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# Explicit awareness supports conditional visual search in the retrieval guidance paradigm

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## Abstract

In two experiments we explored whether participants would be able to use probabilistic cues to simplify perceptually demanding visual search in a task we call the retrieval guidance paradigm. On each trial a background cue appeared prior to (and during) the search task and the diagnosticity of the background cue(s) was manipulated to provide complete, partial, or non-diagnostic information regarding the target's color on each trial. Only when participants were made aware of the possible relationship between the background cues and target features were they able to utilize the cue information for search. When participants were not made aware of the possible connection, they were only able to use target base rates. In the General Discussion we address how a recent computational model of hypothesis generation (HyGene, Thomas, et al., 2008), provides a useful framework for understanding how long-term memory, working memory, and attention coordinate in visual search.

**Keywords:** attention, memory, visual search, hypothesis generation.

In the present research we examined whether participants would be able to use experience in order to reduce the perceptual demands of visual search. More specifically, we ask whether participants would be able to use cues to retrieve associated target features in service of visual search. We argue that much of our day to day visual search relies on such long-term memory (LTM) retrieval to define an attentional set to support search. To investigate the processes unfolding in such circumstances we have developed a novel visual search paradigm in which participants are provided with cues that probabilistically predict a target feature (its color) in a forthcoming search array. We refer to this procedure as the retrieval guidance paradigm as retrieval of likely target colors given a cue will drastically improve search.

The usefulness of the paradigm lies partly in the ecologically relevant variables it affords control over. Importantly, it allows us to assess people's sensitivity to the probabilistic relationships between cues and targets through 1) the global base rate of a target (raw frequency of occurrence) and an individual cue's diagnosticity (i.e., its predictive ability). Both of these characteristics influence the posterior probability and thus should influence retrieval

from LTM.

Related research examining how people use systematic cue-target associations to support visual search has largely focused on the contextual cueing paradigm. The general trend in these experiments is that targets within repeated visual scenes (having the same target to distracter spatial configurations) are found faster than non-repeated scenes (Chun & Jiang, 1998). One of the most intriguing aspects of the results emanating from this paradigm is that the facilitation of repeated scenes operates at an implicit level of awareness as participants are unable to distinguish between repeated scenes versus novel scenes in a recognition task. Much of this research has focused on comparing conditions where cues perfectly predict the location of the target and conditions in which cues are non-diagnostic. However, many of the environments that we encounter are probabilistic such that cues have varying degrees of diagnosticity regarding possible target characteristics. Moreover, recent research has suggested that there is minimal attentional guidance in contextual cueing (Kunar, Flusberg, Horowitz, & Wolfe, 2007), suggesting that the paradigm may be lacking in allowing for the examination of how LTM, working memory (WM) and attention coordinate in a visual search task. In the present study we offer a new paradigm that allows for the promise of: 1) investigation into whether probabilistic relationships can be learned and exploited in a visual search task (c.f. contextual cueing, Zellin, Conci, Muhlenen, & Muller, 2011), and 2) an examination of how LTM, WM, and attention coordinate in a visual search task. We accomplish this by manipulating both target base rates and cue diagnosticities within the same experimental paradigm (and within subject) by pairing background cues (preceding the onset of a search array) with critical target features (i.e., colors). Thus, the background cues provide complete, partial, or non-diagnostic information regarding the color of the target in the upcoming search array.

To foreshadow the findings of the present study, in Experiment 1 we find that participants are able to find a target faster when its color is associated with a more diagnostic cue. However, Experiment 2 reveals that when participants are explicitly aware of the associations between the cues and the color of the target, their visual search

performance is significantly improved (over the participants of Experiment 1). This difference is explained by participants reliance solely on target base rate or retrieval from LTM to guide search processes.

## Experiment 1

Experiment 1 was conducted to assess the degree to which participants would use cue information to simplify a difficult visual search task. Participants were asked to respond to a specific orientation of a “T” (rotated 90 degree clockwise or 90 degrees counterclockwise), while ignoring modified “L” letters in a visual array. Each visual array contained 14 different items (13 distracters and 1 target), with each item being unique in color. Note that there was always a target present in each search array and the search array was presented until participants responded (i.e., there was no time limit).

