Attention to Visual Pattern Information Produces the Attentional Blink in Rapid Serial Visual Presentation

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To investigate the temporal allocation of attention, a series of 7 experiments using rapid serial visual presentation (RSVP) was designed to examine the relationship of the attentional demands of various target tasks to the production of the subsequent visual attentional deficit, or "attentional blink" (AB), recently reported by J. E. Raymond, K. L. Shapiro, and K. M. Arnell (1992). The principal finding is that AB occurs only when a target is an object and does not occur when the target is defined by a temporal interval. Target detection difficulty as estimated by d' analysis reveals no relationship between the attentional demands of the target and the production of the AB. A late-selection account of this phenomenon is offered in place of the early-selection account advanced in Raymond et al.'s previous report.

Many studies of visual attention have addressed issues concerning the allocation of attention to spatially distributed visual information that is presented for brief intervals. The experiments reported in this article, however, are concerned with how attention is allocated to visual information that is distributed over time but presented in a restricted area of the visual field. The present article reports a series of experiments in which we investigated the temporary attentional deficits that ensue when humans are required to select a target from among a temporal stream of stimuli presented at a rapid rate. The task used in all experiments is that of rapid serial visual presentation (RSVP). In the generic task, stimuli are presented briefly in the same location at a rate of between 6–20 items/s. The subject's task is to identify one or more target(s) that is(are) differentiated in some way from the background, or nontarget, stimulus stream. Stimuli that have been investigated with this method include letters, digits, words, and pictures (e.g., D. E. Broadbent & M. H. P. Broadbent, 1987; Intraub, 1985; Kanwisher, 1987; Lawrence, 1971; Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987). Thus the RSVP procedure could be construed as the temporal analogy to spatial search in that a subject must detect a target from among a set of nontargets or distractors.

There are two procedures commonly used with RSVP that differ in the number of targets required for identification (see Raymond, Shapiro, & Arnell, 1992, for a more thorough discussion of this issue). In the first or single-target procedure, a single target is differentiated from the background stream and is required to be identified. Target identification under these conditions is accomplished quite readily and with a high degree of accuracy. Depending on the nature of the target, errors that occur are typically intrusions from some other item in the series, either just before or just after the target.[1] Posttarget intrusions, which are the most common occurrence, suggest that processing of target features to an output stage extends approximately 100 ms beyond the time the target is physically present. D. E. Broadbent and M. H. P. Broadbent (1986, 1987) suggested a two-stage detect-then-identify model to account for the observed pattern of intrusion errors. In the first stage, they hypothesized the existence of an early-selection mechanism where the target defining feature (e.g., color) is detected. In the second, or late-selection stage, the to-be-reported feature (e.g., letter name) is identified from those items available in the sensory store. According to this model, target errors occur when an item other than the target is selected from the available sensory store.

In the second or dual-task RSVP procedure, two targets, rather than one, are differentiated from the background nontarget stream and require identification. For example, D. E. Broadbent and M. H. P. Broadbent (1987) required subjects to identify two uppercase words (i.e., targets) from among an RSVP stream of words printed in lowercase (i.e., nontargets). Targets were embedded in various serial positions within the stimulus stream so that the number of items between the targets could be manipulated systematically. The first target was identified with a high probability. However, for target stimulus onset asynchronies (SOAs) less than 400 ms, subjects identified the second target with a probability of 0.1 and

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[1] See Raymond, Shapiro, and Arnell (1992) for a review of the relationship between target errors and the nature of the target task.

often reported being unaware that a second target had even occurred. For SOAs greater than 400 ms, though, the probability of correct identification rose to approximately 0.7. Thus, although single-target results suggest that processing of the target is complete by 100 ms after its occurrence, the results from dual-target conditions suggest that target processing or some process that occurs as a result of target processing extends well beyond this time. Similar studies have been reported by Weichselgartner and Sperling (1987) using digits rather than words and recently by Raymond et al. (1992) using letters and a simplified task.

Raymond et al. (1992, Experiment 1) replicated the study by Weichselgartner and Sperling (1987) involving similar stimuli (letters instead of digits) and similar presentation rates (11 vs. 10 items/s), and they found a similar attentional deficit. In this procedure, subjects had to report the target's identity (a white letter from among a stream of black non-target letters) and then report the next three letters in the stream. The results showed a significantly reduced ability to report letters appearing between 180–270 ms after the appearance of the target. In Experiment 2, the task was simplified to control for possible memory-based reporting limitations in the previous experimental design by changing the task following report of the first target to that of reporting whether or not a probe stimulus (i.e., the letter X) appeared in the posttarget stream. This second target could appear in any one of eight posttarget positions randomly determined from trial to trial. Similar to the outcome of Experiment 1, Raymond et al. revealed a reduced probability of probe detection occurring between 180–450 ms, indicating a posttarget attentional deficit. A control group that was given instructions to ignore the first target and merely perform the probe task showed a high probability of probe detection in all posttarget positions, suggesting that the experimental group experienced attentional and not sensory limitations. In this report, Raymond et al. coined the term *attentional blink* (AB) to describe this temporary attentional deficit.

