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Input Control Processes in Rapid Serial Visual Presentations: Target Selection and Distractor Inhibition

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The attentional blink refers to the finding that the 2nd of 2 targets embedded in a stream of rapidly presented distractors is often missed. Whereas most theories of the attentional blink focus on limited-capacity processes that occur after target selection, the present work investigates the selection process itself. Identifying a target letter caused an attentional blink for the enumeration of subsequent dot patterns, but this blink was reduced when the dots shared their color with the target letter. In contrast, performance worsened when the color of the dots matched that of the remaining distractors in the stream. Similarity between the targets also affected competition between different sets of dots presented simultaneously within a single display. The authors conclude that the selection of targets from a rapid serial visual presentation stream is mediated by both excitatory and inhibitory attentional control mechanisms.

Keywords: rapid serial visual presentation, attentional blink, selection, inhibition

When a series of visual stimuli is rapidly presented, the visual system often appears limited in the amount of information it can extract from it. This is illustrated by the finding that the detection of the second of two targets (T2) within such a rapid serial visual presentation (RSVP) is impaired when presented within about 500 ms after the first target (T1)—a finding that has been referred to as the *attentional blink* (Raymond, Shapiro, & Arnell, 1992).

The general explanation of the attentional blink has been framed in terms of limited-capacity target-processing resources, which are being used up by T1, leaving little to nothing for T2 (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro, Arnell, & Raymond, 1997). The idea is that all items in the RSVP stream receive some initial processing, but that for conscious report, an item needs to be transferred and consolidated into a second stage, often referred to as short-term memory. Short-term memory is limited in capacity, and when it is occupied by T1 and possibly one or two distractors, few resources are left for T2, resulting in an attentional blink.

Where most theories of the attentional blink concentrate on what happens after T1 has been selected, relatively little is known about the selection process itself. How is T1 extracted from the stream? How does it become eligible for second stage processing? Clearly, any theory of the attentional blink will have to include some mechanism of selecting targets, and all current theories assign a role to a target description of some sort. There just has not been much evidence on the nature of these selection mechanisms.

According to Raymond, Shapiro, and Arnell (1995), the observer sets up a template specifying the target-defining feature or features. The more similar an item is to the target template, the more likely it is to enter the second stage of processing and the more strongly it is represented within this second stage. The notion of a target template determining the likelihood of items entering higher level processing is similar to the notion of an input filter (e.g., as proposed by Visser, Bischof, & Di Lollo, 1999). The consequence is that distractor items that are very similar to the target template may also enter the second stage and interfere with target processing. It has indeed been found that the attentional blink varies with target–distractor similarity (e.g., Chun & Potter, 1995; Ghorashi, Zuvic, Visser, & Di Lollo, 2003; Maki, Couture, Frigen, & Lien, 1997; Raymond et al., 1995; Visser, Bischof, & Di Lollo, 2004).

However, although the above evidence is consistent with a role for target templates and/or input filters, alternative interpretations are possible. Making targets and distractors more similar makes the targets less discriminable. Target discrimination may therefore require more attentional resources, and when applied to T1, this in itself may result in a stronger blink for T2. In a similar vein, by changing the properties of the item immediately trailing T1 (which was often also immediately preceding T2), one changes not only the item's similarity to the targets and their templates, but also its potential to act as a mask for these targets (Brehaut, Enns, & Di Lollo, 1999; Grandison, Ghirardelli, & Egeth, 1997; Maki, Bussard, Lopez, & Digby, 2003; Seiffert & Di Lollo, 1997).

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The Present Study

The goal of the present study was to further investigate the mechanisms underlying the initial selection of information from an RSVP stream. We sought to find additional evidence for the operation of a target template in RSVP tasks, while circumventing the potential problems of discriminability and masking pointed out above. Another question underlying the present study was, What happens to the distractors in the RSVP stream? Current theories do not go much further than stating that distractors are rejected or ignored, without suggesting how this may work. The exception is an early (and later abandoned) proposal by Raymond et al. (1992; see also Maki & Padmanabhan, 1994), which states that to protect T1 from interference, post-T1 items are temporarily inhibited. These post-T1 items may include distractors but may also include T2, leading to an attentional blink. However, this proposal sees distractor inhibition as a consequence of T1 selection, whereas here we examine the possible antecedents of target selection: If, in addition to using an active attentional set for target properties, observers also actively inhibit the distractors, then this inhibition should already be operational before T1 is selected. Thus, in addition to a positive attentional set for the target properties, here we examine the possibility that there is also a negative attentional set against the distractor properties that exists before T1 selection.

The operation of both positive (excitatory) and negative (inhibitory) attentional sets has been demonstrated in many other paradigms requiring the prioritization of targets over distractors, for instance, those involving visual search and negative priming (Cepeda, Cave, Bichot, & Kim, 1998; Folk, Remington, & Johnston, 1992; Kaptein, Theeuwes, & Van der Heijden, 1995; Tipper, 1985; Watson, Humphreys, & Olivers, 2003). However, what these paradigms have in common is that targets and distractors are typically presented at the same time at different locations. Relatively little is known about the operation of attentional sets when targets and distractors are presented at different times at the same location, such as in the RSVP paradigm (although see Folk, Leber, & Egeth, 2002). Yet these processes could play an important role in RSVP tasks. For example, within Chun and Potter's (1995) two-stage theory of the attentional blink, it is assumed that all RSVP items are analyzed for target features, which would correspond to the operation of a positive attentional set for those features. When a match is encountered (in case of a target), the item is promoted to a more durable representation. However, within two-stage theory, the distractors are simply subject to decay or masking by the following item. Here we also investigate the alternative, namely that distractors may be actively suppressed.

