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Top-Down Controlled, Delayed Selection in the Attentional Blink

Mark R. Nieuwenstein
Massachusetts Institute of Technology

In a previous study, it was shown that the attentional blink (AB)—the failure to recall the 2nd of 2 visual targets (T1 and T2) presented within 500 ms in rapid serial visual presentation—is reduced when T2 is preceded by a distractor that shares a feature with T2 (e.g., color; Nieuwenstein, Chun, van der Lubbe & Hooge, 2005). Here, this cuing effect is shown to be contingent on attentional set. For example, a red distractor letter preceding a green digit T2 is an effective cue when the task is to look for red and green digits, but the same red cue is relatively ineffective when the task is to look for only green digits or when the color of T2 is not specified. It is also shown that cuing is not interrupted by a distractor intervening between the cue and T2. These findings provide evidence for a contingent, delayed selection account of the AB.

Keywords: attentional blink, cuing, top-down control, time course, selective attention

When two targets (T1 and T2) are presented within 500 ms of each other in rapid serial visual presentation (RSVP), identification of T2 is often impaired (Broadbent & Broadbent, 1987). This finding, referred to as the attentional blink (AB; Raymond, Shapiro & Arnell, 1992), is typically accounted for by assuming that T1 invokes a slow, capacity-limited, processing or storage mechanism that is also required for the T2 task (e.g., Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998; Shapiro, Raymond & Arnell, 1994). In this view, processing of T2 is postponed during the ongoing processing of T1 at short intertarget intervals, resulting in the AB.

One of the key issues in research on the AB is to understand the nature of the processing limitation that underlies the impairment in T2 report. A recent study suggests that failures to report targets presented during the AB occur because the allocation of attention to these targets is delayed. This study showed that the AB is substantially attenuated when a distractor that shares a feature with the targets directly precedes T2 (Nieuwenstein, Chun, van der Lubbe & Hooge, 2005). For example, in one of the experiments, observers were to identify two digits that were presented in red. These targets were presented in an RSVP stream consisting of letters and digits that were presented in colors other than red. On half of the trials, T2 was preceded by a red letter. The results showed that when T2 was "cued" by the red letter, the AB was substantially attenuated. On the other hand, cuing did not cause a significant improvement in target report when only a single target was presented, and increasing the number of cues preceding a T2 that appeared outside of the AB range revealed that report accuracy decreased as the temporal interval between the first cue and T2 increased.

Based on these findings, Nieuwenstein et al. (2005) proposed that the cause of the failure to report targets presented during the AB lies in delayed engagement of attention: Shortly after selecting T1, attention shifts only slowly to T2, leading to the inadvertent selection and processing of the item following the target on many trials (e.g., Chun, 1997a; Isaak, Shapiro & Martin, 1999). Cuing increases the chance that the engagement of attention coincides with the representation of a following T2, thereby allowing the target representation to be sustained and consolidated in short-term memory. A useful metaphor for the cuing effect derives from the notion of an attention gate introduced by Reeves and Sperling (1986; see also, Shih, 2000; Sperling & Weichselgartner, 1995; Weichselgartner & Sperling, 1987). An attention gate is assumed to control the transfer of RSVP targets between an early, high-capacity and labile stage of conceptual representation and a later, more durable, capacity-limited stage of short-term memory (Chun & Potter, 1995). The opening of the gate is held to occur when a potential target is detected (e.g., Shih, 2000). This results in the transient (i.e., 100–200 ms; Nakayama & Mackeben, 1989; Nieuwenhuis, Gilzenrat, Holmes & Cohen, 2005) release of attentional resources that constitutes what is known as an *attentional episode* (Sperling & Weichselgartner, 1995). During this attentional episode, visual representations can be sustained so that they can be fully identified and consolidated in short-term memory (Davenport & Potter, 2005; Potter, Staub & O'Connor, 2002). Thus, in terms of attention gating, the finding that cuing T2 reduces the effect of the AB suggests that the opening of the attention gate is delayed during the AB.

An important assumption of the delayed engagement account is that it holds that the cuing effect is contingent on the match between the cue and attentional control settings (e.g., Folk, Leber, & Egeth, 2002, Folk, Remington & Johnston, 1992), that is, the cue is assumed to initiate the opening of an attention gate because it is recognized as a potential target. However, as noted by Nieuwenstein et al. (2005), an alternative explanation of why cuing facilitates target report during the AB is also possible. This expla-

Mark R. Nieuwenstein, Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology.

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Correspondence concerning this article should be addressed to Mark R. Nieuwenstein, Department of Brain and Cognitive Sciences, Building 46, Room 4127A, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139-4307. E-mail: nieuwe@mit.edu

nation derives from the so-called temporary loss of control (TLC) model of the AB (Di Lollo, Kawahara, Shahab Ghorashi & Enns, 2005; Kawahara, Enns & Di Lollo, in press). According to this model, the failure to report T2 occurs because the load of identifying and consolidating T1 causes a loss of control over subsequent target selection. In this view, the specifications of the attention gate are under bottom-up control during the processing of T1. As a consequence, distractors following T1 may determine filter settings, resulting in a failure to select and process T2 when it does not match the characteristics of the preceding distractors. This model provides a viable account of cuing by assuming that when there is overlap between the features of T2 and the preceding distractor (the cue), the configuration of the input filter will be tuned so as to allow efficient processing of T2 (e.g., Kawahara, Kumada & Di Lollo, in press; Olivers, van der Stigchel & Hulleman, 2005).

The present study reports five experiments that were aimed at gaining further understanding of the mechanisms that underlie the cuing effect. The main empirical question addressed in these experiments is whether cuing is restricted to conditions in which the distractor directly preceding T2 shares a feature with the following target. According to TLC (Di Lollo et al., 2005), this should indeed be the case because this account holds that cuing should occur only when T2 matches the configuration of the input filter determined by the characteristics of the item directly preceding T2 (e.g., Kawahara, Kumada et al., in press; Olivers et al., in press). The delayed engagement account makes a different prediction, however, as this account holds that cuing depends foremost on whether the cue matches attentional set and on whether the interval separating the onset of the cue and the following target allows the engagement of attention to coincide with the representation of the target. Thus, according to the first premise of the delayed engagement account, any stimulus that matches attentional set can cue a following target, regardless of whether it matches the physical appearance of the following target. In other words, a red letter could act as a cue for a green digit T2 provided that the task is to search for red and green digits. This prediction is tested in Experiments 1A and 1B. The second premise of the delayed engagement account entails that cuing could extend across a distractor that intervenes between the cue and the target, provided that the cue–target interval is sufficiently short to allow T2 to fall within the attentional episode initiated upon detection of the cue. This prediction is tested in Experiment 2.

Experiments 1A and 1B

The first experiments examined whether cuing can occur with a cue that matches attentional set but does not share any characteristics with the following T2. To this end, the effect of cuing a digit T2 with a distractor letter presented in a different color than T2 was compared between two conditions. In one condition (Experiment 1A), observers searched for targets of one color (e.g., red), and T2 could be cued by either red or green distractors. The task in the other condition (Experiment 1B) was to search for red *and* green targets, and T2 could again be preceded by red or green distractors. Thus, in this case, both red and green cues matched attentional set, but T2 could be presented in a different color than the cues. As discussed in the Introduction, the delayed engagement account predicts that different-color cues should produce a stronger effect on T2 report in Experiment 1B (where this color is included in the attentional set) than in Experiment 1A (where this color does not match the target specification). On the other hand, TLC (Di Lollo et al., 2005) would predict that the difference in attentional set between Experiment 1A and 1B should not affect cuing as this account assumes that top-down control over selection is lost during the AB. Moreover, according to this account, different-color cues should not facilitate T2 report in either experiment because they do not match the color nor the category of the following T2.

Method: Experiment 1A

Participants. Sixteen members from the Massachusetts Institute of Technology community volunteered to participate in the experiment in return for monetary compensation. All reported having normal color vision.

