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# Goal-Directed Attentional Selection: Limitations From Input Variables, Not Imprecision

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When searching for a target object in a cluttered scene, the currently attended object is typically matched against a target template, a memory representation of the object being actively searched for. To determine if the currently attended item is the target requires a high degree of similarity to the template; any imprecision would make it difficult to distinguish between targets and visually similar nontargets. Thus, for attention to be efficient in finding targets requires the target template to be highly precise. Initial research on the precision of the target template suggested that the template was a highly precise depiction of the target object. In contrast, more recent findings suggested an imprecise template, demonstrating that participants were inaccurate in detecting a target when it appeared among visually similar distractors. In the current experiments, we demonstrate that visually similar distractors can hinder attentional selection because of limitations in selection and masking, not because of template imprecision. We conclude that the target template can be highly precise yet performance limited by factors not related to the target template itself.

*Keywords:* visual attention, visual search, masking



The visual system is constantly bombarded with incoming neural signals. As is obvious when a pair of missing keys shows up in a place that has already been checked, the system cannot process all of the information it receives, in part because neural "hardware" is both finite and noisy (Sprague, Saproo, & Serences, 2015). Through the use of attentional systems, guidance toward relevant and potentially important visual objects can be controlled, and limited processing resources can be protected. Although stimulus-driven exogenous attentional systems are guided by inhomogeneity in the scene and direct attention to conspicuous locations, goal-driven endogenous attention utilizes task-relevant, object-based features to conduct a search. By selectively directing attention to the visual world, it can be better ensured that the relevant information is sufficiently processed.

Visual search involves top-down, endogenous guidance to locate the desired object or region. Although the numerous models of visual attention offer different mechanisms for conducting searches, most agree on the need for a target template. To perform a goal-directed search, a target must be loaded into visual short-term memory (VSTM). In Bundesen's (1990) theory of visual attention, objects in the visual world are compared to a template held in working memory, and this comparison determines the likelihood of the currently attended object being a target. Similarly, the biased competition model proposes that an object held in VSTM resolves competition between competing elements in the scene (Desimone & Duncan, 1995). Guided search suggests that target features are preferentially activated on feature maps to aid in target localization (Wolfe, 1994, 2007). Although there are subtle differences among conceptualizations of the target template, most large-scale theories of perceptual-level attention incorporate a target template.

Recent work has attempted to address some aspects of the target template. One thread of research focused on the potential attributes that can be used as templates. Numerous studies have demonstrated the use of color, motion, orientation and size for templates that can guide attention (see Wolfe & Horowitz, 2004, for a review). A recent extension of this thread has examined attentional deployment or guidance based on the features held in VSTM, the putative location of the target template. In an early study along these lines, Downing (2000) demonstrated that attention was directed toward a face that was held in VSTM; targets appearing adjacent to the to-be-remembered face were discriminated faster than targets appearing adjacent to nonremembered faces. However, VSTM guidance of attention is not obligatory. When participants are encouraged to *not* attend to items held in VSTM, attention is no longer biased toward the contents of memory (Woodman & Luck, 2007). Along this same thread, several studies have demonstrated that multiple target templates can guide visual attention when searching for specific target features (Adamo, Wozny, Pratt, & Ferber, 2010; Beck, Hollingworth, & Luck, 2012; Irons, Folk, & Remington, 2012; Roper & Vecera, 2012) and, in some task environments, the contents of VSTM can be used to reject objects from attentional search (Arita, Carlisle, & Woodman, 2012; Woodman & Luck, 2007; but see Beck & Hollingworth, 2015).

Another thread of research on the target template has addressed characteristics of the VSTM target template itself, asking questions such as the time required to implement a template or the specificity of the template. Several studies have demonstrated that advance

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information about an upcoming target can speed attention to that target. For example, Wolfe and Horowitz (2004) examined the effect of cuing a trial-unique target template and found that an image of the upcoming target could influence responses very rapidly (within 200 ms), provided the cue depicted the target. Estimates of the speed of template implementation raise a methodological challenge, however, because cuing an exact image of an upcoming target can speed responses through priming, not attentional guidance (see Bravo & Farid, 2009). Wolfe and Horowitz (2004) found relatively little perceptual priming, suggesting that their results were the result of the top-down influence of a target template.

Many studies also have examined the specificity, or precision, of the target template, asking if target templates best guide attention when they faithfully depict the target or when they cue the target more broadly, directing attention based on the target's name or semantic category. The modal result to date suggests that attention is guided most efficiently by cuing specific target templates, that is, by cuing an image of the upcoming target. Wolfe, Horowitz, Kenner, Hyle, and Vasan (2004) found faster RTs following a picture cue that showed the target's image than following word cues that described the target (e.g., "black vertical"). Similarly, Vickery, King, and Jiang (2005) reported that cues depicting an exact image of a polygon or rendered real-world object sped responses and search slopes over both depth- and plane-rotated cues and word cues. Bravo and Farid (2009, Experiment 1) also demonstrated a larger benefit for exact image cues over transformed cues, but to extend this image-specific cuing result, they trained participants to learn name-image pairings and then used the names as word cues to direct visual search. After this training, participants were able to use word cues to guide attention efficiently toward studied targets and transformed versions of the studied targets, but not to unstudied targets. These findings again support the conclusion that target templates are highly specific and guide attention to perceptual inputs that are highly similar to or exact replicas of the template. This conclusion is supported from oculomotor search through scenes, in which the eyes are directed to a target faster following an image cue than a word cue (Malcolm & Henderson, 2009). Apparently, the template does not guide attention toward less precise matches based on either category membership or a verbal label/name, although experience can influence the template's specificity (Bravo & Farid, 2012).

Against this backdrop of results that point to highly specific target templates, two studies suggest that the template might be less precise than previously thought. For example, when monitoring a central rapid serial visual presentation (RSVP) stream for a target image that was cued by a category name (e.g., "flower"), participants were distracted by a peripheral nontarget object that matched the target category (e.g., a picture of a sunflower) than by a distractor that does not match the target category (Wyble, Folk, & Potter, 2013; also see Wyble, Bowman, & Potter, 2009). In the case of rich categories that contain many members (e.g., the category of flowers), attention might be guided by category prototypes. However, this possibility is speculative because Wyble and colleagues (2013) did not cue the target of the RSVP stream with an exact image. Based on the template cuing research reviewed above, one might predict that cuing a target with an image of a sunflower or the word "sunflower" would produce more attentional capture to a peripheral sunflower distractor than to a peripheral milkweed distractor.