On each trial, a background cue appeared prior to (and during) the search array. The background cues consisted either of circles, squares, or triangles and were positioned randomly on the screen (i.e., one cue consisted of only circles, another only squares, and the last only triangles). The statistical relationship between the background cues and the identity of the upcoming target was manipulated in order to provide complete, partial, or non-diagnostic information regarding the color of the forthcoming target. Table 1 provides the contingency table describing how the backgrounds were paired with the different colors (see Figure 1 for an example background). For example, background 2 was paired with colors 2 and 3 (C2 and C3) such that when background 2 was presented the target’s color was C2 on 60% of trials and C3 on 40% of trials (note that although C1 and C4-C14 were always present in the array when background 2 was presented, they were always “L”s in the search array). Each participant was exposed to each of the different background cues throughout the entire experiment (i.e., a within-subjects design was used). Participants went through 360 trials (i.e., 6 Epochs of 60 trials each). Within each epoch the 3 backgrounds were presented 20 times each and were randomly selected for each trial. For each Epoch C1 was the target 20 times given background 1, C2 was the target 12 times given background 2, C3 was the target 8 times given background 2, and each of the fourteen colors (C1-C14) appeared as the target roughly 1.43 times given background 3. Thus, the base rate (raw frequency) of each color appearing as the target per epoch was approximately 21.43 for C1, 13.43 for C2, 9.43 for C3, and 1.43 for C4-C14.

Participants were not informed at the beginning of the experiment that a statistical relationship existed between particular backgrounds cues and the color of the target. Because of this, at the conclusion of the experiment they were asked whether they noticed a statistical relationship between particular backgrounds and the target colors. After providing an answer, participants performed a recognition task. For each trial during the recognition task, participants were provided with a search array that contained a target of

a particular color. The color of the target was either valid (the target was paired with that background in the experiment) or invalid. Participants performed the recognition task for the three different backgrounds. The participant’s recognition performance was used as a measure of their explicit knowledge concerning the cue-hypothesis contingencies.

Table 1: Contingency table, showing how the backgrounds were paired with the different colors (C1-C14) for Experiments 1 and 2. Note that the last column indicates the contingencies for each of the eleven colors (C4-C14).

	C1	C2	C3	C4-C14
<b>Background 1: 100</b>	1.0	0	0	0
<b>Background 2: 60/40</b>	0	0.6	0.4	0
<b>Background 3: Random</b>	0.07	0.07	0.07	0.07

## Method

**Participants** Twenty-two participants (10 females;  $M_{age} = 19$ ) from the University of Oklahoma participated in Experiment 1 for course credit. All participants reported normal or corrected-to-normal vision. Four participants were excluded from the analysis due to high error rates (error rates  $\geq 15\%$ ) during the visual search task, leaving 18 participants for the analysis.

**Stimuli and Apparatus** Stimuli were presented on a 17” monitor, controlled by a Dell computer with a 3 GHz Pentium 4 processor. Distance to the monitor was approximately 60 cm. Stimulus presentation and data recording were controlled via E-Prime 2 by PST, Inc. The following 14 colors were used in all of the experiments presented black, blue, brown, cyan, green, lime, magenta, maroon, orange, pink, red, tan, white, and yellow. All the stimuli (the T’s and L’s) in the visual search array were 22 mm x 22 mm. For each visual array each of the 14 items were placed randomly at one of 35 possible locations based on 3 ellipses of varying sizes.

**Procedure.** Each trial started with a fixation followed by a background cue (2004 ms). The search array then followed. Participants were told to find the rotated “T” as quickly as possible and press the F-key when the “T” was rotated 90 degrees counterclockwise and the J-key when it was rotated 90 degrees clockwise. After responding a brief mask was presented (68 ms) followed by a feedback screen (500 ms) that indicated whether the response to the visual search array was correct. Figure 1 provides a schematic of the main components of each trial (i.e., the background cue and visual search array). Following the completion of all 360 visual search trials the participants then performed the recognition task as described above.

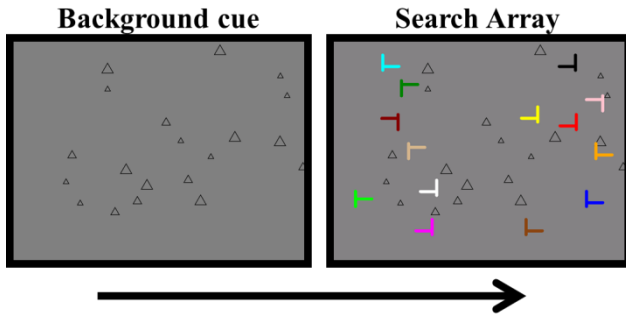


Figure 1: Schematic illustration of the main components of each trial of Experiments 1 and 2. The background cue was presented for 2004ms, while the search array was presented until response.