We cannot simply assume a priori that temporal selection occurs in the same way as spatial selection. Illustrative here may be the discussion on whether inhibition occurs in the preview paradigm (Watson & Humphreys, 1997). In this paradigm, a visual search display is presented in two stages, with one set of distractors appearing before a second set (which then typically includes the target). Whereas Watson and Humphreys (1997) have claimed that the first set of distractors is inhibited in anticipation of the target set, others have claimed that, because of the temporal differences between the stimuli, no such inhibition is necessary (Donk & Theeuwes, 2001; Jiang, Chun, & Marks, 2002).

The present study sought to further explore the role of inhibitory and excitatory selection mechanisms in temporal attention. Figure 1 illustrates the experimental setup used in this study. The first task was to identify a target letter defined by one color (e.g., red) embedded in an RSVP stream of distractor letters defined by a different color (e.g., green). Thus, the reporting feature of T1 was its identity, and its defining feature was color. The second task was to enumerate sets of dots that appeared either immediately after T1 (lag of one) or after another seven distractor letters (lag of eight). The target dots were immediately followed by a white random dot mask. To preclude attentional zooming effects (Eriksen & St. James, 1986), we used large letters so that they encompassed the entire region within which the dots could fall (see Olivers, 2004, for further rationale). Crucially, the dots could have the same color as the target letter, the same color as the distractor letters, or a color unrelated to both the target letter and the distractor letters. Thus, the reporting feature of T2 was its number of elements, and its defining feature was its appearance as a dot pattern (color was not a defining feature). Report for both targets was unspeeded and occurred at the end of each trial.

Our predictions were as follows. When observers were set for the defining property of T1 (i.e., its color), then we expected better enumeration performance on T2 when the dots shared their color with T1 (e.g., both are red) compared with when they had an unrelated color (e.g., T1 was red and the dots were blue or yellow). Furthermore, if observers were set against (i.e., inhibited) the distractor letters, then we also expected a deterioration in T2 enumeration performance when the dots shared their color with the distractors (e.g., all are green), compared with an unrelated color (blue or yellow). Thus, our design allowed us to measure the attentional control processes mediating the selection of T1, through similarity effects on T2.

One advantage of using such dissimilar targets (letters versus dots) is that it allowed for a particularly strong demonstration of the input settings operating on T1. For example, we predicted similarity effects on T2 even though T2 did not share any of its defining or to-be-reported features with T1. This allowed for a relatively pure measure of the selection mechanisms applied to T1. Another advantage of our method was that it controlled for masking. Because the two target types were so dissimilar, low-level visual-masking effects were already quite unlikely. Nevertheless, even more rigid controls were in place: Backward masking was controlled for by the always neutral white mask that followed the dots. Forward masking was controlled at a lag of one, when the T2 dots immediately followed the T1 letter. Here any masking effects would be expected to be strongest when the letter and dots shared the same color. Thus, if we found any benefits of a shared color between the two, then this could not be explained with a masking account. Similarly, any deterioration in T2 enumeration performance when the color was shared with the distractor letters could not be explained with a masking account, because at a lag of one the T2 dots were never directly preceded (or followed) by a distractor letter. A final advantage was that T2 performance at a lag of one allowed us to directly assess the role of the distractors *preced-*

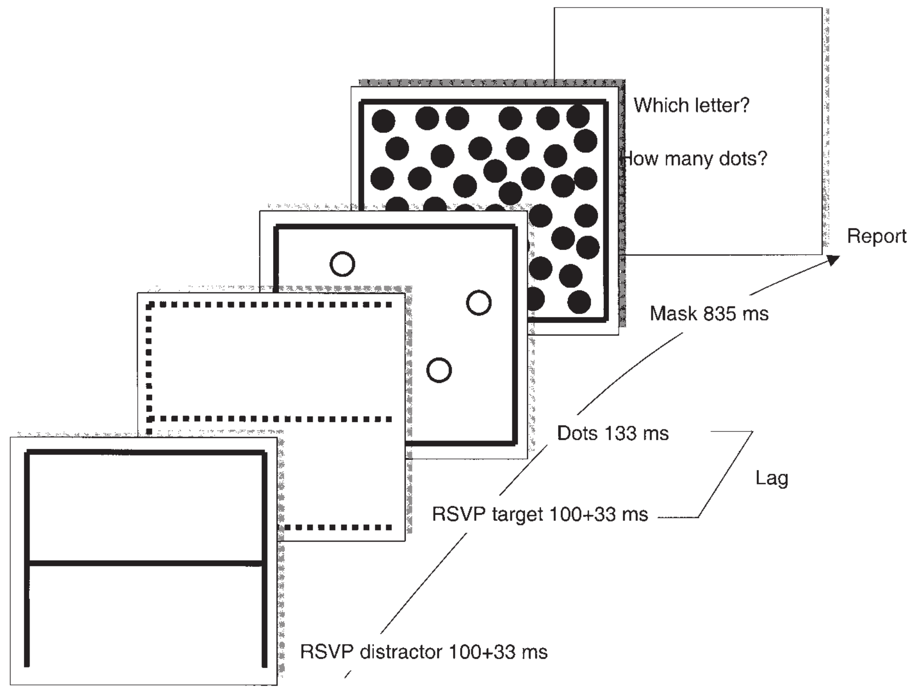

Figure 1. Illustration of the procedure for Experiments 1 and 2. Each letter was presented for 100 ms, followed by a 33-ms blank. The target letter (T1) differed in color from the distractor letters. At varying lags, the target letter was followed by a display containing a varying number of dots (T2; between 0 and 5 in Experiment 1, between 0 and 3 in Experiment 2). The color of the dots could be the same as that of the target letter, the same as that of the distractor letters, or unrelated. The stream ended with a mask consisting of white dots. (In the illustration, light and dark colors are reversed.) RSVP = rapid serial visual presentation; T1 = Target 1; T2 = Target 2.