Apparatus and stimuli. The stimuli used were digits drawn from the set of *2* through *9*, and uppercase letters drawn from the alphabet (excluding *I*, *O*, *M,* and *W*). These stimuli were presented in a Helvetica font, size 36, and they could appear in red, green, blue, or light gray, on a dark gray background. These colors were chosen so as to minimize differences in luminance, with the red, green, blue (RGB) values for red, green, blue, light gray, and dark gray being [108 0 0], [0 70 0], [0 0 108], [125 125 125], and [90 90 90], respectively. The experiment was run in a normally illuminated room using an Apple Macintosh G4 computer. Stimuli appeared on a 17-inch monitor running at 75 Hz with a resolution of 1024 × 768 pixels. Stimulus presentation was controlled using MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

Design and procedure. The construction of the RSVP sequences began with the selection of two targets from the set of digits. The remaining six digits were used as distractors, together with the set of letters. For each trial, 24 items were selected at random from this distractor set, with the restrictions that no item would occur twice on a given trial and that the digit targets would always be preceded and followed by two letters. The first target was inserted in serial position 8 or 12, and T2 was inserted in either the 4th or 12th position to follow T1 (i.e., at Lag 4 or 12). Each item was presented for 40 ms and followed by a 13.3 ms blank, yielding a presentation rate of 53.3 ms per item.[1]

For 8 participants, the targets were presented in red; for the remaining 8 participants, the targets were presented in green. The colors of the distractors alternated between blue and light gray. The two distractors directly preceding T2 could be presented in red, green, or the distractor colors. The latter condition is the uncued condition, while—depending on the color of the targets—the former two conditions make up the *same color* and *different color* cued trials. That is, for the subjects looking for red targets, red cues were same-color cues, and green cues were different-color cues. There were two reasons for using two cues instead of a single cue. The first is that a previous experiment showed that the optimal time-window for the cuing effect lies around cue-target intervals ranging from 100–200 ms (see Experiment 1 in Nieuwenstein et al., 2005). A second reason for using two cues was that this procedure could easily be modified for the purpose of investigating the effect of a distractor intervening between a cue and T2 (see Experiment 2). Each combination of cuing condition (uncued, same-

[1] Previous work has shown that the temporal profile of the AB effect observed with such rapid presentation rates is similar to that observed with more conventional rates of 10 items per second (Wyble & Bowman, 2005; see also, Potter et al., 2002). For the present purposes, the use of a high rate of presentation has the benefit that it allows for the number of cues presented to be manipulated while ensuring that the targets appear within the 500-ms duration of the AB (see Experiment 2).

color cue, or different-color cue), T1 serial position (8 or 12), and lag (4 or 12) was repeated 10 times in the experiment, yielding 20 trials per lag for each cuing condition. The order in which the different types of trials were presented was randomized, and the experiment began with a block of 12 practice trials.

Observers were told they had to search sequences of blue and gray letters and digits for two digits presented in the target color. Their task was to report the targets by typing them at the end of the trial; they were encouraged to enter the targets in the order of appearance, and to guess if they were unsure what the targets were. The experiment was conducted in a single 15-minute session.

Results: Experiment 1A

Two participants were replaced because they failed to identify T1 on more than 60% of the trials, leaving fewer than 8 trials for the analyses of T2 report conditional on correct report of T1. For the analyses of first and second target performance, the data are collapsed across target color, as the results were not affected by whether the targets were presented in green or in red.

First target report was correct on 84% of the trials. Second target performance for trials on which T1 was correctly reported (T2|T1; see Figure 1A) was analyzed with repeated measures analyses of variance, using cuing (uncued, different color, and same color) and lag (4 vs. 12) as factors. There were significant main effects of lag, $F(1, 15) = 21.0$, $MSE = .038$, $p < .01$, and cuing, $F(2, 30) = 8.98$, $MSE = .029$, $p < .01$, as well as a significant interaction between cuing and lag, $F(2, 30) = 11.75$, $MSE = .008$, $p < .01$. Contrasts comparing performance for the uncued condition with performance in each of the two cued conditions separately showed a significant Cuing × Lag interaction for the comparison of the uncued and same-color conditions, $F(1, 14) = 25.92$, $MSE = .013$, $p < .01$. This interaction approached significance for the comparison between the uncued condition and the condition with different-color cues, $F(1, 14) = 4.12$, $MSE = .01$, $p = .06$.

Cuing effects with same- and different-color cues were further evaluated using pairwise *t* tests for comparing T2 report for each of the three conditions at Lag 4. T2 report was significantly better with same-color cues than with different-color cues, $M = 79\%$ versus $M = 59\%$ correct, respectively, $t(15) = 3.42$, $p < .01$, and performance with different-color cues was significantly better than performance in the uncued condition ($M = 52\%$ correct), $t(15) = 2.66$, $p < .05$. Thus, both same- and different-color cues produced attenuation of the AB, although same-color cues had a larger effect on T2 report than different-color cues. In fact, there was no significant effect of lag on T2|T1 when T2 was cued with same-color distractors ($p = .13$), indicating that cuing eliminated the attentional blink.

A second analysis was run to determine whether T1 performance was affected by the difference in T2 performance observed in the three cuing conditions. This analysis used cuing condition (uncued, different-color cue, and same-color cue), and lag (4 vs. 12) as factors, and included only trials in which T2 was correctly reported. Table 1A lists mean T1 performance across lags and cuing conditions. There was no effect of cuing condition on T1 report, $F < 1$, whereas there was a trend toward an effect of lag, $F(1, 15) = 4.23$, $MSE = .0042$, $p = .06$, with T1 performance increasing slightly across increasing lags ($M = 83\%$ vs. $M = 86\%$ correct T1 report at lags 4 and 12, respectively). The Cuing × Lag

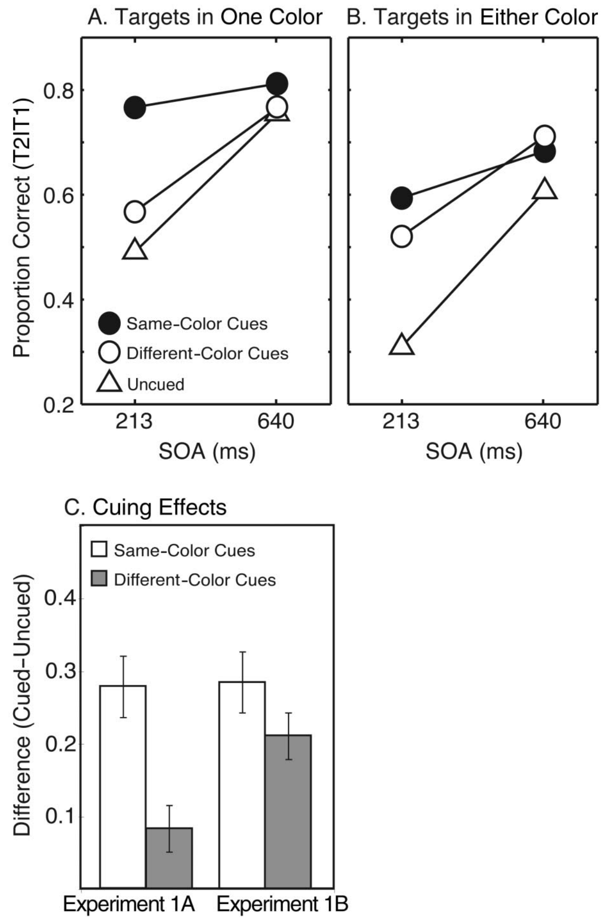

Figure 1. A: Results from Experiment 1A in which targets were always presented in the same color. Graph shows proportion correct identification of T2 on trials in which T1 was correctly identified (T2|T1), plotted as a function of stimulus onset asynchrony (SOA) for the different cuing conditions. B: Results from Experiment 1B in which targets were presented in red and green. Attentional blink effects for uncued T2s and T2s cued by distractors presented in the same or in a different color as T2. C: Difference between cued and uncued targets in Experiments 1A and 1B.

interaction was not significant, $F < 1$. These results indicate that, even though cuing had profound effects on T2 report at Lag 4, this did not affect T1 performance. Further discussion of the results of Experiment 1A is provided after Experiment 1B is reported.