## Results

For our main analysis, we examined RTs for each of the cue validity conditions. Trials in which the orientation of the target was mis-reported (4.19 %), as well as trials with RTs faster than 200 ms or slower than 10,000 ms (2.66 %) were removed prior to analysis. We report the differences in the cue validity conditions collapsed across the last 3 epochs (although see Figure 2 for RT performance throughout the entire experiment). Specifically, the means of the median values (for each cue validity condition at Epochs 3-6) were calculated for each participant for each cue validity condition.

A within subjects repeated measures ANOVA revealed a significant main effect of cue validity on visual search RTs,  $F(2, 34) = 30.31, p < .01, \eta_p^2 = .641$ . Pairwise comparisons revealed a significant difference between all three conditions such that the 100 ( $M = 1942.1$  ms) cue validity condition was significantly different from the 60/40 ( $M = 2667.1$  ms) cue validity condition ( $p < .001$ ) and the random cue validity condition ( $p < .001$ ). The 60/40 cue validity condition was significantly different from the random ( $M = 3033.8$  ms) cue validity condition ( $p = .003$ ).

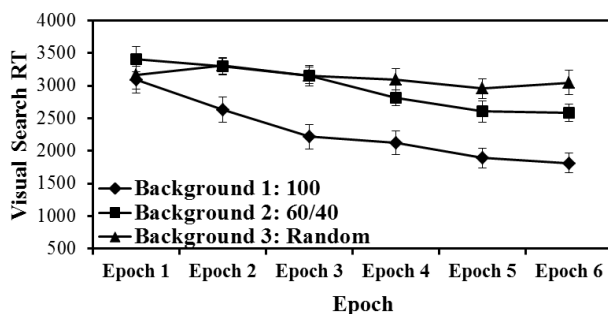


Figure 2: Reaction time performance as a function of epoch and cue validity in Experiment 1.

Seven out of the 18 participants (38.88%) indicated that they had noticed a relationship between the background and

the likelihood of the target being of a particular color<sup>1</sup>. To examine participant's accuracy in the recognition task we only considered the 100 and 60/40 cue-validity conditions. The overall accuracy rate for the recognition task was at chance level (50.93%). Accuracy rates for the different cue validity conditions were 55.56%, and 48.61% for the 100 and 60/40 cue validity conditions. Participants who indicated that they recognized a relationship between the background and the likelihood of the target being a particular color were no better at the recognition task, with accuracy rates of 50% for both the 100 and 60/40 conditions. Note that when the participants that indicated that they noticed a relationship were excluded from the analysis, a similar pattern of RT results as described above was obtained. Additionally, a between-subjects analysis of RTs did not reveal a significant difference between the group that indicated that they noticed a relationship from those that did not,  $F(1, 16) = 1.355, p = .262$ .

## Discussion

In Experiment 1 we found improved search performance in accordance with the diagnosticity of the background cue. This RT result, coupled with the poor recognition performance suggests that participants may have been using the background cues at an implicit level of awareness, which is common in the contextual cueing literature.

One of the striking aspects concerning the results from many contextual cueing studies is its implicit nature (e.g., Chun & Jiang, 1998; 1999). That is, although participants are able to find a target faster when aspects of a scene are repeated (as opposed to when they are changed), this occurs at an implicit level as participants are not able to discriminate the visual scenes they have viewed previously from those they have not (at the end of the training). Therefore, it could be an implicit utilization of contextual cues that explains the observed discrepancy between search and recognition performance in the present data. However, it should be pointed out that there is another possible explanation of the results for Experiment 1, which is explored below.

The second possible interpretation of the results holds that participants were essentially ignoring the background cues (and by extension the cue target associations), but were noting the likelihood of the target colors across all trials (i.e., the target color base rates). That is, participants' expectations regarding the color of the target may have been based on the unconditionalized base rate of the target color across all background conditions. For instance, let's assume that the color of the target is red in the 100 cue validity condition. After enough trials participants adopt an

<sup>1</sup> During debriefing some of the 7 participants that answered affirmatively to the question "Did you notice any relationship between the background and the target colors?" were confusing the probability of target color given background with the probability of the target being a particular color (i.e., the base rate of the target colors). Thus, it is likely that even fewer than 7 participants truly noticed the association between target color and background.

attentional set for red and begin searching for the red item across all background conditions, even though red is not valid for the other cue validity conditions. Likewise the higher likelihood of the targets in the 60/40 condition makes them suitable targets across all background conditions as well. This explanation is supported by a study by Kunar, Flusberg, & Wolfe (2006) that demonstrated improved search efficiency for consistently mapped search arrays when the delay between cue and array onset was sufficiently increased and participants were explicitly told about the relationship between cues and the critical aspect of the target. In Experiment 2 we investigate the two possibilities discussed above, by explicitly informing participants about the possible relationships between the background cues and the colors of the target.