ing T1. Because T2 directly followed T1, without further distractor letters, any distractor-related similarity effect on T2 could only have stemmed from the need to ignore the distractors preceding T1 (i.e., indicative of a negative attentional set developed for the distractor features before the presentation of T1). For this reason, our focus is therefore on the results for a lag of one. We also focused on a lag of one because at a lag of eight, the dots were immediately preceded by distractors and the control for masking was therefore somewhat less stringent. Note that the often found *lag-1 sparing phenomenon* in the attentional blink paradigm does not appear to occur when two different tasks for T1 and T2 are used (Potter, Chun, Banks, & Muckenhoupt, 1998), thus allowing us to use a lag of one as the main indicator of performance in the present experiments.

However, there are also potential disadvantages to the current method. Because the two target types and the associated tasks were so different, they were likely to involve a task switch. It is controversial whether a task switch should be seen as a part of or as a contamination of the attentional blink (Arnell & Jenkins, 2004; Kawahara, Zuvic, Enns, & Di Lollo, 2003; Potter et al., 1998), and one may therefore wonder whether the present results are applicable to attentional blink theories. However, note again that the present study is not directly concerned with the blink itself but with the selection mechanisms for T1, which must operate before the blink or a task switch occurs. It seems reasonable to suggest that such initial selection mechanisms would be the same in RSVP paradigms with or without a task switch. Thus, the present results should apply equally well to nonswitch RSVP tasks. Another potential disadvantage is that the initial selection mechanisms that we are trying to measure may be weaker under task switch conditions, because the resources involved in trying to maintain two task goals and/or anticipate the task switch may impact on the processing needed for the selection task. In that case, the present findings may reflect an underestimation of the real effects.

Experiment 1: Similarity Affects T2 Performance

Participants identified a target letter (T1) and then enumerated a display consisting of a varying number of target dots (T2) presented either immediately following T1 at a lag of one or at a lag of eight. We expected dot enumeration to suffer at the shorter lag, and some component of this may have been due to a task switch. The T2 dots could have the same color as the target letter (*same-as-target-letter condition*), the same color as the distractor letters (*same-as-distractor condition*), or a color different from both the target letter and the distractor letters (*unrelated condition*). If similarity of T2 to the T1 template increased the chances of being selected, we should expect enumeration accuracy to have improved in the same-as-target-letter condition, relative to the unrelated condition. Similarly, if the distractors in the RSVP stream were inhibited even before T1 occurs, we would expect accuracy to suffer in the same-as-distractor condition.

Method

Twelve students from the Vrije Universiteit Amsterdam (9 male, 2 left-handed) took part. Their ages ranged from 17 to 28 years ($M = 21.5$).

Stimuli and apparatus. Stimulus presentation and response recording were performed with custom software written in Turbo Pascal running on a Pentium PC linked to a 17-in. super visual graphics array monitor running in $800 \times 600 \times 256$ mode, which was viewed from 75 cm. The RSVP letters were $5.3° \times 5.3°$ visual angle box-shaped capitals. The to-be-counted target dots (0.45° diameter) were plotted randomly in one of the cells of a 6×6 virtual matrix, comprising the same $5.3° \times 5.3°$ area as the letters. Within the cells, the dots were randomly displaced by between 0.0° and 0.2° in any direction. The mask consisted of the same 6×6 virtual matrix but was now fully filled with dots, which were again randomly displaced within their cells. The target letter, distractor letter, and target dots could be red (0.61, 0.35, 7.90 cd/m^2), green (0.26, 0.60, 10.10 cd/m^2), blue (0.16, 0.10, 7.40 cd/m^2), or brownish yellow (0.41, 0.50, 12.60 cd/m^2; CIE [Commission Internationale de l'Eclairage] color model *x, y* coordinates and luminance within brackets), on a black background (approximately 0.50 cd/m^2). These colors were chosen to be isoluminant for Christian N. L. Olivers according to a flicker test (Ives, 1912), except for yellow, which was chosen to be somewhat brighter to make it more distinct from the other colors (i.e., less brown). The mask was white (53.00 cd/m^2).

Design and procedure. A trial started with a 750-ms blank, followed by a fixation square the size of the subsequent characters. After 600 ms, a stream of between 15 and 20 letters started, randomly drawn (with replacement) from the set {A, C, E, F, H, J, L, P, O, S, U, Y}, with the limitation that no two consecutive letters were identical. Each letter was presented for 100 ms, followed by a 33-ms blank. All letters were of one color (e.g., green), except the target letter, which was of a different color (e.g., red). The target letter was randomly drawn from the same set as the distractors and was presented at either one or eight temporal positions from the end of the series, corresponding to lags of 133 and 1,067 ms, respectively.

The letter series was immediately followed by the presentation of a set of dots for 133 ms, varying in number between zero and five dots. Furthermore, the similarity between the letters and the dots was varied. The dots either had a color unrelated to the target and distractor letters (unrelated condition), the same color as the target letter (same-as-target-letter condition), or the same color as the distractor letter (same-as-distractor-letter condition). The dots were followed by the white mask for 835 ms. The participants were then asked to type in the target letter and the number of dots they had seen (they were instructed that the number would vary between zero and five). Instructions stressed that accuracy was important, but that response speed was not. To keep letter-detection accuracy high, errors on the letter task were followed by a feedback tone. Counting errors were not followed by feedback, because we thought that the expected large number of errors in this task might discourage participants.