A recent set of experiments has examined template precision using simple feature stimuli more akin to stimuli typically used in visual attention studies. Anderson (2014) set out to test whether the target template was precise and able to operate equally well when distractors were similar or dissimilar to the target. Participants searched four concurrently presented RSVP streams for an orange target and made a present/absent response. Distractors in the streams could include colors similar to the orange target (red, gold, green, and blue, where red and gold were similar to the orange target) or were all dissimilar colors from the orange target (blue, green, purple, and white). Accuracy rates across all participants were significantly worse when the distractors were similar to the target compared to when they were dissimilar, suggesting that the target template was relatively imprecise and could not distinguish between the target (orange) and similar distractors (red and gold). In contrast to these findings from the RSVP paradigm, participants were very efficient finding an orange target among similar distractors in a typical visual search task. To explain efficient visual search to a target among similar distractors, Anderson (2014) suggested that visual search relies on comparisons between stimuli that are present simultaneously, as is typical in a spatial visual search task. In an RSVP task, similar colored distractors are mistaken for targets because the target and distractors are not present simultaneously, which prevents target-distractor comparisons and requires items to be matched directly to the target template.

Anderson's (2014) imprecise template account offers an interesting perspective on why target-similar distractors are particularly hard to ignore. However, although an RSVP task offers some advantages over visual search by reducing or eliminating comparisons among stimuli, an RSVP task involves other processes that can limit performance. Stimuli in the stream must first be attended sufficiently enough to extract the relevant information. A display containing multiple, briefly presented streams may limit this initial selection process, producing poorer performance when a target appears among similar distractors than among dissimilar distractors. Moreover, items in an RSVP stream are masked by successive items (e.g., Keysers & Perrett, 2002), and many forms of masking are stronger for similar stimuli than for dissimilar stimuli (Breitmeyer & Öğmen, 2006; also see Bevan, Jonides, & Collyer, 2013; Sekuler, 1965; Yellott & Wandell, 1976, for specific results). Such masking likely necessitates the use of VSTM in performing target detection in an RSVP stream, because a potential target must be selected and stored before it is masked by a subsequent item; further, VSTM is needed in an RSVP task because participants report target presence/absence at the end of the stream, well after the target has been presented.

Along this same vein, some of the impairment in the similar color condition may be attributable to an attentional blink. An attentional blink is typically found in RSVP tasks where two targets must be reported. When the first and second targets are separated by 200–500 ms, the second target is often missed (see Shapiro, Raymond, & Arnell, 1997). This effect is believed to reflect a bottleneck in processing that occurs before stimuli are identified (Chun & Potter, 1995). If the second target is presented while the first target is being processed, it must be maintained in VSTM. During this wait, the VSTM representation of the second target degrades creating impairment when it is finally processed. Although there is only one target in the Anderson (2014) task, similar distractors may act as a first target by utilizing the limited processing resources to be rejected. The presence of two similarly colored distractors on each screen makes this even more plausible. Each screen in the similar distractor condition creates circumstances that may cause forward masking in the form of an attentional blink.

These various influences on RSVP tasks raise a straightforward alternative explanation for Anderson's (2014) imprecision account: Target detection is more difficult among similar distractors than among dissimilar distractors because of masking similarity. Specifically, the target is masked more by a similar subsequent item than by a dissimilar subsequent item. Under our alternative, the target template does not limit performance. Rather, lower-level interactions among visual features (specifically, color) might either alter target perception or affect the time required to consolidate an item into VSTM for comparison to the template.

In the following experiments, we examine the role of distractor similarity on target detection performance in an RSVP task. Participants monitor RSVP streams for an orange target, and in different blocks, this target is presented among either similar distractors (red, gold) or dissimilar distractors (white, purple; see Anderson, 2014). In Experiment 1, we replicate the finding that target detection is dramatically impaired in the similar distractor condition compared to the dissimilar distractor condition. In Experiments 2 and 3, we demonstrate that reducing or eliminating masking correspondingly reduces the performance decrement in the similar distractor condition. Finally, in Experiment 4, we show that by further reducing masking demands—specifically, consolidation masking (Vogel, Woodman, & Luck, 2006)—performance is equated between the similar and dissimilar distractor conditions. We conclude that the target template can be relatively high in precision, as suggested by other studies (e.g., Bravo & Farid, 2009; Vickery et al., 2005; Wolfe & Horowitz, 2004). However, encoding items into visual memory and comparing them to the target template may be prone to slowing and interference when targets and distractors are highly similar.

## Experiment 1

### Method

**Participants.** Ten undergraduates from the University of Iowa participated in exchange for course credit. All participants were 18 years old and nine participants were female. All had normal or corrected vision.

**Apparatus.** Participants were seated in a dimly lit room 60 cm from a 17- in. CRT monitor. The experiment, programmed using Matlab software with the Psychophysics Toolbox extension (Brainard, 1997) was run on a Mac Mini computer. Responses were collected on a standard keyboard using the "M" and "Z" keys. Response mappings were counterbalanced across participants.

**Task.** Participants were instructed to maintain fixation on a central, white [RGB: 255 255 255] cross (0.8° × 0.8°) while monitoring RSVP streams for an orange [RGB: 250 130 0] target letter (see Figure 1). The RSVP presentation consisted of eight frames presented for 117ms each. Four differently colored letters (1.0° × 1.0°) were concurrently presented 4.2° above, below, to the left, and to the right of fixation on a uniform, black [RGB: 0 0 0] background. Letters appeared in Helvetica font. The letters A, B, C, D, E, F, G, H, J, K, L, M, N, and P were selected randomly for each stream and frame. The distractor letter colors were blocked as target color similar (red [RGB: 255 0 0], gold [RGB: 192 192 0], blue [RGB: 0 0 255], green [RGB: 0 255 0]), and target color dissimilar (white, purple [RGB: 155 48 255], blue, and green). Target presence was pseudorandomly assigned with an equal number of target present and target absent trials in each block. A blank screen was presented for 267 ms between the final frame and the response prompt, which reminded participants of the key mappings. Participants completed 12 blocks of experimental trials alternating between color similar and color dissimilar distractors. The initial distractor color set was counterbalanced across participants. Between blocks, participants were allowed to take a break. Before entering the testing phase of the experiment, participants completed 20 practice trials. Here, all distractors appeared in white. The presentation durations for each frame were also modified. Durations in the practice block were sped up every five trials with frames lasting 1,000 ms, 550 ms, 250 ms, and 117 ms, respectively.

### Results and Discussion

Mean accuracy for the two distractor conditions and target position appear in Figure 2. As is evident from the graph, participants were more accurate detecting the target in streams with dissimilar distractors than in streams with similar distractors. Overall, the mean accuracy was 94.8% for trials with dissimilar color distractors and 75.2% for trials with similar color distractors.