## Experiment 2

Experiment 2 assessed whether participants in Experiment 1 were merely using base rate information to inform search or if they were using the background cues to improve search performance by developing a conditional attentional set. The experiment was nearly identical to Experiment 1 except there was a knowledge test at the end of each epoch, as opposed to the recognition test administered at the end of Exp. 1. The intention of this manipulation was to provide a hint to the participants that the background cues and the color of the targets were systematically associated.

## Method

**Participants** Twenty-Seven participants (23 females;  $M_{\text{age}} = 20.6$ ) from the University of Oklahoma participated in Experiment 2 for course credit (26 participants) or \$10. All participants reported normal or corrected-to-normal vision. Two participants were excluded from the analysis due to a high error rate (error rate  $\geq 15\%$ ) and one was excluded for having exceptionally long RTs as determined by having a mean RT value more than 3 standard deviations higher than the average for the mean of the collapsed 100, 60/40, and random conditions.

**Procedure** The same procedure used in Experiment 1 was used in Experiment 2 with the following exception. At the end of each epoch, participants were asked to indicate the most likely colors of the target (up to 4) given the cue.

## Results

Error trials were excluded from analysis (2.3 %) as well as trials with RTs faster than 200 ms and slower than 10,000 ms (5.1%). Errors were not analyzed in any manner.

As in Experiment 1 we collapsed across the last 3 epochs (see Figure 3 for RT performance across all epochs). A within subjects ANOVA revealed a main effect of cue validity,  $F(2, 32) = 133.302, p < .001, \eta^2_p = .847$  on search

RTs. Pairwise comparisons revealed a significant difference between the 100 ( $M = 1053.5$  ms) cue validity condition to the 60/40 ( $M = 1885.3$  ms) cue validity condition ( $p < .001$ ) and the Random ( $M = 3243.3$  ms) cue validity condition ( $p < .001$ ). The 60/40 cue validity condition was also significantly different from the Random cue validity condition ( $p < .001$ ).

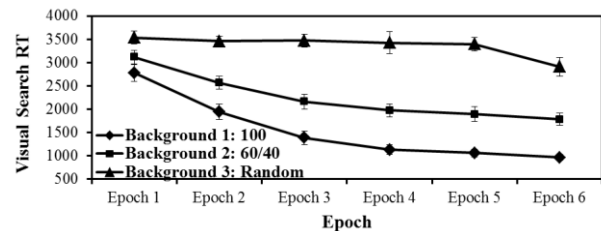


Figure 3: Reaction time performance as a function of epoch and cue validity in Experiment 2.

We next performed a between subjects analysis comparing the respective cue validity conditions of Experiment 2 to Experiment 1 (the mean values obtained whilst collapsing across the last epochs) with cue validity (100, 60/40, Random) as a within subjects variable and Experiment as a between subjects variable.

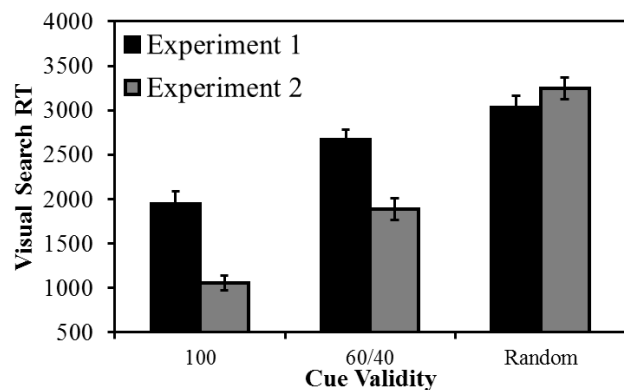


Figure 4: Reaction time performance comparing the participants of Experiment 2 with the participants of Experiment 1. Error bars represent standard errors. Note that the bars represent the means for Epochs 4-6.