The number of dots (6 levels), different lags (2 levels), and similarity relationships (3 levels) were randomly mixed within a block of 72 trials (2 trials per combination). Each participant completed 10 blocks (with breaks in between), resulting in 20 trials per cell. The experiment was preceded by 1 practice block of 72 trials, in which presentation times gradually decreased. The colors used (red, green, blue, and yellow) were counterbalanced partly within and partly across participants. For each participant, there were 2 types of block, which alternated regularly. For instance, a participant would extract red targets from an otherwise green stream in half the number of blocks. For this participant, the dots (when more than 0) would be red on same-as-target-letter trials, green on same-as-distractor trials, and either blue or yellow on unrelated trials (with blue and yellow varying at random). In the remaining number of blocks, the participant would extract green targets from an otherwise red stream of letters, and the colors of the dots would be manipulated accordingly. Across the 12 participants, each of the six possible target–distractor color combinations (i.e., red–green, red–blue, red–yellow, green–blue, green–yellow, blue–yellow) was represented twice in counterbalanced order.

Results

Letter-identification errors (T1). On average, 6.73% of the T1 letter targets were misidentified. Error rates were arcsine-transformed to correct for end-of-scale artifacts (Winer, 1970) and entered in an analysis of variance (ANOVA) with number of dots present (1 to 5), lag (133 and 1,066 ms), and the similarity between dots and RSVP letters (same as target letter, same as distractor letter, or unrelated) as variables. The zero dot condition was left out of the analyses because there cannot be any similarity effects in this condition. However, the general pattern of results held even with this condition included. There was a main effect of lag, $F(1, 11) = 12.86$, $MSE = 0.020$, $p = .004$, as the error rate was overall lower at the short lag (133 ms, 4.7%) compared with the long lag (1,066 ms, 8.8%). No other effects were significant (all Fs < 1.5). There are two likely reasons for this lag effect: (a) At a lag of eight, participants may have forgotten T1 on a larger number of trials, or (b) at a lag of eight, T1 was immediately followed by a number of distractor letters, which might have interfered more with T1 recognition than when T1 was immediately followed by the dots (as was the case at lag of one). In any case, in our view, the effect is not directly relevant to our research question, and we do not dwell on it further.

Dot-counting errors (T2). Trials on which T1 was missed were excluded. Note that, a priori, enumeration errors may not be equally distributed across the range of dot numbers because of response biases. For example, observers may show a tendency toward reporting higher numbers because they believe it is more likely for dots to be missed when numbers are high, or they may show a tendency toward the center of the response scale, because at the ends of the scale, errors can only go in one direction. Dot-counting error rates were therefore corrected for response biases following the method of Kerr, Ward, and Avons (1998). Applied to the present case, this method derives the corrected proportion correct (P_{corr}) for a particular number of dots (k) as follows:

$$P_{\text{corr}} = (C_k/X) \times (C_k/N_k),$$

where C_k is the number of responses correct for k number of dots, N_k is the total number of responses for k number of dots, and X is the mean number of responses averaged across all numbers of dots.

It takes into account both the relative and the absolute number of correct responses for each number of dots.[1]

Figure 2 shows the bias-corrected error proportions for the dot enumeration task as a function of the number of dots present, lag, and the similarity between dots and RSVP letters. An ANOVA on arcsine-transformed rates[2] (again with the zero dot condition excluded) revealed that errors increased with increasing number of dots, $F(4, 44) = 74.40$, $MSE = 0.034$, $p < .001$, and increased with the shorter lag, $F(1, 11) = 44.25$, $MSE = 0.148$, $p < .001$. There was also a main effect of similarity, $F(2, 22) = 17.02$, $MSE = 0.006$, $p < .001$, as errors were overall increased when the dots matched the color of the distractor letters relative to when they matched the target letter or were unrelated. There was a significant Number of Dots × Lag interaction, $F(4, 44) = 13.88$, $MSE = 0.014$, $p < .001$, as the number of dots had a stronger effect at the short lag than at the long lag. There was also a trend toward a Similarity × Lag interaction, $F(2, 22) = 2.52$, $MSE = 0.005$, $p = .10$, as similarity effects were a little stronger for the short lag than for the long lag. There were no further reliable interactions (Fs < 1). Separate analyses for each lag revealed that error rates in the same-as-distractor conditions were significantly higher than in the unrelated conditions, $F(1, 11) = 16.23$, $MSE = 0.006$, $p = .002$, for a lag of one, $F(1, 11) = 8.25$, $MSE = 0.005$, $p < .02$, for a lag of eight. Error rates in the same-as-target conditions did not differ significantly from the unrelated conditions (Fs < 1.5), but did differ from the same-as-distractor condition, $F(1, 11) = 24.62$, $MSE = 0.006$, $p < .001$, for a lag of one, $F(1, 11) = 6.60$, $MSE = 0.002$, $p < .05$, for a lag of eight.

Discussion

Overall, enumeration performance was considerably worse under short lag conditions than under long lag conditions, which is indicative of an attentional blink. Although a component of the deficit may be due to the task switch, note that performance was hardly affected when only a single dot was presented, which suggests that task switching was playing only a minimal role here.