We conducted statistical analyses over target present trials by first calculating mean percent correct for targets at each position in the RSVP stream. We computed accuracy separately for both distractor conditions. In preliminary analyses we found that the resulting accuracy rates violated the Shapiro-Wilk test for normality, so we transformed the data with an arc-sine-inverse transformation. All analyses were conducted on the transformed data, but the results for transformed and nontransformed raw data were qualitatively similar. Mauchly's test for sphericity was used to determine when corrections needed to be used to account for violations of sphericity. In these cases, the Huynh-Feldt correction was applied.

We analyzed the accuracy data with a two-factor within-subjects analysis of variance (ANOVA), with distractor type (similar vs. dissimilar) and target position (4, 5, 6, 7, or 8) as factors. As is evident in Figure 2, distractor color significantly affected accuracy, $t(9) = 9.64$, $p < .001$, $\eta_p^2 = .91$, with lower accuracy when the target appeared among similar color distractors than among different color distractors. There was no reliable effect of target position in the RSVP stream, $F(2.07, 18.66) = 1.49$, $p = .251$, $\eta_p^2 = .14$. The interaction between distractor color and position did not reach significance, $F(4, 36) = 2.63$, $p = .050$, $\eta_p^2 = .23$. Target absent accuracy rates (correct rejections) were also transformed by the arc-sine-inverse function. There was once again a large effect of distractor color, $t(9) = 5.35$, $p < .001$, $\eta_p^2 = .76$, with lower accuracy in the similar distractor condition than in the dissimilar distractor condition.

These results clearly replicate the pattern reported by Anderson (2014). Target detection and rejection accuracies suffered in the similar distractor color condition as compared to the dissimilar distractor condition, and the target absent results suggested a response bias in the similar distractor condition. The overall decrement in the similar distractor condition was true at the level of individual participants—each of our 10 participants exhibited the pattern depicted in Figure 2—and in the aggregate. Anderson (2014) suggested that these results indicate an imprecise target

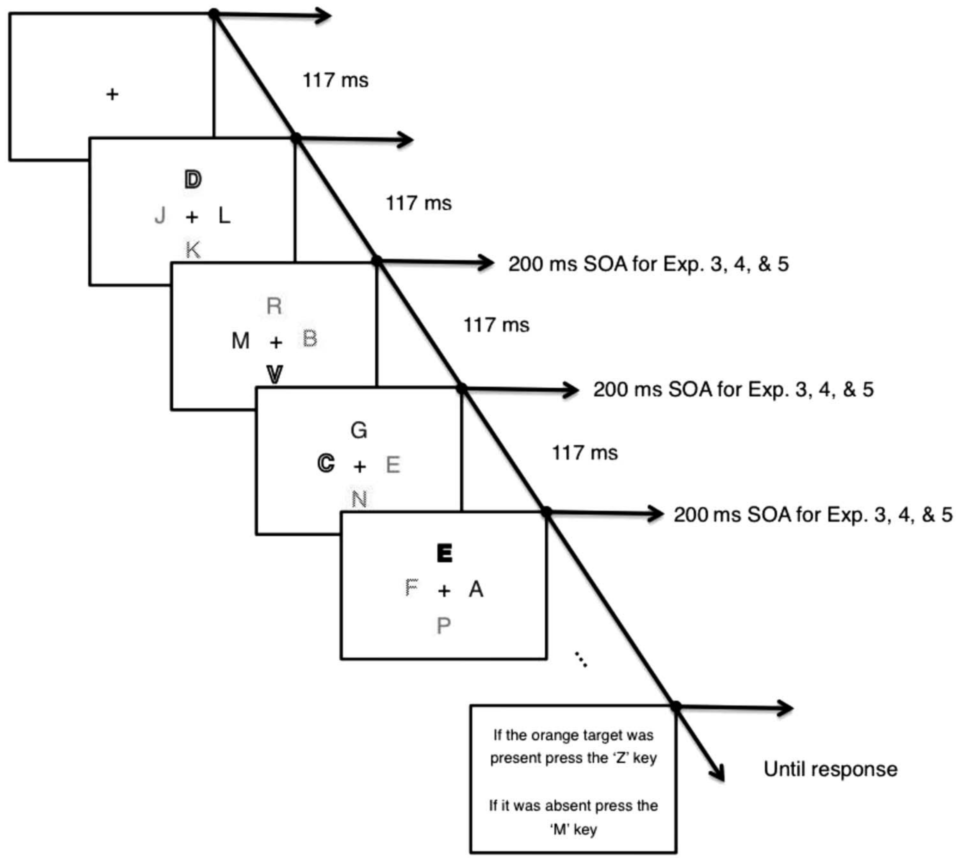


*Figure 1.* Experimental paradigm. This is an example of a trial from Experiment 1. As is elaborated on in the text, minor changes were made for Experiments 2–4.

template that is unable to distinguish between a target and distractor falling within a narrow color space.

However, as we have discussed, there are other possible mechanisms that would produce poor target detection performance when targets appear among similar distractors in an RSVP task. For one, target detection may have been prevented by an attentional blink. Specifically in the similar distractor color condition, processing of the distractors may have caused the target to be missed. Additionally, it is well-established that targets presented in an RSVP stream are masked by subsequently presented items (Keysers & Perrett, 2002). Giesbrecht and Di Lollo (1998; also see Vogel & Luck, 2002) methodically examined masking of the second target in an attentional blink task that used an RSVP stream. To evaluate masking of the second target (T2), they examined identification performance when T2 was embedded in the stream and masked versus when T2 appeared as the final item in the stream and was not masked. When T2 appeared in the final position of the RSVP stream, no attentional blink was observed, because eliminating the masking extended the time to consolidate T2 into visual memory.

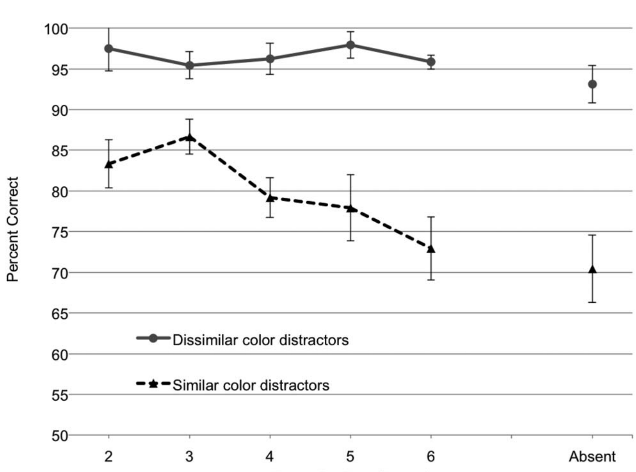


*Figure 2.* Percent of correct trials for each condition in Experiment 1. Error bars are within subject (Morey, 2008).