Method: Experiment 1B

Experiment 1B was identical to Experiment 1A, with the exception that observers were now instructed to search for red *and* green digit targets. All combinations of target colors were used equally often, so both targets could be presented in green or red, or one of the targets could be presented in red while the other target appeared in green. On half of 240 trials, the targets were presented in the same color, whereas they appeared in different colors on the other 120 trials. As in Experiment 1A, T2 could be preceded by two distractors presented in red, in green, or in the distractor colors (i.e., blue and light gray). The order in which different trial types were presented was randomized. A new group of 16 members of the Massachusetts Institute of Technology participated in this experiment in return for monetary compensation. None of the observers was color blind. The experiment was run in a single 30-minute session.

Results: Experiment 1B

Four observers were replaced because they failed to identify T1 on more than 60% of the trials. Averaged across lags, cuing conditions, and target colors, the first target was correctly identified on 65% of the trials. Second target performance was analyzed with repeated measures analyses of variance using cuing condition (uncued, same color, and different color), and lag (4 vs. 12), as factors, including only those trials on which T1 was correctly reported. The data were collapsed across target color (i.e., T1 and T2 in same or different colors) because this factor did not have a significant influence on the effects of lag and cuing condition. There was, however, a trend toward better T2 report when the targets were presented in the same color (M = 60 vs. M = 54% correct for same- and different-color targets, respectively, $F(1, 15) = 3.83$, $MSE = .044$, $p = .07$).

Figure 1B shows T2 report for the three cuing conditions, plotted as a function of lag. There were significant effects of cuing and lag, $F(2, 30) = 34.01$, $MSE = .009$, $p < .01$, and $F(1, 15) = 34.76$, $MSE = .025$, $p < .01$, respectively, and a significant interaction between cuing and lag, $F(1, 15) = 6.55$, $MSE = .019$, $p < .05$. Contrasts comparing performance for the uncued condition with performance in each of the two cued conditions separately showed that T2 report was significantly worse in the uncued condition (M = 46% correct) than in the condition with same-color cues (M = 64% correct, $F(1, 15) = 41.72$, $MSE = .025$, $p < .01$) and in the condition with different-color cues (M = 62% correct, $F(1, 15) = 56.30$, $MSE = .014$, $p < .01$). In addition, both comparisons showed that the cuing effect depended on lag, with a significant Cuing × Lag interaction for the comparison between the uncued and same-color condition, $F(1, 15) = 7.95$, $MSE = .043$, $p < .05$, whereas the Cuing × Lag interaction approached significance for the comparison between the uncued and different-color conditions, $F(1, 15) = 3.55$, $MSE = .025$, $p = .07$. Pairwise t tests for T2 report at Lag 4 showed that T2 report was significantly better with same-color cues than with different-color cues, M = 59 versus M = 52% correct, respectively, $t(15) = 3.98$, $p < .01$, and that performance with different-color cues was significantly better than performance in the uncued condition (M = 31% correct), $t(15) = 6.39$, $p < .01$.

A second analysis using only those trials on which T2 was correctly reported compared T1 report across cuing conditions and lags. Table 1B lists mean T1 performance for the different cells in the design. There were significant effects of cuing condition and lag on T1 report, $F(2, 30) = 4.38$, $MSE = .0058$, $p < .05$, and $F(1, 15) = 28.15$, $MSE = .008$, $p < .01$, respectively. It is important to note, however, that although there was no significant interaction between cuing condition and lag, $p = .24$, the effect of cuing condition on T1 report was limited to Lag 12 (see Table 1B): When only Lag 4 trials were included, the effect of cuing condition failed to reach significance, $F < 1$.

Comparison of Experiments 1A and 1B

The results from Experiments 1A and 1B show the same pattern of cuing effects at Lag 4: Compared to the uncued condition, same-color cues produced the strongest effect on T2 report,

Table 1A
Proportion Correct T1 Report in Trials on Which T2 was Correctly Reported in Experiment 1A

Condition	Lag 4 M	Lag 4 SE	Lag 12 M	Lag 12 SE
Uncued	0.85	0.035	0.85	0.038
Same-color cue	0.81	0.044	0.86	0.036
Different-color cue	0.83	0.038	0.86	0.031

Table 1B
Proportion Correct T1 Report in Trials on Which T2 was Correctly Reported in Experiment 1B

Condition	Lag 4 M	Lag 4 SE	Lag 12 M	Lag 12 SE
Uncued	0.56	0.048	0.68	0.048
Same-color cue	0.54	0.040	0.60	0.037
Different-color cue	0.56	0.038	0.66	0.038

whereas different-color cues produced a significant, but smaller, benefit for T2 report. However, as can be seen by comparing Figures 1A and 1B, the extent to which different-color cues enhanced T2 report depended on the different task instructions for Experiments 1A and 1B. This can be seen more clearly in Figure 1C, which plots the difference between T2 performance in the two cuing conditions and the uncued condition for trials on which T2 appeared at Lag 4. The interaction between cuing condition and experiment was significant, $F(2, 60) = 3.40$, $MSE = 0.012$, $p < .05$. This interaction comprised two effects. First, the difference between same and different-color cues was significantly smaller in Experiment 1B than in Experiment 1A, $F(1, 30) = 8.0$, $MSE = 0.016$, $p < .01$. A second effect was that the difference between performance in the uncued and different-color conditions was larger in Experiment 1B than in Experiment 1A, $F(1, 30) = 4.09$, $MSE = 0.016$, $p < .05$. Both effects indicate that the effect of cuing T2 with different-color distractors was larger when the color of these cues was included in the target set.

Another notable difference between the results obtained in the two experiments was that target report performance was worse in Experiment 1B than in Experiment 1A. In particular, T1 was correctly identified on 84% of the trials in Experiment 1A, and on 64% of the trials in Experiment 1B ($p = .001$). Similarly, T2 report accuracy on trials in which T1 was correctly identified also differed significantly between the experiments, with T2 being correctly reported on 73% of the trials in Experiment 1A and on 57% of the trials in Experiment 1B ($p = .003$). It is interesting that, even though target identification appeared to be more difficult in Experiment 1B than in Experiment 1A, this did not affect the AB. For example, a comparison of T2 report accuracy in the uncued conditions of the two experiments showed a main effect of the experiment, with T2 report being worse in Experiment 1B than in Experiment 1A (45.8 vs. 65.5% correct, respectively, $p = .004$), but no interaction of lag and experiment (see Figures 1A and 1B). Although at present it is unclear how uncertainty about the target's color might affect overall report without interacting with the effect of lag in the AB, it is interesting to note that similar effects have been observed in studies of visual search (e.g., Moore & Osman, 1993; for a recent overview of related work, see Wolfe, Butcher, Lee & Hyle, 2003). In particular, these studies typically show that although response times decrease when target color is repeated across a series of trials, this effect is constant across display sizes and therefore does not appear to affect the guidance of attention toward the target.

Discussion: Experiments 1A and 1B

Taken together, the results from Experiments 1A and 1B replicate those reported in the study by Nieuwenstein et al. (2005), in that they show that precuing T2 attenuates the AB and that T1 performance does not suffer from the increase in T2 report, even when T2 appears within 213 ms of T1. Note that this cuing effect could be so large that it fully prevented the effect of an AB, as is shown by the results with same-color cues in Experiment 1A. The main finding of interest from Experiments 1A and 1B is that the results showed that distractors drawn from a different category and presented in a different color than T2 were highly effective cues for T2 when their color matched one of two possible target colors. This finding is consistent with the delayed engagement account as it shows that the effectiveness of a cue depends foremost on its match to the attentional set, and not so much on whether it shares characteristics with the following target. On the other hand, this finding poses a significant problem for the TLC account (Di Lollo et al., 2005), which would predict that cuing should occur only when the distractor directly preceding T2 shares a characteristic with the following target.