The important finding was that enumeration performance was modulated by the color similarity between the T2 dots and the T1 letter. When they shared the same color, enumeration improved slightly but nonsignificantly. In contrast, performance deteriorated markedly when the dots shared their color with the distractor letters of the RSVP stream. It suggests that observers were actively inhibiting the distractors in the RSVP stream. This inhibition then carries over to the dots presented later in the stream, on the basis of shared features, even though color is not a defining feature for the dot pattern. Note that the similarity-based inhibition must already have been present before the letter target was selected, because in the short lag condition, the last distractor letter actually preceded the T1 letter (there were no distractor letters between T1 and T2). If the inhibition had been a consequence of target selection, then the dots of the unrelated color also should have been relatively suppressed, which was not the case. In this respect, the inhibitory processes proposed here differ from the earlier inhibition account offered by Raymond et al. (1992), which stated that the inhibition is a consequence rather than an antecedent of the selection of T1.

Also worth noting here is that the similarity effects appeared to diminish with lag, suggesting that the operation of the attentional set changes during the course of the stream. At the longer lag, participants have time to abandon the attentional set for T1 and prepare themselves for T2. However, caution is in order here: The Similarity × Lag interaction only approached significance, and furthermore, real performance may be distorted by scaling effects in error proportions (despite the arcsine transformation).

Although Experiment 1 revealed significant effects of similarity on target selection in the RSVP stream, the effects were overall of rather small size (at a lag of one, across one to five dots, target similarity led to a nonsignificant average improvement of 2%, and distractor similarity led to a significant average decrement of 9%, totaling to an 11% effect). Experiment 2 therefore served to replicate and extend these effects.

Experiment 2: Similarity Modulates Competition Within T2

To further explore the role of similarity, in Experiment 2, the T2 dots were embedded in a frame filled with what we refer to as

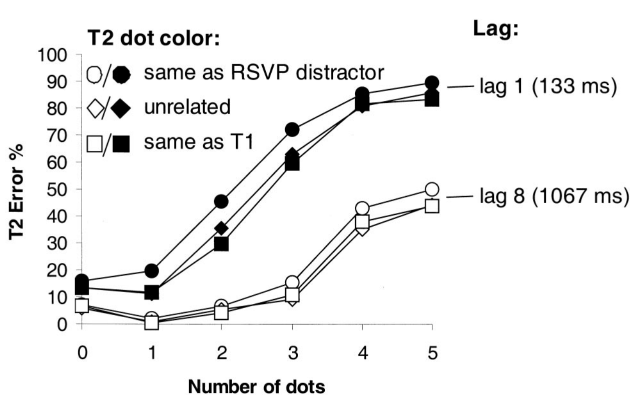

Figure 2. Average accuracy (corrected for response biases) for the dot enumeration task (T2) of Experiment 1 as a function of the number of dots, lag, and similarity. T1 = Target 1; T2 = Target 2.

[1] As mentioned, biases may also be induced near the ends of the response range (i.e., 0 and 5 in the present case) because erroneous responses can go in only one direction. To a large extent, the method used should already correct for this. Furthermore, as mentioned in the *Results* section for Experiment 1, we left the zero dot condition out of the ANOVAs, because there is no sensible similarity relationship with T1 for this condition. We also applied the response bias correction with not only the zero dot but also the five dot conditions removed, with virtually the same pattern of results (if anything the effects grew larger). Moreover, we looked at another method for correcting response biases, namely by subtracting the number of incorrect responses from the number of correct responses. This also did not lead to different conclusions about the data (again effects only appeared to grow stronger). Finally, the data were analyzed without any corrections for response biases, again leading to the same pattern of findings.

[2] Before the arcsine transformation, the error proportions were divided by the maximum to bring the range back to between zero and one. This was done because the response bias correction allows for corrected proportions to exceed one. Since this is a linear transformation, it should not affect the inferential statistics.

background dots (to avoid confusion, we would like to reserve the term *distractor* for the distractor letters in the RSVP stream). We assumed that the target dots would have to compete with the background dots for selection; that is, we assumed the target dots would have to be segregated from the background dots, potentially allowing for additional similarity effects. To this extent, we not only varied the similarity between the target dots and the preceding RSVP letters, but also between the background dots and the preceding RSVP letters. Our prediction was that performance should improve when the target dots shared their color with T1, but also when the background dots shared their color with the ignored RSVP distractor letters. Conversely, we predicted that performance should suffer when the target dots shared their color with the RSVP distractors or when the background dots shared their color with T1. To replicate Experiment 1, we also included a condition without background dots.

Method

Eighteen students from the Vrije Universiteit Amsterdam and the University of Warwick (8 male, 3 left-handed) took part. Their ages ranged from 17 to 28 years ($M = 21.3$). The experimental method was the same as in Experiment 1, except for the following changes. We used only the shortest lag (133 ms), in which dots were presented immediately following the target letter. Furthermore, in the *with-background-dots condition,* the target dots were embedded in a 6 × 6 virtual grid filled with background dots. Each dot was randomly displaced by between 0.0° and 0.2° in any direction. The similarity of the target and background dots to the target and distractor letters was independently varied, with the restriction that target and background dots always differed in color. The background dots could be of a color the same as the target letter, the same as a distractor letter, or unrelated to both. Similarly, the target dots could be of a color the same as the target letter, the same as a distractor letter, or unrelated to both. Note that in this design there were nine potential cells, but only seven could be realized. The design could not be fully crossed because target and background dots always differed in color (the target and background dots could not both be the same color as the distractor letter and could not both be the same color as the target letter because this would have rendered the target dots indistinguishable from the background dots; note that they could both be unrelated becaues there were always two unrelated colors in each color combination). In the without-background-dots condition, manipulations were the same as in Experiment 1. The color of the target dots was the same as the target letter, the same as the distractor letters, or unrelated to both. The number of dots varied among zero, one, two, and three. All conditions were randomly mixed within 10 blocks of 80 trials each, resulting in 20 trials per cell. The experiment was preceded by 1 practice block of 80 trials, in which presentation times gradually decreased. As in the previous experiments, all colors were counterbalanced.