Giesbrecht and Di Lollo's (1998) manipulation provides an elegant test of the masking account of Anderson's (2014) results. In Experiment 2, we asked if targets appearing among similar distractors might be masked more potently than targets appearing among dissimilar distractors. To manipulate masking, we compared masked targets, presented in Positions 4–7, to unmasked targets presented on the final (eighth) position, where no distractors followed. If low accuracy in the similar distractor color condition is due to masking, we should observe an accuracy improvement for targets appearing in the final, unmasked position compared to targets appearing in the middle, masked positions. In contrast, if low accuracy in the similar distractor condition is due to an imprecise target template, we would expect no differences in accuracy across the different target positions, replicating the results of Experiment 1.

In addition to backward masking we were interested in the possibility of forward masking caused by the local distractor environment. Specifically, we examined how the color of the distractor presented immediately before the target could impair target detection. To test this, we analyzed the results of the similar distractor condition based on the distractor color presented in the target position one frame before the target appeared. If the results of Experiment 1 are due to color similarity influencing forward masking not template imprecision, then we would expect poorer target detection accuracy when targets were preceded by similar colors than dissimilar colors. Template imprecision makes no strong predictions regarding preceding distractor colors and focuses only on the taskwide target-distractor similarity.

## Experiment 2

### Method

**Participants.** Thirty-seven undergraduates ($M$ = 18.7 years, 27 female) from the University of Iowa participated in exchange for course credit. All had normal or corrected vision. We excluded four participants due to near chance accuracy. Our power analysis indicated that a sample size this large was required to allow sufficient power to test for forward masking when target accuracy was broken down into conditions based on the preceding distractor color.

**Apparatus and task.** The hardware and software we used for this experiment were the same as for Experiment 1. Other than one timing modification, the task was unchanged from Experiment 1. Between the final frame and the response prompt, an additional 350 ms was added to the duration of the blank screen. This made the entire delay between the two screens 617 ms.

### Results and Discussion

Mean accuracy for the two distractor conditions across target position appear in Figure 3. As is evident from the graph, participants were more accurate detecting the target in streams with dissimilar distractors than in streams with similar distractors. Importantly, however, the difference between target detection among similar and dissimilar was reduced when the target appeared in the final position and was not masked by subsequent items. Our statistical analyses corroborated these observations.

The accuracies for this experiment violated assumptions of normality and an arc-sine transformation was applied. Note, however, that when the following analyses were run on the raw accuracy data, the results were consistent. Mean accuracy for trials with dissimilar color distractors was 97.3% and 77.8% for trials with similar distractor colors. Participants' average accuracy was

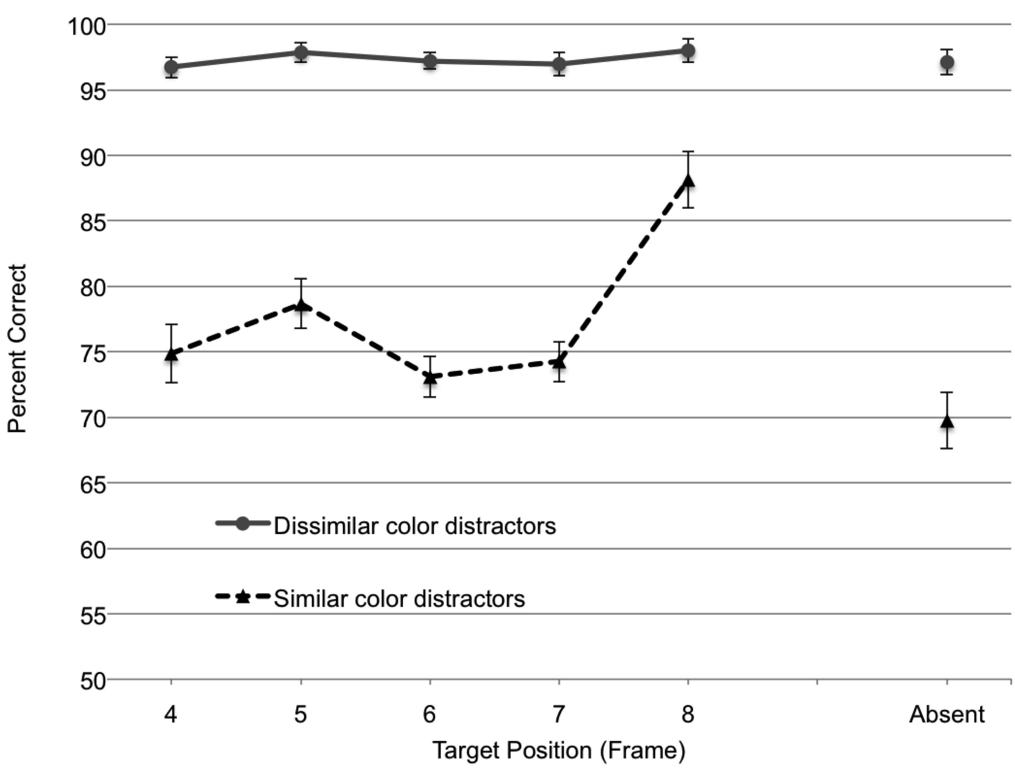


*Figure 3.* Percent of correct trials for each condition in Experiment 2. Error bars are within subject (Morey, 2008).

analyzed as in Experiment 1. Once again, there was a large main effect of distractor condition, $t(32) = 17.03$, $p < .001$, $\eta_p^2 = .90$. Additionally, the main effect of target position was highly reliable, $F(4, 128) = 16.33$, $p < .001$, $\eta_p^2 = .34$, with greater accuracy when the target appeared in the final position (93.1%) than in other positions (86.2%). Most important, the interaction between color and frame was also statistically significant, $F(4, 128) = 8.39$, $p < .001$, $\eta_p^2 = .21$. The accuracy difference between the distractor color conditions at the final target position was smaller than at the other positions. A *t* test comparing accuracies for target absent trials indicated a large difference between the distractor conditions, $t(32) = 15.29$, $p < .001$, $\eta_p^2 = .88$, with lower accuracy in the similar distractor condition than in the dissimilar distractor condition.

As is evident in Figure 3, the results of Experiment 3 demonstrate a target detection improvement when the target appeared on the final screen and was not masked. Although there was a significant difference that remained between the distractor conditions for targets presented at the final position, $t(32) = 7.05$, $p < .001$, $\eta_p^2 = .61$, the magnitude of this difference was reduced greatly compared to the other target positions. Our current findings clearly suggest that some of the reduced accuracy for detecting targets among similar distractors is due to backward masking, not to a relatively imprecise target template.