Experiment 2

The aim of Experiment 2 was to provide a further test of the delayed selection account by determining whether the cuing effect observed with two cues in the previous experiments is disrupted when the cue directly preceding T2 is replaced with a distractor. The delayed selection account predicts that this should have little effect on cuing because replacing the second cue with a distractor does not change the temporal separation between the onset of the first cue and T2. Therefore, the probability that T2 falls within the attentional episode initiated by the first cue is equal across the condition with two cues and the condition with a single cue in the penultimate position prior to T2. On the other hand, the TLC account (Di Lollo et al., 2005) would predict that an intervening distractor would disrupt cuing, as this distractor would result in a filter that is no longer optimally configured for the following target.

Experiment 2 used the same setup and procedure as that used in Experiment 1A, with the difference that the targets were now presented in red for all participants. Performance for T2 report was compared between an uncued condition and two cued conditions. In one of these cued conditions, the cue-cue-target (CCT) condition, T2 was preceded by two red distractors. The other, critical condition was identical to this condition with the exception that the distractor directly preceding T2 was presented in one of the distractor colors. Thus, in this condition, hereafter referred to as the cue-distractor-target (CDT) condition, there was a single cue in the penultimate position before T2 and a distractor intervened between this cue and T2. Twenty members from the Massachusetts Institute of Technology community participated in the experiment. All reported having normal color vision, and none had participated in the previous experiments.

Results: Experiment 2

The first target was correctly identified on 83% of the trials. T1 performance was not affected by cuing condition or lag, all *p*s > .10. T2 report was compared across cuing conditions and lags, using only those trials on which T1 was correctly reported. These results are plotted in Figure 2. The results from repeated measures analyses of variance showed a significant main effect of lag, $F(1, 19) = 8.38$, $MSE = .037$, $p = .009$. In addition, there was a significant interaction of lag and cuing condition, $F(2, 36) = 11.01$, $MSE = .013$, $p < .001$.

Performance in each of the two cued conditions was separately compared with performance in the uncued condition. The results showed a significant Lag × Cuing Condition interaction for both comparisons, $F(1, 19) = 12.24$, $MSE = .040$, $p = .002$, and $F(1, 19) = 22.21$, $MSE = .017$, $p < .001$, for the comparisons of uncued T2 report with T2 report in the CCT and CDT conditions, respectively. Pairwise *t* tests showed that, at Lag 4, T2 report was significantly worse in the uncued condition than in either of the two cued conditions, $t(19) = 4.26$, $p < .001$, and $t(19) = 3.27$, $p = .004$, for the differences with the CCT and CDT conditions, respectively. At Lag 4, performance did not differ between the two cued conditions, $t(19) = 1.3$, $p = .21$. For Lag 12, the only

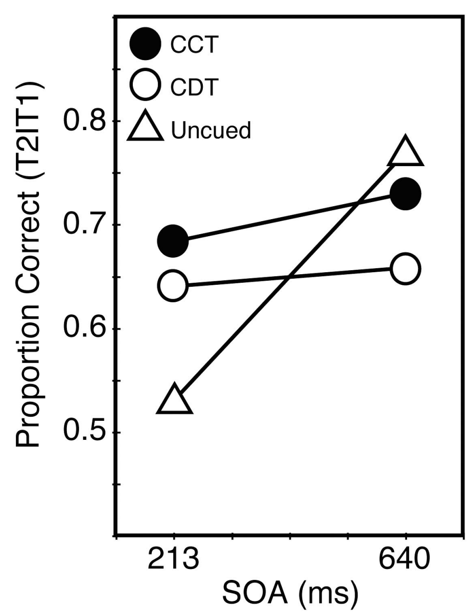

Figure 2. Results from Experiment 2. Proportion correct identification of T2 is plotted as a function of SOA and cuing condition for trials on which T1 was correctly identified (T2|T1). CCT refers to the condition in which T2 was preceded by two cues, CDT refers to the condition in which a cue was presented only in the penultimate position prior to T2, with a distractor intervening between the cue and T2.

significant difference was that between T2 report in the uncued and the CDT conditions, $t(19) = 2.27$, $p = .04$. Thus, both cuing conditions produced a marked improvement in T2 report during the AB. Analyses comparing T2 report in the CDT and CCT conditions showed that there was no significant effect of lag on T2 report in either of the two cued conditions, both $ps > .20$, while the difference between T2 report in these conditions approached significance, $M = 65\%$ versus $M = 70\%$ correct T2 report in the CDT and CCT conditions, respectively, $F(1, 19) = 3.72$, $MSE = 0.018$, $p = .07$.

Discussion: Experiment 2

The results from Experiment 2 show equivalent cuing effects for the CDT and CCT conditions during the AB, such that both conditions resulted in improved report of T2 when compared to the uncued control condition. However, when T2 was presented at Lag 12 (i.e., at a stimulus onset asynchrony of 640 ms), target report was worse in the CDT condition than in the uncued condition, while the difference between the CCT condition and the uncued condition was nonsignificant. Thus, the distractor intervening between the cue and T2 in the CDT condition had little effect during the AB, although it did appear to disrupt the allocation of attention outside of the temporal extent of the AB.

The reversal in performance in the uncued and CDT conditions across lags can be argued to reflect the changing agility of processes involved in target selection across the time course of the AB. During the AB, the initiation of attention allocation upon detection of the first cue is delayed. As a consequence of this delay, the engagement of attentional resources may coincide with T2 and not with the item intervening between the first cue and T2. Outside of the AB, however, the allocation of attention can be initiated rapidly and therefore T2 has a greater chance of falling outside of the temporal extent of the attentional episode triggered upon detection of the first cue. Although this interpretation is consistent with the finding that report accuracy for T2s presented outside of the AB decreases as the number of cues preceding T2 increases from one to three (Experiment 1 in Nieuwenstein et al., 2005), it does not account for the difference observed between the CDT and the CCT conditions at the long lag in the present experiment. Notably, this result suggests that the temporal extent of an attentional episode is not fixed, but is instead determined by the task relevance of the stimuli that are presented during the episode. In this view, the impairment observed for T2 report in the CDT condition may reflect the disruption of attention allocation due to the inadvertent selection of the distractor that intervened between the first cue and T2, rather than T2 (e.g., Olivers et al., in press). This explanation is supported by the finding that observers have little difficulty in reporting the last of three consecutive targets while report of the same target is substantially impaired when the second of the three targets is replaced by a distractor (Di Lollo et al., 2005). A more detailed discussion of these issues is provided in the General Discussion.

Experiment 3

The results from the previous experiments support the delayed engagement account by showing that (a) a cuing effect can be triggered by a distractor that does not match the color or category of the following target; and (b) the cuing effect is not disrupted when a distractor intervenes between the cue and T2. However, the results from these experiments also consistently showed that the cuing effect tended to be strongest when the distractor directly preceding T2 was presented in the same color as the target. The aim of Experiment 3 was to determine whether this beneficial effect of color repetition depends on the fact that the repeated color matched attentional set. To this end, the effect of color repetition was compared between two conditions: one in which T2's color was not specified, and one in which the color in which T2 would appear was specified at the beginning of each trial. The logic for this comparison was that if the effect of color repetition observed in the previous experiments was driven by the task relevance of the color being repeated, it should occur only in the condition in which T2's color was specified.

Method: Experiment 3

Participants. Sixteen members from the Massachusetts Institute of Technology community participated in the experiment. All reported having normal color vision.

Apparatus and Stimuli. The stimuli and apparatus were the same as those used in the previous experiments.