Results

Letter-identification errors. On average, 5.66% of the letter targets were misidentified. An ANOVA on arcsine-transformed error rates of the conditions in which dots were present revealed no significant effects of the number of dots or types of similarity (all Fs < 1.7, *ns*).

Dot-counting errors. Trials on which the letter target was missed were excluded. To assess if the presence of background dots per se had an effect on performance, a first analysis compared performance (as indicated by error proportions) with unrelated background dots to performance without background dots, as is shown in Figure 3A. Errors increased with the number of dots, $F(2, 34) = 62.89$, $MSE = 0.007$, $p < .001$, and overall more errors were made when background dots were present, $F(1, 17) = 33.52$, $MSE = 0.035$, $p < .001$. Furthermore, similarity had an effect, as more errors were made when the target dots shared their color with the distractor letters than when they shared it with the target letter, $F(2, 34) = 6.04$, $MSE = 0.025$, $p < .01$. There was an interaction between number of dots and the presence of background dots, $F(2, 34) = 7.09$, $MSE = 0.005$, $p < .01$, as the number of dots appeared to have less of a detrimental effect when background dots were present. There was also a Number of Dots × Similarity interaction, $F(4, 68) = 3.80$, $MSE = 0.004$, $p < .01$, as similarity effects

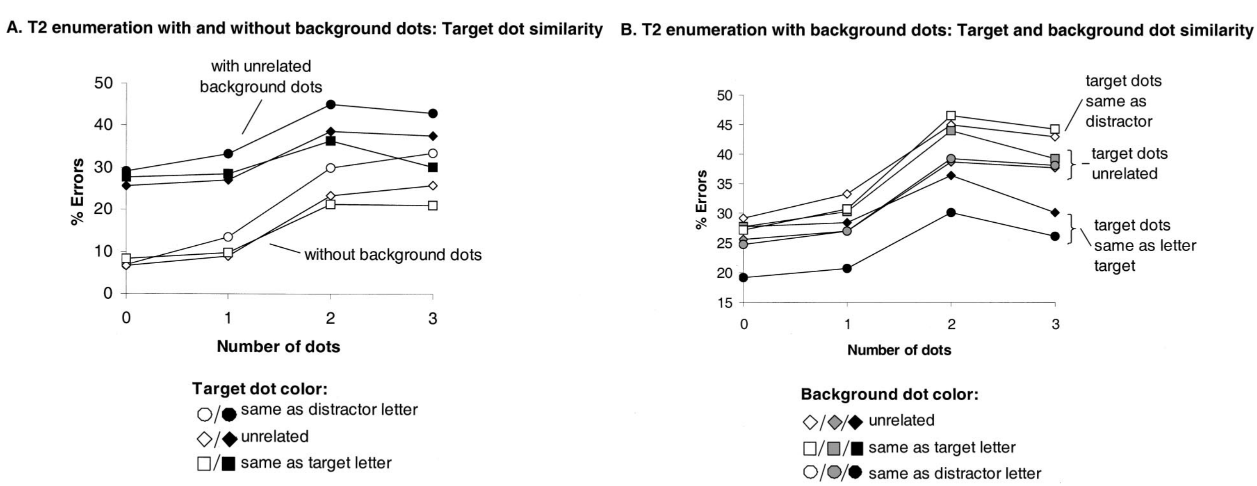

Figure 3. Average accuracy (corrected for response biases) for the Target 2 (T2) dot enumeration task of Experiment 2 as a function of similarity, and the number of dots in the second set. Figure 3A compares performance with and without background dots. Figure 3B compares performance for all target-dot and background-dot similarity relationships when background dots were present.

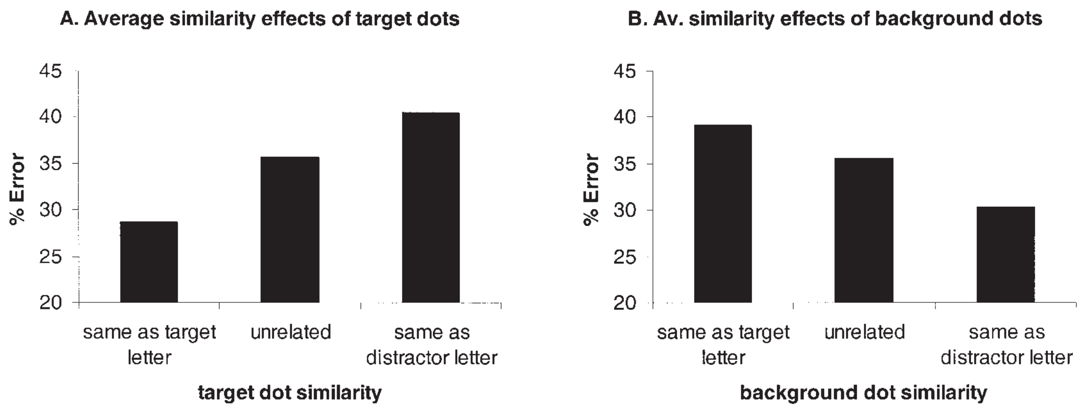

Figure 4. The average effects of (A) target dot and (B) background dot similarity across dot numbers one through three (corrected for response biases). Av. = average.

increased with increasing dot numbers. No other interactions were significant (all Fs < 1.2, *ns*).