To further evaluate this difference, we examined the effect of the distractor color occupying the target's position one frame before the target was presented for the similar distractor color condition. For this analysis, accuracy data was collapsed across the middle target positions (screens four through seven) for each color because the previous analysis indicated that there were no differences for target detection on these screens. An ANOVA was used to compare accuracy at the middle positions to accuracy on the final target screen for each target preceding color.

Figure 4 depicts the effects of the preceding distractor color on target identification. The main effect of target position was once again significant, $t(32) = 11.20$, $p < .001$, $\eta_p^2 = .80$, as was the main effect of preceding color, $F(3, 96) = 24.47$, $p < .001$, $\eta_p^2 = .43$. The interaction between target position and preceding color was not significant, $F(0.66) = 3.02$, $p = .58$, $\eta_p^2 = .02$. Dunn-Sidak corrected paired *t* tests revealed that the main effect of preceding color was driven by red distractors impairing target detection significantly more than the other distractor colors (all *p*s $< .001$), but that the other colors did not differ from each other significantly. This effect is clear in Figure 4.

The present results suggest that both forward and backward masking impair target detection in the similar color condition. Target detection was greatly improved for targets appearing in the final frame because when no backward masking occurred, there was sufficient time for consolidation of the target into visual memory for a later report. The remaining accuracy differences between the distractor conditions seem to be attributable to the presence of a red distractor in the target's location immediately before the target is presented. In fact, forward masking was strongest with a red distractor preceding the target at all positions. The data supporting this analysis only includes target present trials, meaning that imperfect accuracy reflects missed targets. Red distractors may take longer to consolidate and reject than other colors, thereby creating an attentional blink during which the target is missed. In fact, the attentional blink is known to be stronger for masks that are similar to the target compared to dissimilar masks (Chun & Potter, 1995). This same mechanism can explain the high false alarm rate in the similar distractor color condition. In these highly masked displays, it is plausible that an incompletely processed red distractor is mistaken for a target. This does not occur in the dissimilar color condition, because none of the distractors are confusable for the target and all can be easily rejected. Although this impairment could be taken as evidence of an imprecise template, it is also likely that similar colored distractors require additional resources to double check that they are not targets.

One potential concern with the current results, however, is that the improvement in target detection for targets in the final

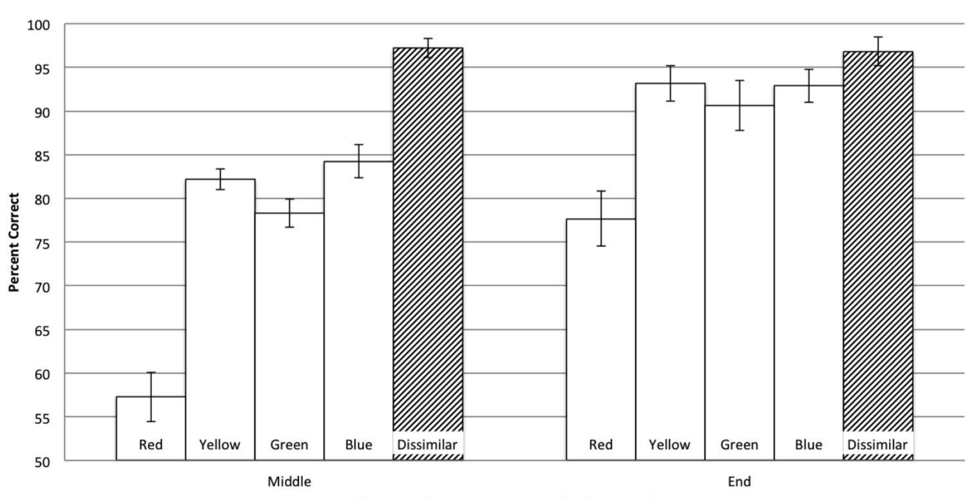


*Figure 4.* Percent of correct trials each of the distractor colors in the similar condition for targets appearing in the middle (Screens 4–7) and end (Screen 8) of the stream in Experiment 2. Accuracy data for the dissimilar condition is provided for reference. Error bars are within subject (Morey, 2008).

position could be caused by a recency effect—these targets were simply encountered close to the time of response. However, this interpretation should predict a similar uptick in accuracy for targets in both the similar and dissimilar distractor conditions, and we observe that accuracy increase only in the similar distractor condition. To further test our masking hypothesis, we attempt to ameliorate target detection throughout the RSVP stream in the similar distractor condition by increasing the delay between frames in the RSVP stream, which would reduce masking and allow more time for consolidation into visual memory. In Experiment 3, we inserted a 200-ms delay between each frame of the RSVP stream, making it more likely that the target could be processed before the following screen masks it. The stimulus-onset asynchrony selected for the experiment was chosen in accordance with Vogel et al.'s (2006) results that consolidation processes take roughly 50 ms per item; with four RSVP streams, an additional 200-ms delay should improve the consolidation of the streams into visual memory. Our masking account predicts that accuracy in the similar distractor condition should increase for targets in all positions of the RSVP stream. If the results of Experiment 2 were due to a mere recency effect, then we should replicate those results in Experiment 3.

## Experiment 3

### Method

**Participants.** Ten undergraduates ($M$ = 20.3 years, eight female) from the University of Iowa participated in exchange for course credit. All had normal or corrected vision.

**Apparatus and task.** All procedures were identical as in Experiments 1 and 2, with the following exceptions: In Experiment 3, a 200-ms delay was added between each RSVP frame.

### Results and Discussion

Mean accuracy for the two distractor conditions across target position appear in Figure 5 Comparing Figures 3 and 4 reveals that participants become increasingly accurate in detecting the target among similar distractors when a delay is added between frames. Overall, the difference between target detection among similar and dissimilar distractors shrinks to 4.4 percentage points, which is similar to the difference for the final position reported in Experiment 2 (9.9 percentage points).

Once again, an arc-sine-inverse transformation was applied to normalize the data. Additionally, in some cases, tests for normality indicated that a correction needed to be applied. For these analyses, Huynh-Feldt corrections were used. The average accuracy rate for blocks with similar colored distractors was 94.1% and 98.5% for blocks with dissimilar colors. This is a marked accuracy improvement for similar distractor trials. Participants' average accuracy was analyzed as in Experiments 1 and 2. A within-subjects ANOVA indicated a significant main effect of distractor condition, $t(9) = 3.83$, $p = .004$, $\eta_p^2 = .62$, despite this difference being numerically very small compared to our previous experiments. The main effect of target location frame was not significant, $F(3.23, 29.09) = 2.10$, $p = .101$, $\eta_p^2 = .19$. The interaction between distractor condition and target position was significant,

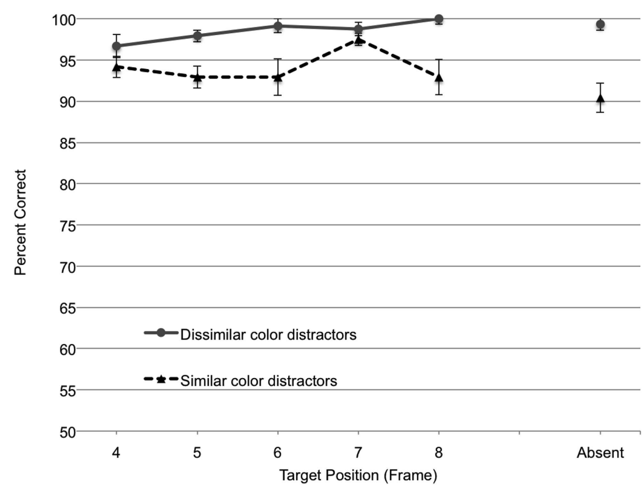


*Figure 5.* Percent of correct trials for each condition in Experiment 3. Error bars are within subject (Morey, 2008).