Design and Procedure. On each trial, an RSVP sequence of 26 letters was presented at a rate of 67 ms per item (i.e., each item was presented for 40 ms and followed by a 27-ms blank interval). Targets were two digits. T1 was presented as the 8th or 12th item in the sequence, and T2 was inserted in either the 4th or 10th position to follow T1 (i.e., at Lag 4 or 10, corresponding to stimulus-onset asynchronies of 267 and 667 ms, respectively). T2 was equally often presented in blue, red, green, or light gray, and the first target and the distractors were presented in the three remaining colors. So, if T2 was presented in red, T1 and the distractors were presented in blue, green, and light gray. On half the trials, the distractor preceding T2 was presented in the same color as T2 (i.e., the cued trials).

In order to investigate if the effect of presenting a same-color distractor in advance of T2 depends on whether or not this color is specified in the target set, there were two blocks of trials in this experiment. In one block, the T2 color-known condition, the color in which T2 would be presented was indicated by the color of the fixation cross that preceded the RSVP sequence. In this block, the fixation cross changed color to the color of T2 for one second when subjects pressed the spacebar to begin the trial. The fixation cross was subsequently presented in black for another 400 ms before the RSVP sequence began. In the other block, the T2 color-unknown condition, the fixation cross was always presented in black, and remained on screen for 400 ms after subjects pressed the spacebar to begin the trial.

Each combination of cuing condition (uncued or cued), T1 serial position (8 or 12), and lag (4 or 10) was repeated eight times in each of the two blocks, yielding 16 trials per combination of lag, cuing condition, and T2 color condition. The order in which the two blocks were run was counterbalanced between subjects, and the order in which different types of trials in each block were presented was randomized. Both blocks began with a set of 12 practice trials.

Before each of the two blocks, the instructions for the task were presented on the screen. In the T2 color-unknown condition, observers were instructed to identify two digits presented in an RSVP sequence of colored letters. They were told that the digits could appear in any of the four colors. In the T2 color-known condition, they were instructed to look for two colored digits, with the color of the second digit being indicated by the color of the fixation cross at the beginning of the trial. As in the previous experiments, observers reported the two targets by typing them in on the keyboard at the end of the trial and they were encouraged to type in the targets in the order of appearance, and to guess if they were unsure. The experiment was conducted in a single 15-minute session.

Results: Experiment 3

One subject was replaced because of very low performance for T1 report in the condition in which T2's color was known (i.e., 21% correct vs. 83% correct in the T2 color-unknown condition). Apparently, this subject used a color-based selection strategy in this condition, which significantly harmed T1 report because T1 was always presented in a different color than T2. For the other subjects, T1 report was not affected by whether or not T2's color was known, which suggests that they did not use color as a primary selection criterion for target search. In addition, T1 report was not affected by lag or cuing condition (all *p*s $> .13$). Averaged across conditions, T1 was correctly reported on 85% of the trials.

Figures 3A and 3B show T2 report accuracy for the conditions in which T2's color was unknown and known, respectively. Repeated measures analyses of variance using task instruction (T2 color unknown vs. known), lag (4 vs. 10), and cuing (T2 preceded by same-color distractor or not) as factors showed that there were significant main effects of task instruction and lag, $F(1, 15) = 6.28$, $MSE = .018$, $p < .05$, and, $F(1, 15) = 29.35$, $MSE = .032$, $p < .01$, respectively. The interaction between task instruction and cuing was significant, $F(1, 15) = 7.71$, $MSE = .01$, $p < .05$, whereas the interaction between task instruction and lag approached significance, $F(1, 15) = 3.55$, $MSE = .011$, $p = .08$. The latter finding shows that the effect of lag tended to be more pronounced when T2's color was known as compared to when T2's color was unknown. The three-way interaction between task instruction, lag, and cuing was also significant, $F(1, 15) = 6.10$, $MSE = .047$, $p < .05$.

Separate analyses for the effects of lag and cuing condition in the conditions in which T2 color was known or unknown showed that cuing tended to have a negative effect on T2 report when T2's color was unknown, $F(1, 15) = 4.30$, $MSE = .011$, $p = .06$. This effect did not interact with lag, $F < 1$. For the condition in which T2's color was known, however, there was a significant interaction between lag and cuing, $F(1, 15) = 6.97$, $MSE = .009$, $p < .05$. As can be seen in Figure 3B, this interaction reflects the finding that cuing produced selective enhancement for second targets presented at Lag 4. A pair-samples *t* test confirmed that the difference between performance for cued and uncued second targets was significant at Lag 4, $t(15) = 2.77$, $p < .05$.

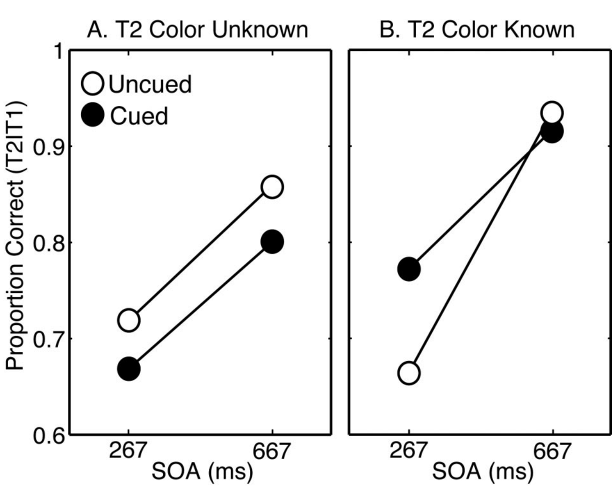

Figure 3. A: Results from Experiment 3 for the condition in which T2's color was unknown. Proportion correct identification of T2 is plotted as a function of SOA and cuing condition for trials on which T1 was correctly identified (T2|T1). B: Results for the condition in which T2's color was known.

Discussion: Experiment 3

The results from Experiment 3 show that presenting a same-color distractor in advance of T2 facilitates T2 report only when T2's color is specified. It is interesting to note that the same cuing manipulation seemed to interfere with report when T2's color was unknown to the observer. This effect may have been due to the reduced demarcation of the onset of T2 when it was preceded by a distractor in the same color. Notably, in this condition the onset of T2 was marked only by a change in category and not by a change in both color and category. As a consequence, detection of the target may have been further delayed, leading to a slower attentional response and greater interference between T2 and its mask. Taken together, these findings show that the beneficial effect of feature repetition observed in the previous experiments occurred because observers paid attention to that feature, thereby demonstrating that attentional set is maintained during the AB.

The magnitude of the AB tended to be larger when T2's color was known than when T2's color was unknown, as was indicated by the fact that the interaction of lag and T2 color approached significance. This effect may reflect the cost of an endogenous switch in attentional set from T1 to T2 in the T2 color-known condition. In particular, because T1's color was unknown while T2's color was known, observers had to switch from searching for any digit to searching for a digit in a particular color. Such a switch in attentional set may have further delayed processing of T2 (Kawahara, Zuvic, Enns & Di Lollo, 2003), resulting in a larger impairment for T2 report at the short lag. However, at the longer lag, observers appeared to benefit from having advance knowledge of the color of T2.

Experiment 4

There have been several recent studies that used RSVP paradigms with more than two targets to investigate how report of a third target (T3) is affected when this target is directly preceded by T2, as compared to when it is preceded by a distractor (Di Lollo et al., 2005; Kawahara, Enns et al., in press; Kawahara, Kumada et al., in press; for a four-target variant see Olivers et al., in press). The main finding in these studies is that T3 is spared from the AB triggered by the first target when T3 is directly preceded by T2, a finding that is highly similar to the cuing effect. Although this result has been interpreted as support for the TLC account by Di Lollo and colleagues (e.g., Di Lollo et al., 2005; Kawahara, Kumada et al.), it can be argued that it is equally consistent with the delayed engagement account advocated in the present study (e.g., Olivers et al.). The aim of Experiment 4 was to contrast the roles of delayed attentional engagement and exogenous filter reconfiguration in the finding that report of a third target is spared from the AB when it is directly preceded by T2. This was done by examining a condition for which the two accounts make different predictions: the case in which T2 and T3 do not appear in direct succession, but are instead separated by a single distractor (see also Experiment 2). As argued previously, the TLC account would predict that the intervening distractor should prevent sparing of T3 report, while the delayed engagement account predicts that an intervening distractor should still allow for a cuing benefit.