Figure 3B shows all the conditions in which background dots were present. It again suggests an effect of similarity. Performance was best when the color of the target dots matched the color of the target letter (especially if the background dots were the same as the distractor letters). Performance was overall worst when the target dots matched the distractor letter (especially if the background dots matched the target letter). Other combinations fell in between. Note that a full ANOVA (with number of dots, target similarity, and background similarity as variables) was not possible given that the design was not fully crossed (because the target and background dots could not share the same color without the target dots being undistinguishable). However, to illustrate the general effects involved, Figure 4 shows the proportions correct, averaged across dot numbers one, two, and three, for each type of similarity manipulation (target-dot similarity and background-dot similarity), averaged across the other type of similarity (i.e., background-dot similarity and target-dot similarity, respectively). This way, the graphs correspond to what can be regarded as the main effects of target-dot similarity and background-dot similarity. An ANOVA on these averages revealed that similarity had an effect for target dots, $F(2, 34) = 9.29$, $MSE = 0.004$, $p = .001$, and background dots, $F(2, 34) = 4.98$, $MSE = 0.004$, $p < .02$.[3]

Discussion

As in Experiment 1, enumeration errors increased with an increasing numbers of dots, even for the small range (zero to three) used here. The important finding was that enumeration performance was again modulated by the similarity relationship to T1. Target dots were better selected when they shared T1's color, and background dots were better ignored when they shared the RSVP distractor color. Performance was overall best when the target dots matched T1's color and the background dots matched the distractor color. This shows that the input control processes not only operate across frames, but can even bias the competition within a single frame. It suggests that the control processes operating across time and space may be identical. Again, these control processes appear to work in two ways: Items similar to the target are prioritized above unrelated items, whereas items that are similar to distractors are inhibited relative to unrelated items.

General Discussion

Both experiments revealed clear effects of similarity. In Experiment 2, the enumeration of dots in T2 improved when their color was the same as the color of the T1 letter. In both Experiments 1 and 2, enumeration of dots was worse when their color was the same as that of the distractor letters in the stream. The present manipulations offer stronger evidence than previous studies for a role for similarity, which could also be explained in terms of masking (Grandison et al., 1997; Maki et al., 2003). The present experiments directly manipulated the similarity of T2 to the other items in the stream, such that masking effects would go against the similarity hypothesis.

The findings point toward the operation of a target template or input filter specifying and prioritizing target properties, in accordance with earlier proposals (Raymond et al., 1995; Visser et al., 1999). The other important finding was that T2 was inhibited if it was similar (in color) to the distractors in the RSVP stream. Apparently, selection of T1 was aided not only by activating its properties, but also by suppression of the distractors. A T2 similar to those distractors would then suffer. In the present setup, this inhibition was not a consequence of selection of T1, but rather preceded it, because at the shortest lag (at which the inhibitory effects were the strongest), the last distractor was presented before

[3] Note that in Figure 3B, there also appear to be some effects of similarity when there were no target dots (zero dot condition), which at first sight may appear strange. However, note that although there were no target dots, there were still background dots. Participants may have found it easier to reject the background as containing no dots when it had the same color as the distractor letters in the RSVP stream. Furthermore, the response bias correction also contributes: Observers often chose 0 if they did not see any dots, even if there were one or more dots. This was less likely to occur in the condition where the target dots matched the RSVP target letter in color, and hence the correction for false positives in the zero dot condition was less strong. In any case, as mentioned before, the zero dot condition was left out of the statistical analyses.

T1. Thus, the present results indicate that inhibition indeed plays an important role in the attentional blink paradigm, just as in other paradigms that require the selection of targets over distractors (Cepeda et al., 1998; Folk et al., 1992; Kaptein et al., 1995; Tipper, 1985; Watson et al., 2003). Furthermore, the finding that this inhibition operates before the appearance of the crucial target information fits with results from tasks using staggered presentations of spatial visual search displays (i.e., the preview paradigm; Watson & Humphreys, 1997; see Olivers, Humphreys, & Braithwaite, 2006; and Watson et al., 2003, for recent reviews).

Positive and Negative Attentional Sets in RSVP Processing

The conclusion that the operation of a target template, or attentional set, plays an important role in RSVP processing corroborates an attentional capture study by Folk, Leber, and Egeth (2002). For example, in one condition, they found that when observers were instructed to search for a red target embedded in a centrally presented RSVP stream, detection suffered when the target was preceded by briefly flashed peripheral distractors drawn in the same color (i.e., red) compared with when the peripheral distractors were drawn in a different color (e.g., green). Whereas these studies have shown the importance of a positive attentional set for target properties, the present study reveals an at least equally strong (if not stronger) role for a negative inhibitory set operating on the distractors.

Such a role for a negative attentional set was also suggested by Maki and Padmanabhan (1994). They used an attentional blink task in which, in the standard version, T1 was a white letter and T2 was a black digit among black letter distractors. They found that performance improved with practice. However, they then presented participants with a condition in which T2 foils (i.e., other black digits, which should not be reported) were mixed into the distractor stream. Despite the earlier practice, T2 detection dropped substantially. Maki and Padmanabhan argued that observers used an inhibitory set against the distractors, and by including digits in the distractor set, digit targets were suppressed too. In a similar experiment, Loach and Marí-Beffa (2003) asked participants to report T1 and then rapidly respond to T2, which was always the last item in the stream. However, T2 could also return as a distractor earlier in the stream (i.e., immediately after T1). Loach and Marí-Beffa found that T2 report was slowed when T2 had indeed been a post-T1 distractor, providing evidence for inhibition. However, whereas we argue that the inhibition already occurs before T1 selection, Maki and Padmanabhan and Loach and Marí-Beffa argued that the inhibition is triggered by T1, following Raymond et al.'s (1992) original account that the attentional blink is the consequence of posttarget suppression and serves to prevent interference with T1 processing. It is interesting, though, that Maki and Padmanabhan also found T2 detection to be affected when the foils were presented before T1, consistent with earlier inhibition.