$F(4, 36) = 3.61$, $p = .041$, $\eta_p^2 = .29$. Follow-ups tests analyzing the simple main effects of distractor color on target frame revealed that accuracies differed significantly across target frame for dissimilar distractor colors, $F(4, 36) = 3.94$, $p = .009$, $\eta_p^2 = .31$, but not for similar distractor colors, $F(2.73, 24.57) = 1.93$, $p = .156$, $\eta_p^2 = .18$. A $t$ test comparing accuracies for target absent trials indicated a large difference between the distractor conditions, $t(9) = 8.94$, $p < .001$, $\eta_p^2 = .90$, with lower accuracy in the similar distractor condition than in the similar distractor condition. The analysis of distractor color in the frame immediately before the target revealed a pattern similar to that of Experiment 2. Red distractors preceding the target created greater impairment than other colors.

The current results demonstrate a reduced effect of distractor condition.[1] Adding a delay between successive items in the RSVP stream improves target detection performance, particularly when the target is similar to the distractor colors. This result could be taken as evidence that the target template has increased in precision with the added time. However, the more parsimonious expla-

[1] To verify that the manipulation of increasing the delay between the screens of the RSVP task really did affect performance, we ran a between-experiment comparison. All of the main effects were highly significant: distractor condition, $t(41) = 8.42$, $p < .001$, $\eta_p^2 = .63$, target screen, $F(4, 164) = 5.73$, $p < .001$, $\eta_p^2 = .12$, experiment, $t(41) = 5.08$, $p < .001$, $\eta_p^2 = .37$. The two-way interactions were also all significant: distractor condition and target screen, $F(4, 164) = 2.60$, $p = .038$, $\eta_p^2 = .06$, distractor condition and experiment, $F(1, 41) = 28.24$, $p < .001$, $\eta_p^2 = .41$, and target screen and experiment, $F(4, 164) = 6.30$, $p < .001$, $\eta_p^2 = .13$. Most importantly, the three-way interaction between distractor color, target screen, and experiment was significant, $F(4, 164) = 6.29$, $p < .001$, $\eta_p^2 = .13$. The simple interactions between experiment and target screen for the dissimilar distractor condition were not significant, $F(4, 164) = 1.07$, $p = 371$, $\eta_p^2 = .03$. However, for the similar distractor color condition, this interaction was highly significant, $F(4, 164) = 7.02$, $p < .001$, $\eta_p^2 = .15$. The pairwise comparisons of between the two experimental groups for each target screen in the similar distractor color condition were all significantly different ($ps < .001$), except when targets were presented on the final target screen, $t(41) = 1.34$, $p = .183$, $\eta_p^2 = .04$. This suggests that it is indeed the increased delay that caused improvement for target detection in the similar distractor color condition.

nation is that the delay reduced masking in the stream and that this decreased masking increased the efficiency with which participants could match a current stimulus to the target template. In short, reducing masking improves participants' ability to encode the current item into visual memory, where it can then be matched against a target template. The precision of the target template need not vary to explain the results across our first three experiments and, moreover, masking, not template imprecision, can explain the results of Experiment 1 and of Anderson (2014).

Although our consolidation masking account explains the improvement in accuracy we have observed, there was nevertheless a small, but significant, difference between targets appearing in the two distractor conditions. This could reflect a persistent imprecision in the target template, an imprecision that prohibited targets from being detected as accurately among similar distractors as among dissimilar distractors. However, there is another possibility: that it simply takes more time than our task has provided to consolidate items from four RSVP streams. Indeed, Vogel and colleagues (2006) showed that consolidating four items into VSTM took longer than consolidating fewer items. By systematically manipulating the delay between a memory array and a mask array, they could improve visual memory for larger display sizes. Relevant for our current results, Vogel et al.'s (2006) memory performance, even with a substantial stimulus-onset asynchrony of almost 600 ms, was poorer when the memory array contained four items than when it contained fewer items.

To further test our consolidation masking account, we asked participants to monitor a single RSVP stream instead of four streams. Presentation of a single stream should further speed consolidation into visual memory (see Vogel et al., 2006); thus, our consolidation masking account predicts further improved target detection performance in the similar distractor condition. Importantly, a single RSVP stream also eliminates any possibility that participants could make comparisons among the items within a frame of the RSVP stream, providing a strong test of the claim that evidence for a precise template is the result of spatial comparisons among stimuli that can occur in search tasks when multiple items appear simultaneously (Anderson, 2014). If the small but reliable differences between the distractor conditions in Experiment 3 were due to comparisons among stimuli occurring in the four RSVP streams, then reducing the task to a single stream should prevent these comparisons and should increase the difference between the similar and dissimilar distractor conditions. Specifically, accuracy in the similar distractor condition should plummet, producing results that appear similar to those reported in Experiment 1.

## Experiment 4

### Method

**Participants.** Ten undergraduates ($M$ = 19.00 years, eight female) from the University of Iowa participated in exchange for course credit. All had normal or corrected vision.

**Apparatus and task.** All procedures were identical as in Experiment 3, with the following exceptions: In Experiment 4, there was only one stream of letters lasting for 16 frames. The target could appear on screens 4, 8, 12, 14, and 16. Again, there was a 200-ms blank screen between frames and a 617-ms blank screen before the response prompt. Participants completed 10 interleaved blocks of 40 trials. No other changes were made in the design.

### Results and Discussion

The arc-sine-inverse transformation was applied to normalize the data. Additionally, in some cases, tests for normality indicated that a correction needed to be applied. For these analyses, Huynh-Feldt corrections were used. Mean accuracy for the two distractor conditions across target position appears in Figure 6. As is readily apparent in the graph, there is no longer any difference detecting targets among similar and dissimilar distractors. Overall, the difference between target detection among similar and dissimilar distractors is negligible, 2.33 percentage points.