A main effect of cue validity was found ( $F(2,82) = 134.183, p < .001, \eta^2_p = .766$ ) as well as a main effect for Experiment such that participants were faster in Experiment 2 than in Experiment 1, ( $F(1,33) = 15.533, p < .001, \eta^2_p = .275$ ). An interaction between Experiment and cue validity was observed, ( $F(2,82) = 18.26, p < .001, \eta^2_p = .308$ ). A Post-hoc analysis revealed a significant difference when comparing the 100 cue validity condition in Experiment 2 to the 100 cue validity condition in Experiment 1 ( $p < .001$ ) and also the 60/40 cue validity condition was significantly different across experiments ( $p = .012$ ), but the Random cue validity condition was not significantly different across Experiments ( $p = 1.0$ ). Thus, participants were significantly faster to find the target when they were informed of the possible connection between the cues and the color of the

target, suggesting that the participants in Experiment 1 were merely relying on base rate information to guide search<sup>2</sup>. There were also quite large differences in memory performance as well in Experiment 2. To examine whether this had an influence on the visual search process we split the participants into two groups based on their performance in the memory task. If a participant named the 100 color first for background 1 and the 60/40 colors first or second (in any order) for background 2 at one time during testing (out of the 6 times to do so), and only those colors, they were placed into the good memory performance group (17 participants) and the others were placed into the poor memory performance group (8 participants). Figure 5 plots the good and poor memory performers in the knowledge test.

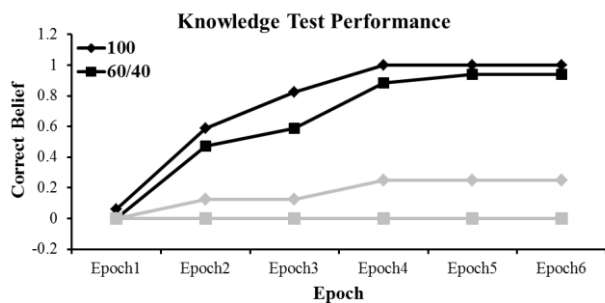


Figure 5: Performance in the knowledge test as a function of epoch, cue diagnosticity, and memory performance classification for Experiment 2. Poor memory performers are plotted in gray and good memory performers are plotted in black. Those that performed well increased dramatically over the course of the experiment whereas the poor memory participants did not.

We performed a between subjects analysis on the visual search RTs to compare the good memory performers from the poor memory performers, with cue validity (100, 60/40, Random) as a within subjects variable and memory performance (good, poor) as a between subjects variable. This analysis revealed a significant main effect of cue validity ( $F(2, 46) = 123.781, p < .001, \eta_p^2 = .843$ ) as well as memory performance on search RTs ( $F(1, 23) = 12.881, p = .002, \eta_p^2 = .359$ ) such that participants who performed well in the memory task were faster overall in the visual search task. An interaction between cue validity and memory performance type was also revealed  $F(2,46) = 5.007, p =$

.011,  $\eta_p^2 = .179$ . Although a between subjects analysis using a post-hoc Bonferonni test did not reveal a significant difference when comparing the 100 cue validity condition of the good memory performers ( $M = 893$ ) to the poor memory performers ( $M = 1394.7$ ) of Experiment 2 ( $p = .59$ ), a significant difference was observed when comparing the respective 60/40 cue validity conditions ( $p = .012$ ). The good memory performers were faster in the 60/40 condition ( $M = 1601.1$ ) relative to the poor memory performers ( $M = 2489.2$ ).

Because there seemed to be a qualitative difference in search RTs for the poor memory performers to the good memory performers, we next compared the poor memory performers of Experiment 2 to the participants of Experiment 1 to examine whether these two sets of participants were qualitatively similar. A main effect of cue validity was found ( $F(1, 48) = 51.985, p < .001, \eta_p^2 = .684$ ). There was no effect for Experiment 2, ( $F(1, 24) = 1.028, p = .321, \eta_p^2 = .041$ ). An interaction was observed, ( $F(2, 48) = 3.568, p = .036, \eta_p^2 = .129$ ), however, a post-hoc analysis revealed that the 100 cue validity condition was not significantly different across groups ( $p = .91$ ) nor was the 60/40 cue validity condition ( $p = 1.0$ ), nor the Random cue validity condition ( $p = 1.0$ ). Thus, it appears that the poor memory performers: 1) were qualitatively different than the good memory performers of Experiment 2, particularly for the 60/40 cue validity condition and 2) were qualitatively similar to the participants of Experiment 1 for the 100 and 60/40 cue validity conditions.