An additional important issue that can be addressed using a three-target paradigm concerns the effect of T2 report on report of the following T3. In particular, considering that report accuracy for targets presented during the AB seldom approaches chance, it is interesting to examine how report of T3 is affected by whether a preceding T2 that appeared within the AB period could be reported. It is striking, however, that none of the studies that used a three-target (or four-target) paradigm included T2 report accuracy as a factor in the analyses of the data for T3 report. Instead, these studies either looked only at trials on which T2 was reported (Chun & Potter, 1995) or they averaged across trials in which T2 was or was not reported (Di Lollo et al., 2005; Kawahara, Kumada et al., in press; Olivers et al., in press).

In order to examine these issues, a three-target task was used in which the targets were three letters presented in an RSVP sequence of digit distractors (for a similar design, see Experiment 2 in Chun & Potter, 1995). The T1-T2 lag was either short (i.e., Lag 4, corresponding to a stimulus onset asynchrony [SOA] of 267 ms) or long (i.e., Lag 10, corresponding to a 667-ms SOA), and T3 followed T2 at Lag 1, 2, or 3 (corresponding to T2-T3 SOAs of 67, 133, and 200 ms). Thus, in the case wherein T2 appeared at 267 ms from T1, T3 could still be presented within the temporal extent of the AB triggered by T1 (i.e., at T1-T3 SOAs of 334, 400, and 467 ms). In order to evaluate if and how T3 report would be affected when preceded by T2, the observers also participated in a two-target condition in which the second target could occur at T1-T2 lags that included all possible T1-T2 and T1-T3 lags used in the three-target condition. This allowed for a comparison between accuracy for T3 report in the three-target condition and accuracy for T2 in the two-target condition.

Method: Experiment 4

Participants. Ten members from the Massachusetts Institute of Technology community volunteered to participate in the experiment in return for monetary compensation. All reported having normal or corrected-to-normal vision.

Apparatus and Stimuli. The stimuli used were digits drawn from the set of *2* through *9*, and uppercase letters drawn from the alphabet (excluding *I*, *O*, *M,* and *W* that were presented in a Helvetica font, size 20. Stimuli were presented in black on a light gray background. The setup was the same as that used in the previous experiments.

Design and Procedure. There were two blocks of trials for each observer. In one block, the three-target condition, the RSVP sequences contained 21 distractors and three targets. The sequences began and ended with the presentation of a fixation cross. Distractors were chosen randomly from the set of digits with the constraint that a particular distractor could not have been presented in the two previous serial positions. Targets were drawn randomly from the set of letters with the constraint that the three targets were always different letters. The first target was inserted in the 6th or 8th serial position of the RSVP sequence. T2 was inserted in either the 4th or the 10th position following T1 (i.e., at Lag 4 or 10), and T3 was inserted either in the 1st, 2nd or 3rd position to follow T2 (i.e., at Lag 1, 2, or 3). All combinations of T1 serial position (6 or 8), T1-T2 lag (4 or 10), and T2-T3 lag (1, 2, or 3), were repeated 10 times across the experiment, resulting in a total of 120 trials, with 20 replications per combination of T1-T2 lag and T2-T3 lag.

In the other block of trials, the two-target condition, each RSVP sequence contained only two targets that were presented at Lag 4, 5, 6, 7, 10, 11, 12, or 13. These lags corresponded to all possible T1-T2 and T1-T3 lags used in the three-target condition. There were 20 replications for each lag, yielding a total of 160 trials.

For both blocks, the order in which the different trial types were presented was randomized. The three-target block began with a set of 12 practice trials, and the two-target block began with a set of 16 practice trials. Observers were instructed to identify the letters in each sequence, and they had to report these letters at the end of the trial by typing them in on the keyboard. They were informed of the number of letters used in the two blocks, and they were asked to guess when they were unsure which letters had been presented. The order in which the two blocks were run was counterbalanced between participants and the experiment was run in one session of approximately 45 minutes.

Results: Experiment 4

The first target was correctly identified on 85% of the trials in the three-target condition, and on 86% of the trials in the two-target condition. A first analysis compared report of T2 at the 267-ms and 667-ms T1-T2 SOAs in the two conditions (three targets vs. two targets; see Figure 4), and included only trials on which T1 was correctly reported. The results showed a significant effect of SOA, replicating the typical AB effect, $M = 47$ versus $M = 73\%$ correct report of T2 at SOAs of 267 and 667 ms, respectively, $F(1, 9) = 25.76$, $MSE = 0.026$, $p < .01$. There was no interaction between lag and condition, $F < 1$, indicating that the number of targets to be reported did not influence the lag functions for T2.

The main results of interest concern the comparison between T2 report in the two-target condition and T3 report in the three-target condition across short SOAs (i.e., 334, 400, and 467 ms). Two separate analyses were done to compare the results for T3 report accuracy with T2 report accuracy in the two-target condition (i.e., the control condition): one analysis included trials from the three-target condition on which T2 could not be identified (henceforth referred to as the *T2 missed condition*), and one that included only those trials on which T2 was correctly identified (referred to as the *T2 reported condition*). As can be seen in Figure 4, T3 report in the T2 missed condition was substantially better across short SOAs than accuracy for T2 report in the control condition. This was confirmed by the analyses of target report accuracy using condition (T2 missed vs. control) and SOA (334, 400, and 467 ms), as factors, which showed a significant SOA × Condition interaction, $F(1, 9) = 5.49$, $MSE = .04$, $p < .05$. Pairwise t tests comparing target report between the T2 missed and control conditions across each SOA showed that report was significantly better in the T2 missed condition than in the control condition at the 334-ms SOA, $M = 77$ versus $M = 52\%$ correct, $t(9) = 2.97$, $p < .05$, and at the 400-ms SOA, $M = 78$ versus $M = 63\%$ correct T3 report, $t(9) = 4.45$, $p < .01$. At a 467-ms SOA, report accuracy did not differ between these conditions, $p = .67$. Thus, T3 report was enhanced

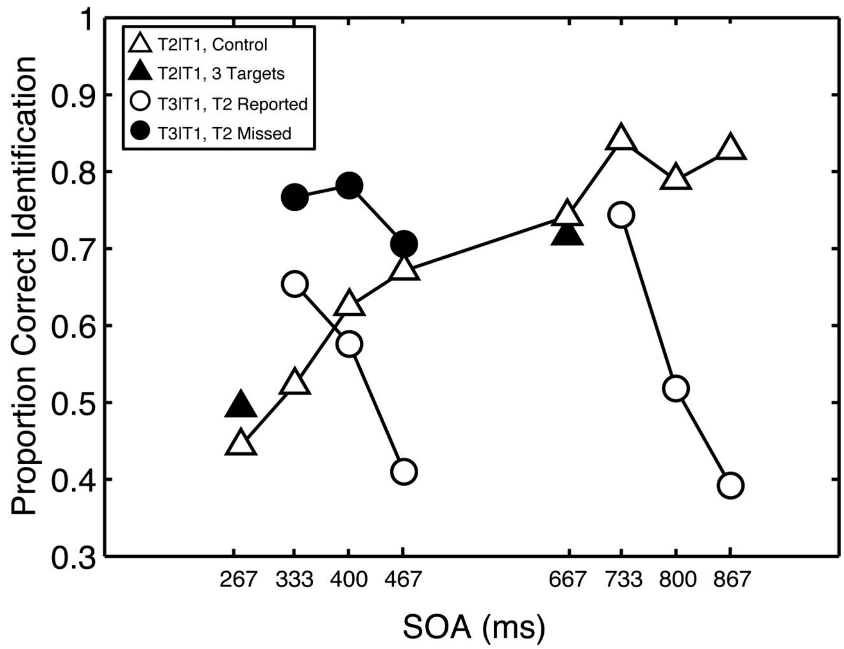

Figure 4. Results from Experiment 4. Accuracy for T2 and T3 report, conditional on correct report of T1 (i.e., T2|T1 and T3|T1). SOA refers to the stimulus onset asynchrony between T1 and either T2 (in the two-target condition) or T3 (in the three-target condition). Proportion correct report for T3 is depicted separately for trials on which T2 was missed and reported. Control condition refers to T2 report in the two-target condition. Note that performance for the T2 blinked condition is not shown for the long SOAs because there were too few trials on which T2 was missed.

when it was preceded by a target that could not be reported, and this cuing effect extended across an intervening distractor.

