditions may be telling as to how, and when, negative cues are used.
929

930 A reader might object that in our experiments we only used two colors in the
931 search displays and that this may have encouraged strategic recoding that
932 allowed search to be more efficient, especially in light of the fact that participants
933 did choose to encode only positive cues in Experiments 3 and 4 (Beck &
934 Hollingworth, 2015; Becker, Hemsteger, & Peltier, 2016). While this is a
935 possibility, the alternative choice of coloring non-target stimuli heterogeneously is
936 unattractive for different reasons. In some studies of negative search, the cued
937 (and therefore irrelevant) set is drawn in a homogenous color, and the uncued
938 set (and therefore relevant) is then drawn in multiple colors (Kugler, Marius, 't
939 Hart, Kohlbecher, Einhäuser, & Schneider, 2015; Kawashima & Matsumoto,
940 2018; Beck, Luck, & Hollingworth, 2018). While this discourages strategic
941 recoding, it necessarily confounds the positive and negative stimulus subsets
942 with visual heterogeneity. As a consequence, it is inherently unclear whether
943 differences in search efficiency between positive and negative search conditions
944 in such designs reflect difficulties in grouping heterogeneous stimuli (Duncan &
945 Humphreys, 1989), or difficulties in suppressing irrelevant information using top-
946 down control. One possible solution is to cue multiple colors in both negative and
947 positive cue conditions, and present displays with an equal number of cued and
948 uncued colors (see Experiment 2 of Kugler et al., 2015). This ensures that both

949 stimulus subsets (relevant and irrelevant) are heterogeneous, which may
950 discourage recoding.
951
952 In Experiment 3, we found that participants overwhelmingly chose to rely on
953 positive information in both positive and negative blocks. Because the non-cued
954 color always ended up being the target color for negative-cue blocks, participants
955 were clearly able to realize that they could form a template by reversing the
956 arrow-cue. Although this is not a complex strategy to learn, it is noteworthy that
957 we did not allude to it being available when instructing participants, and that
958 participants were explicitly aware of the shift (that is, it was not an implicit bias).
959 Most strikingly, the CDA was able to track this strategy switch, providing a neural
960 correlate of these subjective templates. We interpret this result as an attempt by
961 participants to choose the task strategy that minimized the number of cognitive
962 operations required on each trial (Kool et al., 2010; Pauszek & Gibson, 2018).
963 Across various tasks, negative information is seen to involve additional cognitive
964 steps (Becker, Hemsteger, & Peltier, 2016; Clark & Chase, 1972; Moher & Egeth,
965 2012), and so choosing to rely on positive cues is a cognitive path of least
966 resistance. Cognitive neuroscience is beginning to develop a better
967 understanding of how cognitive effort is computed and minimized (Shenav et al.,
968 2017), and our results suggest that the CDA provides a viable neural correlate of
969 the information that participants choose to rely on during tasks. A preference for
970 cues that allow for a visual matching strategy fits with related arguments
971 suggesting the concept of sameness is somehow cognitively fundamental

972 (Hochmann, Mody, & Carey; 2016; Zentall, Andrews, & Case, 2018). Relatedly, it
973 is surprising that we did not observe a decline in the CDA as expected when
974 cues repeated (Carlisle, et al., 2011). It is not clear why this is the case, though
975 the present experiments differed from previous experiments in several ways. We
976 used highly discriminable colors as cues (compared to Landolt Cs and
977 photographs of objects: Carlisle et al., 2011; Reinhart & Woodman, 2015;
978 Servant, Cassey, Woodman, & Logan, 2017), and the cues displayed a feature
979 that needed to be attended, but not reported, which could exhibit less learning
980 (Olivers & Meeter, 2006).

981

982 Finally, it is worth considering whether the advantage for positive cues is merely
983 a consequence of visual priming (Awh, Belopolsky, & Theeuwes, 2012). As we
984 discussed earlier, our results are consistent with a strategic, memory-driven
985 capture account. That is, participants choose to do the task in such a way that
986 they can take advantage of their memory for the cue color. However, on the
987 basis of these results alone we cannot determine whether the critical component
988 of the positive template advantage is in knowing the target's color or actually
989 having that color stored in visual working memory. While we do not yet have an
990 answer to this question, the literature on memory-driven capture may provide
991 some indication. Kawashima and Matsumoto (2017) compared the magnitude of
992 memory-driven capture when the contents of working memory were either a
993 visual code (i.e., remember a particular colored square) or a verbal code (i.e.,
994 remember the word "red"). The authors varied the probability that either a target

995 or distractor would match the feature held in memory. They found that both
996 remembered codes led to memory-driven capture (see also Soto & Humphreys,
997 2007; Beck, Luck, & Hollingworth, 2018), and that memory driven capture was
998 weaker for both when distractors were more likely to match memory than the
999 target. While this could reflect strategic changes in the state of working memory
1000 during search, it nonetheless is consistent with the possibility that knowing a
1001 target's features may be part of the positive template advantage over and above
1002 having the target's features stored in visual working memory.

1003

1004 Overall, our results demonstrate that both positive and negative cues lead
1005 to working-memory based templates, as indicated by participants' brain activity.
1006 When participants were provided with both positive and negative cues prior to
1007 search both explicitly and implicitly, they preferred to rely solely on the positive
1008 cues to perform the visual search task. This provides evidence that positive cues
1009 may be easier to implement as templates than negative cues, but both types of
1010 cues are used and stored as templates in visual working memory when they are
1011 all that is available.

1012

1013

Acknowledgements

1014 We thank Chong Zhao and Sarah Whitaker for helping with data collection. We
1015 also thank Sisi Wang, Christopher Sundby, David Sutterer, and Mathieu Servant
1016 for technical help and useful discussions. Findings from this paper were
1017 presented at the 2019 Vision Sciences Society Meeting.

1018

Funding

1019 Grants support was provided by the National Institutes of Health to GFW (R01-
1020 EY025275, R01-EY019882, R01-MH110378, and P30-EY08126).

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