The conclusion that the distractors before T1 are inhibited has also been made recently by Dux, Coltheart, and Harris (2006). They asked participants to report two black letter targets (T1 and T2) from a stream of black digit distractors. They found that T2 detection improved when the distractor immediately following T1 was identical to the distractor immediately preceding T1. Dux et al. argued that T2 performance benefits from successful suppression of the post-T1 distractor, because it reduces interference with T1 processing, leaving more resources for T2. This interference is then further reduced if the same distractor can already be suppressed earlier in the stream, before T1.

Finally, the role of inhibition in the RSVP paradigm is consistent with a recent event-related potential study by Martens, Munneke, Smid, and Johnson (in press). They found that efficient RSVP target selection coincided with reduced event-related potentials to the distractors.

Relation to Attentional Blink Theories

Input control processes have been relatively underspecified in most attentional blink theories, which have concentrated mostly on what happens after an item (typically T1) has been selected. An exception is the temporary loss of control account by Di Lollo, Kawahara, Ghorashi, and Enns (2005; Kawahara, Enns, & Di Lollo, in press), which puts the input filter itself at center stage. According to their theory, observers seek to sift the information in the RSVP stream by setting up an input filter allowing items matching the target category to pass, whereas items matching the distractor category are rejected. It is proposed that the active maintenance of such an attentional set demands a certain amount of executive control. However, this same executive control function is also needed to process a target when it enters. Thus, when the executive control is assigned to the processing of T1, control over the input filter is lost. This loss of control is harmless as long as the incoming items are targets, but it becomes harmful when it allows distractors to enter. According to the temporary loss of control account, a distractor exogenously disrupts the now vulnerable input settings, affecting the selection of subsequent items. Given sufficient time, attentional control is regained, and the input filter is reinstated. In support of this, Di Lollo et al. (2005; Kawahara et al., in press) found that no attentional blink was induced as long as the incoming items after T1 were targets rather than distractors. The present study provides direct evidence for the operation of an input filter with two components: a positive attentional set for the defining target feature (cf. Folk et al., 2002) and a negative attentional set for distractor-related features.

The importance of input control processes in the RSVP paradigm also becomes clear from a recent study by Olivers, Van der Stigchel, and Hulleman (in press). Replicating Di Lollo et al.'s (2005) results, they found that T1 does not induce an attentional blink as long as there is no distractor presented yet (only targets). This points to a special role for the distractors (rather than processing of T1 per se) in triggering the blink. An important additional result was that even once a proper attentional blink had been induced, subsequent targets could be spared from this blink if they were immediately preceded by another target. Olivers et al. proposed that the attentional gate may be preliminarily reopened if evidence for target information is entering the system. This would suggest that even during the attentional blink period, the input filter (i.e., the target template) is still operational because it can distinguish target information from distractor information. Similarly, Nieuwenstein, Chun, Van der Lubbe, and Hooge (2005) have recently found that targets are relatively spared from the blink even if the preceding item is not a target but is simply a distractor carrying the target-defining property. This also points toward the attentional set remaining intact because the system is still responsive to target features, even during the blink.

To account for the attentional blink, Olivers, Van der Stigchel, and Hulleman (in press; see also Olivers & Nieuwenhuis, 2006) proposed that the attentional blink may be the result of too tight attentional control: Invoking the earliest explanation of the blink (Raymond et al., 1992), Olivers, Van der Stigchel, and Hulleman suggested that the post-T1 distractor, when it is matched to the inhibitory template of the attentional set, induces a too strong (and rather unnecessary) inhibitory state, which affects the processing of later targets. Subsequent targets may survive this inhibition only if sufficient evidence for a match with the target template has accrued, for instance, when two targets are presented in a row or the target is cued. What the accounts of Di Lollo et al. (2005) and Olivers, Van der Stigchel, and Hulleman have in common is that the attentional blink is not due to a structural bottleneck (Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998), nor is it due to some exceptionally long attentional dwell time (Duncan, Ward, & Shapiro, 1994) specific to temporal selection. Attentional blink is instead due to rather run-of-the-mill selection processes that are active throughout the RSVP stream and that normally also operate on simultaneously presented stimuli. The present results fit with this idea, in that the excitatory and inhibitory components of the attentional set appear similar to those operating in visual search and similar tasks involving a spatial layout of stimuli. The idea of attentional sets being applied to the RSVP stream from the moment it starts running also strikes a chord with data from Nakama and Egeth (1999; as reported in Egeth, Folk, Leber, Nakama, & Hendel, 2001). They found that under some circumstances, detection of T1 may suffer from the requirement to detect T2, even if T2 was presented 600 ms later. T1 performance was affected even when the later T2 did not appear, but observers only expected it. Nakama and Egeth concluded that T1 detection suffered from the need to monitor the stream for T2, suggesting competition between conflicting attentional sets operating across the RSVP stream.

In short, the post-T1 suppression that is measured as an attentional blink does not necessarily reflect a special T1-induced process, but instead reflects a particularly strong implementation of the attentional set already operating throughout the RSVP stream. Thus, even if inhibition is maximal shortly after T1, this does not mean it is caused by that target: Inhibition may be a prerequisite for, not a consequence of, target selection.

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