The second analysis contrasted T2 report in the control condition with performance on T3 for trials on which T2 was reported (the T2 reported condition), again using only those trials in which the targets appeared shortly after T1 (i.e., at the 334, 400, and 467-ms SOAs). The results for this comparison showed a significant interaction of SOA and condition, $F(1, 9) = 21.51$, $MSE = .036$, $p < .01$. Pairwise t tests showed that the difference between conditions was significant only at the 467-ms SOA, where performance in the T2 reported condition was worse than in the control condition, $M = 41$ versus $M = 67\%$ correct T3 report, respectively, $t(9) = 2.80$, $p < .05$. At the 334-ms SOA, performance in the T2 reported condition seemed better than in the control condition, $M = 65$ versus $M = 52\%$ correct, respectively, but this difference was not significant, $t(9) = 1.74$, $p = .12$. Thus, a reported T2 appeared to trigger an AB, with T3 report showing some initial sparing at Lag 1 followed by a marked decrease in accuracy across Lags 2 and 3. The ABs observed for T3 report in the T2 reported condition were equivalent for trials wherein T2 appeared 267 ms after T1 and trials wherein T2 appeared 667 ms after T1 ($p > .10$ for the interaction).

Discussion: Experiment 4

The results from Experiment 4 reveal several interesting findings. To start, the results replicate the finding that T3 report is not affected by the AB when it is directly preceded by T2 (Di Lollo et al., 2005; Kawahara, Enns et al., in press; Kawahara, Kumada et al., in press; Olivers et al., in press). However, the results also show that the magnitude and time course of this cuing effect depend strongly on whether T2 was reported. In particular, the results for trials on which T2 was reported showed a short-lived, nonsignificant, cuing effect for report of T3, while the results for trials on which T2 could not be reported showed a stronger cuing effect that extended across an intervening distractor. These results imply that the findings from previous multiple-target studies should be interpreted with caution, as these studies collapsed the data across trials in which T2 was reported and missed. In addition, it can be argued that these results demonstrate that the beneficial effect of a preceding target on T3 report reflects the delayed allocation of attention initiated by the preceding target, and not the exogenous reconfiguration of an input filter as argued by Di Lollo and colleagues. Notably, the latter interpretation does not allow for cuing effects that extend across an intervening distractor, a finding that was observed in both Experiments 2 and 4 in the present study.

General Discussion

During the last decade, there has been intensive debate about the nature of the processing limitation that underlies the AB (e.g., Chun, 1997b; Chun & Potter, 1995; Di Lollo et al., 2005; Giesbrecht & Di Lollo, 1998; Jolicœur & Dell'Acqua, 1998; Nieuwenhuis et al., 2005; Potter et al., 2002; Raymond et al., 1992; Raymond, 2003; Shapiro, Arnell & Raymond, 1997; Vogel, Luck & Shapiro, 1998). This debate has culminated in two recent proposals regarding the cause of the AB: the delayed engagement account proposed by Nieuwenstein et al. (2005) and the TLC account proposed by Di Lollo and colleagues (Di Lollo et al., 2005; Kawahara, Enns et al., in press; Kawahara, Kumada et al., in press). Both of these accounts are based on the finding that the impairment in report of targets presented during the AB is substantially reduced when the target is preceded by either a distractor that shares a feature with this target (Nieuwenstein et al.), or by another target (Di Lollo et al.). Using different variants of the cuing paradigm introduced by Nieuwenstein and colleagues, the present study tested assumptions of the delayed engagement account that differentiate this account from TLC.

Summary of Empirical Findings

The results from Experiments 1A and 1B show that a distractor drawn from a different category and presented in a different color than T2 can be an effective cue when its color matches one of two possible target colors, thereby indicating that cuing can occur in the absence of any shared features between the cue and T2. In Experiment 2, it was shown that the cuing effect is not disrupted by a distractor intervening between the cue and T2. The results from this experiment also showed that when a cue-distractor-target sequence was presented outside of the temporal extent of the AB, the cue did appear to have a detrimental effect on target report. Experiment 3 showed that presenting a same-color distractor in advance of T2 only facilitates T2 report when observers know in which color T2 is presented, thereby indicating that cuing effect with color-defined targets does not reflect color priming. In Experiment 4, the results obtained with color-defined targets were found to generalize to a condition in which the targets were defined by category. In particular, this experiment showed that a second target that could not be reported due to the AB cued a following third target. This cuing effect was similar to that observed in Experiment 2 in that it extended across a distractor intervening between the two targets. A final noteworthy finding that was consistent across all of the experiments was that T1 identification was not affected by whether or not a shortly following target was cued and reported (see also Nieuwenstein et al., 2005).

Contingent, Delayed Selection During the AB

The findings obtained in the four experiments reported here provide consistent support for the two main premises of the delayed engagement account proposed by Nieuwenstein and colleagues (2005). The first of these is that the allocation of attentional resources remains under top-down control during the AB. This assumption predicts that the cuing effect should be triggered exclusively by stimuli that match attentional set for the targets. This prediction was confirmed in Experiments 1 and 3 in which the attentional set of the observers was manipulated by means of varying the instructions for the task, while the types of stimuli presented in RSVP were held constant. The main finding from these experiments was that whether a particular distractor elicited a cuing effect depended on whether or not its characteristics matched the characteristics of the targets provided in the task instruction. For example, when the task was to search for red digits, a green letter distractor was a relatively ineffective cue compared to a red letter that matched attentional set (Experiment 1A); a green distractor was as effective as a red distractor in cuing a following red target, however, when the task was to search for red and green digits (Experiment 1B). These findings, together with the similar finding observed in Experiment 3, clearly demonstrate that cuing is contingent on the match between the cue and the initial attentional set, a notion that is also supported by other work showing that attentional capture during the AB is contingent on whether or not the capture stimulus matches attentional set (Wee & Chua, 2004; Visser, Bischof & Di Lollo, 2004).

The second assertion of the delayed engagement account that was investigated in the present study is that the effect of cuing is to counteract a delay in the allocation of attentional resources that is specific to the AB. This prediction was tested in Experiments 2 and 4, which examined whether the cuing effect can extend across a distractor that intervenes between the cue and the following target. The results from these experiments confirmed the prediction by showing that the cuing effect was not disrupted by an intervening distractor. In addition, the results from these experiments also showed that cuing can have a detrimental effect on report of targets presented outside of the temporal extent of the AB, thereby confirming that the delay in attention allocation is specific to the AB. This conclusion is further supported by the finding that increasing the number of cues that precede a target that is presented outside of the AB results in a progressive decrease in target report accuracy (Nieuwenstein et al., 2005).