The average accuracy rates for similar and dissimilar distractor conditions were 95.8% and 96.8% correct respectively. Participants' average accuracy was analyzed as in the foregoing experiments. An ANOVA indicated no reliable effects of distractor condition, $t(9) = 2.20$, $p = .055$, $\eta_p^2 = .35$. The effect of target position was significant, $F(4, 36) = 3.36$, $p = .020$, $\eta_p^2 = .27$. However, their interaction was not significant, $F(2.75, 24.79) = 2.32$, $p = .105$, $\eta_p^2 = .21$. Dunn-Sidak corrected pairwise comparisons revealed that only differing target positions were the fourth and 16th screens ($p = .012$, all other $ps > .05$). A $t$ test comparing accuracies for the target absent trials suggests that the distractor color conditions did not differ reliably, $t(9) = 1.94$, $p = .084$, $\eta_p^2 = .30$. An analysis investigating the effect of distractor color on the screen before the target revealed no differences between trials with different colors.

When stimuli were presented in a single steam with a sufficient delay between frames to eliminate masking and permit memory consolidation, the effect of distractor type evaporated. Across all target positions, both distractor conditions demonstrated target detection accuracy above 92%. These findings indicate that when limitations for selection and consolidation are accounted for, the

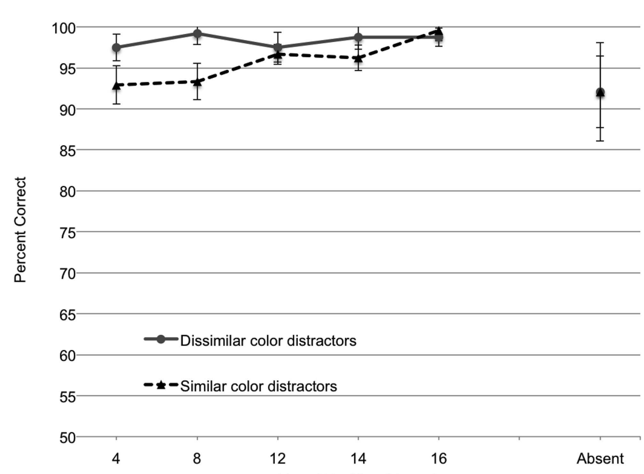


*Figure 6.* Percent of correct trials for each condition in Experiment 4. Error bars are within subject (Morey, 2008).

target template is similarly employed regardless of search difficulty or distractor color. The current results, when taken with Experiments 1–3, suggest that eliminating multiple sources of masking correspondingly eliminates the difference between the distractor conditions. There is little difference in participants' performance in the dissimilar distractor condition, which was highly stable across Experiments 1–4 (94.8%, 97.3%, 98.5%, and 96.8%). Thus, in the dissimilar distractor condition when there is little, if any masking and few perceptual limitations (see Experiment 4, Anderson, 2014), performance is near ceiling. As we systematically eliminate masking sources in the similar distractor condition, we find that performance approaches that of the dissimilar distractor condition.

We would argue that the current results do not represent a simple ceiling effect that obscures the difference between the two distractor conditions. Critically, as Figure 6 shows, we can observe the difference between the distractor conditions for targets that appear early in the RSVP stream. The difference between the distractor conditions is eliminated only when masking is fully removed by the added time between frames and the target appearing in the final position. One challenge with reducing accuracy off ceiling is that any manipulation that increases the difficulty of the task will do so by either increasing masking or increasing perceptual demands. This underlies our exact point, however: that performance differences between the two distractor conditions is due to differences in the input to the system maintaining template, not a limitation in that system itself (i.e., an imprecise template).

Nevertheless, in an attempt to reduce accuracy without inducing masking, in Experiment 5, we required participants to identify the target letter, instead of merely detecting the presence of the target letter. This manipulation also allows us to eliminate response biases that were present in our earlier experiments and, presumably, in Anderson's (2014) results.

## Experiment 5

### Method

**Participants.** Ten undergraduates ($M$ = 18.4 years, seven female) from the University of Iowa participated in exchange for course credit. All had normal or corrected vision.

**Apparatus and task.** All procedures were identical as in Experiment 4, with the following exceptions: In Experiment 5, participants were asked to respond to the identity of the orange target letter that was present in every trial. For this experiment, only the letters E, H, L, and T were used and none of the letters repeated on two subsequent screens. No other changes were made in the design.

### Results and Discussion

Mean target identification accuracy for the two distractor conditions across target position appears in Figure 7. The differences between the conditions are small and decrease as the target is presented closer to the end of the trial. Overall, the difference between target identification among similar and dissimilar distractors is 3.9 percentage points.

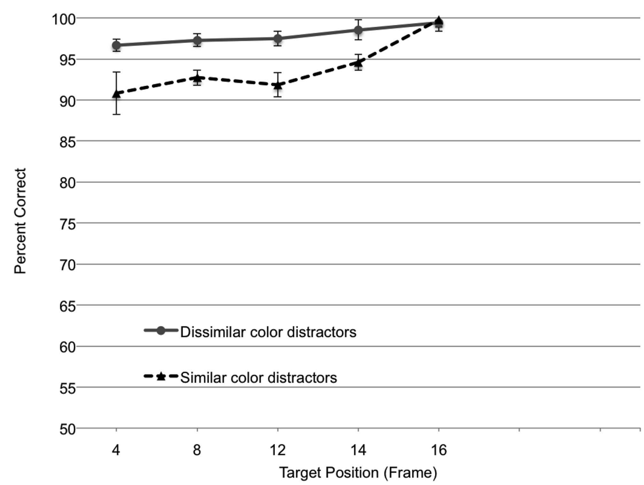


*Figure 7.* Percent of correct trials for each condition in Experiment 5. Error bars are within subject (Morey, 2008).

The arc-sine-inverse transformation was used to normalize the data. The average accuracy rates for similar and dissimilar distractor conditions were 94.0% and 97.9% correct respectively. Participants' average accuracy was analyzed as in the foregoing experiments. An ANOVA indicated a reliable effects of distractor condition, $t(9) = 2.96$, $p = .016$, $\eta_p^2 = .49$, and target position, $F(4, 36) = 10.58$, $p < .001$, $\eta_p^2 = .54$. There was a trend toward an interaction similar to that observed in our previous experiments, $F(4, 36) = 2.34$, $p = .074$, $\eta_p^2 = .21$. Dunn-Sidak corrected pairwise comparisons of the target locations revealed significant differences between the final position and all other positions (all $ps < .015$) and a significant difference between the sixth and 12th positions ($p = .036$).