## Discussion

Experiment 2 revealed that the participants who learned the associations between the cues and the critical features of the target were able to leverage that information in the visual search task. Although participants were unable to pick up on the cue-target associations without a suggestion from the experimenter that such a relationship may exist (see Footnote 2 and General Discussion), most participants were able to do so once this relationship was suggested in Experiment 2. We also found that performance of the poor memory performers was similar to that of the participants in Experiment 1. In the General Discussion we posit that an important cognitive mechanism (i.e., attentional selection) was not operating over the cues for the participants of Experiment 1 and the poor memory performers in Experiment 2, thus disabling them from using the cues to improve their search.

## General Discussion

In two experiments we explored whether participants would be able to use cues to simplify a perceptually demanding visual search task. We found that although participants were sensitive to base rate information in Experiment 1, Experiment 2 revealed that the participants in Experiment 1 were likely not utilizing the background cues. Although this conclusion may be un-warranted given that a cue validity effect was found in Experiment 1, we ran an additional

<sup>2</sup> Although this statement is conjecture, we have additional empirical evidence that the participants' performance in Experiment 1 is entirely compatible with the notion that they were only using base rate information. In an additional follow up experiment we eliminated the diagnosticity of the background cue(s) by presenting only one background throughout the entire experiment (i.e., on each trial they saw the same background cue). We found remarkably similar performance in this experiment as compared to Experiment 1. Post hoc analysis revealed no differences between the 100 and 60/40 cue validity conditions across experiments (both  $p$ 's = 1.0).

experiment where the diagnosticity of the background cues was eliminated by using the same background cue for the different cue validity conditions. We found remarkably similar performance to Experiment 1 such that there were no differences for the 100 and 60/40 cue validity conditions (see Footnote 2).

In Experiment 2 we also found a qualitative difference between participants who performed well on the knowledge tests versus those that did not. The good memory performers were faster overall and were particularly faster when the background cue suggested two features (i.e., the 60/40 condition). Thus, it appears that suggestion of the possible cue to target color connection and explicit knowledge of the cue-target associations (as evidenced by good performance in the memory task) are important factors in contributing to the use of cues from the environment to support conditional visual search in the retrieval guidance paradigm (c.f. contextual cueing; Chun & Jiang, 1998; 1999). The results suggest that the paradigm used allows for an examination of how LTM memory, WM, and attention coordinate in a visual search task.

We argue that the difference between these two sets of participants is due to attentional selection (see Turk-Browne, Jungé, & Scholl, 2005). We suggest that the poor memory performers of Experiment 2 and the participants of Experiment 1 were not attending to the background cue on each trial and thus were not able to exploit the cues later in the experiment (i.e., Epochs 3-6). The good memory performers, on the other hand, were attending to the cues, thereby allowing them to encode the cue-target color associations into LTM, and exploit their memories as the task progressed. We now turn to a discussion of how a recent model of hypothesis generation called HyGene (short for Hypothesis Generation; Dougherty, Thomas, & Lange, 2010; Thomas, Dougherty, Sprenger, & Harbison, 2008) provides a useful framework for theorizing about interactions between visual search and memory within the retrieval guidance paradigm and beyond.

Although HyGene was originally developed to bridge research concerning LTM, WM, and judgment & decision making, we argue that it provides a useful framework for understanding how WM and LTM interact to support visual search. In this framework, an individual receives information from the environment, such as the background cue in the present experiment, which prompts the generation of hypotheses previously associated with the observed information. In the case of the retrieval guidance paradigm, the hypotheses being retrieved are the likely colors of the forthcoming target on each trial. The retrieved hypotheses are placed into WM and are then available to drive search processes in a top-down manner (e.g., Desimone & Duncan, 1995), affording the filtering out of perceptual information that is discordant with WM content.

Although we believe that HyGene provides a useful framework for understanding ecological visual search, it currently does not have direct access to the outside world (i.e., visual input). Because of this, the model cannot yet

make specific predictions which are likely important to visual search researchers (e.g., RTs, fixations). Thus, it would be fruitful to integrate HyGene with models of visual search, such as the guided search model (Wolfe, 1994) or the more recent target acquisition model (Zelinsky, 2008). Not only would such models be able to perform visual search, but they would also would generate predictions concerning information foraging (e.g., Hypothesis testing; Dougherty, Thomas, & Lange, 2010).

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