The Case Against TLC

On the basis of the present findings, the contingent, delayed selection account of cuing can be contrasted with the TLC account (Di Lollo et al., 2005; Kawahara, Enns et al., in press; Kawahara, Kumada et al., in press). To reiterate, TLC assumes that the AB occurs because the processing load of T1 identification results in a temporary loss of endogenous control over selective attention. As a consequence, distractors presented during the processing of T1 may exogenously reconfigure an input filter that was initially set to select targets and to exclude distractors from further processing. Applied to tasks in which observers search for digits in a particular color (e.g., red), this model thus assumes that a blue letter distractor following a first red digit target reconfigures attentional set, with the implication that observers will subsequently inadvertently select and process blue letters instead of red digits. In this view, cuing can facilitate T2 report because the cue resets the filter to the correct color or category so as to allow a following target to be selected.

The present findings raise several arguments against the way in which the TLC account would explain cuing, insofar as this account predicts that cuing should occur only when the cue matches the features of the following target. The present results show that this is not the case: Items drawn from a different category and presented in a different color than T2 were found to be highly effective cues when they matched attentional set (Experiment 1B). In addition, a cuing effect was still observed when a distractor intervened between the cue and the following target (Experiments 2 and 4), that is, a case in which the target was preceded by a distractor. On a similar note, it is unclear how TLC would accommodate the finding that cues that shared the color of the following target could fully mitigate the AB even though these cues were letters while the following targets were digits. Notably, this finding would have to be interpreted as evidence that a filter that is set exogenously for red letters allows for efficient selection of a following red digit target. If the attentional filter were insensitive to differences in category, however, ABs should not have been observed in experiments in which the targets were designated by the fact that they were drawn from a different alphanumeric category than the distractors (e.g., Chun & Potter, 1995).

Taken together, it is clear that the cuing effect cannot be accounted for in terms of the cue resetting a filter to the right configuration for a following target. Therefore, the TLC account would need substantial modification in order to accommodate the present findings. In particular, it would have to assume that the attentional set that was maintained prior to T1 and lost upon presentation of the following distractor is reinstated upon detection of a cue (i.e., to account for cuing effects with different-color, different-category distractors), and then maintained in the presence of exogenous conflicting signals (i.e., to account for the lack of an effect of distractors intervening between the cue and the target). It can be argued, however, that this lost –and found control version of the TLC account is less parsimonious than an account that assumes that control over selective attention is sustained during the AB, thereby allowing selection to be triggered by detection of features that match the target template (e.g., Chun & Potter, 1995; Folk et al., 1992), including color, category, or any other characteristic of visual stimuli that can be used to differentiate between targets and distractors.

The Case for Sustained Control in the AB

Assuming that observers maintain control over selective attention during the AB, one issue that must be addressed is whether such a *sustained* control account can explain the findings on which the *loss* of control account was based (Di Lollo et al., 2005). This account was based on the finding that when three targets from the same category (i.e., letters) are presented consecutively, report of the last target is accurate, whereas report of the last target is impaired when the second target is replaced with a digit. As argued by Di Lollo and colleagues, the finding of accurate report of the last letter in the former condition provides compelling evidence against the idea that AB is caused by resource depletion (Shapiro et al., 1994) or a processing bottleneck invoked by a leading target (Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998), a notion that is buttressed by the present finding that cuing T2 did not affect T1 report. However, the main basis for the TLC account was not the fact that participants did well with three-letter triplets. Instead, this account was based on the fact that performance for the last letter was so much worse in the condition with an intervening digit. Therefore, the question that is most relevant for the present purpose is whether this difference can only be explained in terms of a loss of control induced by the digit distractor, or if an alternative explanation that is consistent with the present finding of sustained control is also possible.

As noted by Di Lollo and colleagues (2005), one alternative explanation of the finding of impaired report of the last letter with an intervening distractor digit is that this effect reflects the effort involved in suppressing a response to the middle distractor digit. According to Di Lollo et al., this interpretation was falsified by the fact that report of the last letter was impaired regardless of whether observers were instructed to ignore (suppress) or to report the intervening digit. However, a crucial aspect of the design of the experiment in which the intervening digit had to be reported was that the target triplets were embedded in sequences of digit distractors. This raises the possibility that, despite the instruction to report the middle stimulus, the digit nonetheless triggered an effort to suppress a response because it belonged to the category of items that had to be ignored throughout the trial, an effect akin to negative priming. According to this interpretation, the disruptive effect of the intervening digit may be ascribed to a failure to switch attentional set, endogenously, from *ignore digits and report letters* to *report digits*, with the consequence that observers will often fail to select the digit and the following letter for report. A prediction that follows from this interpretation of the results reported by Di Lollo and colleagues is that the difference between report accuracy for letter-digit-letter triplets and three-letter triplets should be reduced when the target triplet is presented in a sequence of distractors unrelated to either type of target (e.g., symbols). Unfortunately, neither Di Lollo et al. or Kawahara, Enns et al. (in press) included this condition in their tests of the TLC account and, therefore, a more definitive test of these hypotheses awaits future research. Nevertheless, it is clear that the findings on which the TLC account were based also allow for an interpretation that assumes that control over selective attention is sustained rather than lost during the AB.

A Working Hypothesis for the AB

The present findings demonstrate that the main cause of errors in report of targets presented during the AB is a delay in attentional allocation that can be mitigated by precuing the target with a distractor that bears a target-defining feature. What was not specifically addressed in the present experiments, however, is what causes this delay.

Recent work has provided some interesting insights regarding the cause of the AB. To start, the findings reported by Di Lollo and colleagues (2005) illustrate the crucial role of the nature of the post-T1 stimulus. When this stimulus belongs to the category of distractors, a blink occurs for a following target, whereas no blink occurs when this stimulus belongs to the target category. This result is reminiscent of the present finding that a cue-distractor-target sequence led to impaired target report compared to an uncued condition when this sequence was presented outside of the AB (Experiment 2). One possible explanation of this finding is that stimuli that are presented in close temporal proximity to a target, and that are evaluated as being irrelevant to the task, trigger the suppression of processing of subsequent events (Olivers and Nieuwenhuis, in press; Olivers et al., in press). In accordance with recently proposed computational models of the AB (Nieuwenhuis et al., 2005; Wyble & Bowman, 2005), such suppression may involve the inhibition of mechanisms responsible for the allocation of attentional resources. While these mechanisms are inhibited, newly presented targets will often fail to elicit sufficient resources for successful encoding, resulting in the AB effect. In this view, cuing T2 mitigates the effect of the AB because a cue will trigger the disinhibition of mechanisms mediating resource allocation in advance of the target, with the result that the following target can be responded to rapidly.

Taken together with the cuing effects reported in the present study, the resource-suppression account also can provide an explanation of the finding of accurate report of sequences of consecutive targets that has been observed in recent studies using multiple-target RSVP tasks (Di Lollo et al., 2005; Kawahara, Enns et al., in press; Kawahara, Kumada et al., in press; Olivers et al., in press; Nieuwenstein & Potter, in press). In particular, this may reflect a case in which each target acts as a cue for the next. In this view, detection of T1 triggers an attentional response that allows both T1 and the directly following target to be encoded. Starting with T1, each following target will, in turn, also elicit an attentional response because it matches attentional set. This results in a sustained allocation of attentional resources across the sequence of consecutive targets. As shown by Nieuwenstein and Potter, however, there is a limit to the number of targets that can be stored in memory for later report. This limit appears to amount to four letters, an estimate that is highly reminiscent of the capacity of visual short-term memory for unrelated, distinct visual stimuli (Alvarez & Cavanagh, 2004; Luck & Vogel, 1997). Thus, as long as the allocation of resources is not disrupted by the presentation of a task-irrelevant item, encoding of visual inputs can proceed unabated up to the point where short-term memory has been filled.

Conclusion

In conclusion, the present study shows that the attentional blink reflects a temporal limitation in selection of the second of two successive targets that can be overcome by cuing the second target. Cuing occurs only when the cue matches the target specification, yet it does not require a match between a feature of the cue and that of the following target. Thus, cuing is contingent on attentional set, showing that control over selective attention is maintained during the AB.

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