We used target identification, rather than detection, in an attempt to reduce accuracy for both distractor conditions. The results from Experiment 5 replicated those from Experiment 4, namely we found that target identification in the similar distractor condition was nearly flawless in the when masking was removed by increasing the time between stimuli and placing the target in the final position. Overall accuracy was similar between Experiments 4 and 5, suggesting that masking parameters, not overall task difficulty, is the main determinant of performance in this task. Again, reducing accuracy in a variety of tasks is typically done by decreasing the perceptibility of the target, either by reducing presentation time or introducing a mask. As evidenced in the experiments here, such manipulations obscure the potential locus of the results presented by Anderson (2014).

## General Discussion

The series of experiments presented here systematically identified factors limiting target detection performance in an RSVP task. In Experiment 1, we replicated previous findings that demonstrated reduced target detection accuracy for targets among similar distractor compared to those among dissimilar distractors; this result was initially interpreted to reflect an imprecise target template (Anderson, 2014). In contrast, we hypothesized that input factors, including attentional selection demands imposed by the

RSVP task and consolidation masking differences between similar and dissimilar distractor conditions produced the results, not a relatively imprecise template. Manipulations that reduced or eliminated backward masking (Experiments 2–4) and selection demands (Experiments 4 and 5) drastically improved accuracy between the different distractor conditions, consistent with our masking hypothesis. In Experiment 2, when the target was presented at the end of an RSVP stream and was therefore unmasked by subsequent displays, accuracy differences between the similar and dissimilar distractor color conditions were reduced. This improvement in accuracy for the similar distractor condition was extended to all frames of the RSVP stream when we inserted an increased delay between the frames, a manipulation that extended the time to consolidate frames into visual memory. Further, we observed forward masking effects in all experiments, which we formally evaluated in Experiment 2. Targets were frequently missed when immediately preceded by a red distractor at the target's location. Although these various manipulations did not abolish the accuracy differences between the two distractor conditions completely, in Experiment 4, we further reduced selection demands by presenting a single RSVP stream. In this experiment, accuracy no longer differed between the similar and dissimilar distractor conditions for targets appearing in the final (unmasked) position of the RSVP stream. Overall, our results suggest that masking and the time required to consolidate items into visual memory places severe limitations on performance and that performance limitations need not be produced by a relatively imprecise target template.

Our findings mesh well with previous studies that suggested a relatively precise template (e.g., Bravo & Farid, 2009; Vickery et al., 2005; Wolfe & Horowitz, 2004). However, we would not want to claim that the target template has a fixed precision that is always relatively high (i.e., allows observers to make subtle discriminations between targets and nontargets). It is quite possible that the precision of a target template is influenced by some factors, including the number of target templates that must be maintained and matched against (e.g., Beck et al., 2012; Irons et al., 2012; Roper & Vecera, 2012) or whether a template is used to bias attention toward targets or away from distractors (e.g., Arita et al., 2012; Woodman & Luck, 2007). Before the impact of such factors on the target template can be investigated, however, studies must carefully rule out alternative causes of performance that might be interpreted as reflecting the relative precision of the target template, and the current studies represent exactly this approach.

The present results make both theoretical and methodological contributions to understanding the target template. On the theoretical front, our results illustrate the intimate connection between target templates in memory and perceptual processes. Templates may appear imprecise (cf. Anderson, 2014) because of perceptual limitations, such as stimulus locations in color space or masking. For example, in Bundesen's (1990) theory of visual attention, the target template is a memory representation of perceptual characteristics, enmeshing templates and perceptual factors and causing a perceptual limitation to appear as a template limitation. Further evidence for the close connection between target templates in visual memory and perceptual processes comes from Serences, Ester, Vogel, and Awh (2009), who found that maintaining stimuli in VSTM involved sensory representations in early visual cortex.

The upshot of the linkage between target templates and sensory-perceptual processes is that measuring the precision of an attentional target template might amount to measuring perceptual thresholds or perceptual discriminability. For example, psychophysically determining perceptual discriminability between various colors—such as those used here—would mirror the discriminability in visual memory and, therefore, as target templates. Because red and orange are more confusable perceptually, they are also more confusable when one is a target and the other a distractor in an attention task (e.g., Bauer, Jolicoeur, & Cowan, 1996; D'Zmura, 1991) This raises a methodological issue concerning the measurement of template precision. Precision is a measure of discriminability across various stimuli, and a variety of stimuli need to be tested to determine an overall tuning curve for a particular target color. The resulting tuning curve could then be compared across conditions to determine the factors that influence precision, but an individual discriminability tuning curve could not be characterized as "precise" or "imprecise."

One difference between the current studies and other studies of the target template is that our participants searched for a single target value (the color orange) across trials (following Anderson, 2014); previous studies cued attention to a target value on a trial-by-trial basis. Thus, our results speak to the repeated use of a target template that likely resides in visual long-term memory, as opposed to templates stored in VSTM. Because target template representations are thought to undergo a "hand off" process in the transfer from VSTM to visual long-term memory (e.g., Carlisle, Arita, Pardo, & Woodman, 2011; Woodman, Carlisle, & Reinhart, 2013), there may be corresponding changes in template characteristics across the hand off. That is, shorter-term and longer-term templates may operate differently based on differential experience or the use of different memory systems.

Having identified masking as a source of poor performance when examining the target template, we are now in a better position to pursue future studies of the target template. For example, following Anderson's (2014) suggestions, using an RSVP stream instead of a search task seems reasonable to prevent simultaneous comparisons among stimuli. Based on Experiment 4, we would suggest that a single RSVP stream is the logical choice for minimizing interstimulus comparisons. Of course, based on the sum of all the current experiments, RSVP streams are not without shortcomings—such as masking and the reliance on visual memory—and care must be given to rule out these shortcomings as contributors to a participant's overall performance. Further, there are numerous ways to directly probe the target template. For example, following previous work, visual memory for the precise color of the target could be probed at the end of a trial (e.g., Zhang & Luck, 2008) as an assay of the template's precision across different conditions. The difference between reported target color and actual target color can provide a great deal of information. If distractor colors fall within the region of colors that the template is holding, target accuracy should suffer. However, if the distractor colors are sufficiently discriminable from the remembered target color, as indicated by visual memory precision, participants should be able to make distinctions between targets and distractors. Alternately, attentional capture by distractors that vary in similarity to the target (e.g., Roper & Vecera, 2012) could provide an indirect measure of the tuning curve of the target template. When holding a target color in memory, participants are reliably captured to a temporally proximate distractor of the target color, and template precision could be determined by establishing the range of distractor colors (relative to the target) that create capture, essentially measuring a tuning curve of for the target's representation in visual memory.

In conclusion, the present work has revealed that selection and consolidation processes, not template limitations, contribute to misidentifying a similar colored distractor as a target. Now, with an understanding of these limitations, ongoing studies can more directly probe the operation of the target template.

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