Raymond et al. (1992) further concluded that simply performing the target task did not produce the AB but that it resulted from a combination of having to perform the target task and being presented with the first posttarget item. They reported that when the item normally presented immediately following the target was removed (Experiment 3), the blink was attenuated to the performance of controls not required to perform the target task. In the same article (Experiment 4), however, when the first posttarget item was retained in the stream but the item normally occupying the second, third, or fourth position was removed, the blink returned to the same level seen in Experiment 2, in which the stream contained a continuous visual flow. This latter finding demonstrates the importance of the occurrence of the *first* posttarget item interacting with the target task to cause the AB, as opposed to the blink resulting from the continuous stream of posttarget items.

In the present article, we continue this investigation of the nature of the AB phenomenon by examining the contribution of the attentional demands of the target task to the production *of the blink. Since a serial processing, limited-capacity mechanism has formed the basis of most models of spatial-*

visual search, it is reasonable to postulate that a similar mechanism underlies visual search in the temporal domain. In the spatial domain, such a model predicts the general outcome that spatial search becomes more difficult with increasing attentional demands of the target task. With this in mind, we manipulated the set-size of the target task in the present experiments, in an attempt to derive the relationship between attentional demands and the magnitude of the blink. In subsequent experiments, we manipulated identification versus detection requirements of the target task to investigate the contribution of the postulated detect-then-identify requirement of the target task to the observed AB. The general strategy used in the following set of experiments was to manipulate the target task and to leave all other elements of the RSVP procedure unaltered.

Experiment 1

The purpose of the first experiment was to investigate the possibility that the results observed in Raymond et al. (1992, Experiment 2) were due to the target's set-size (i.e., 25 items) imposing an overload on a limited-capacity attentional mechanism required to detect and identify the target stimulus. Thus in Experiment 1 the set-size from which the target could be drawn was reduced from 25 to 3 letters. The subject's task was to identify which of three possible white target letters was embedded in a stream of black letters and then to detect whether the probe (i.e., second target) was present or absent in the remaining stream. A different, smaller group of control subjects performed the probe task but not the target task, although the stimulus stream remained the same.[2]

Method

Design. The present study used a two-factor design with group (experimental vs. control) as a between-subjects variable and relative serial probe position (positions 1–8) as a repeated measures variable. A second two-factor analysis was conducted to test the hypothesis that set-size is responsible for the AB observed in Raymond et al. (1992, Experiment 2). Set-size (3 vs. 25) was analyzed as a between-subjects variable and relative serial probe position (Positions 1–8) as the repeated measures variable in this second analysis. (Set-size 25 data was obtained from the experiment published by Raymond et al. and was not run as part of the present study.)

Subjects. Thirteen university students (8 women and 5 men), ranging in age from 20 to 43 years ($M = 25.0$), volunteered to participate in the experiment. Ten subjects participated in the experimental condition and 3 in the control condition. In this and in all subsequent experiments the following conditions were met: Subjects had approximately 10 practice trials prior to participation and had no prior experience with RSVP tasks. Subjects had normal or corrected-to-normal visual acuity, and informed consent was obtained prior to participation.

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[2] Since extensive controls of a very similar nature were run in Raymond, Shapiro, and Arnell (1992) and never revealed an AB, a smaller control group in the present experiment was run to enable the appropriate comparison to be made.

Apparatus. The stimuli for this and all subsequent experiments were generated by an Apple Macintosh II computer using custom software and displayed on an Apple 28.6 cm (13-in.) color monitor. Subjects viewed the display in this and all other experiments binocularly from a distance of 35 cm and stabilized their head position with the aid of a chin rest. Responses were reported verbally and were recorded by an experimenter with the aid of a second computer. The experimenter was blind to the correct responses for all trials in this and all subsequent experiments.

Stimuli and procedure. For the particular manipulation of the present experiment, each subject participated in one session that consisted of 160 RSVP trials. In this and all subsequent experiments, each trial consisted of a series of successively presented simple, block-style capital letters, as shown in Figure 1 (Panel A). Each letter was presented for 15 ms with an interstimulus interval (ISI) of 75 ms, producing a presentation rate of 11.11 letters/s. Each letter was displayed singly at the same location in the center of a uniform gray field (9.1 cd/m²), which subtended 16.3° by 12.5°.

Letters were 0.82° in height and approximately the same width. All letters appeared black with the exception of the target letter, which was white (32.9 cd/m²). The number of pretarget letters was randomly chosen by the computer on each trial and varied between 7 and 15 (Figure 1, Panel B). Eight letters always succeeded the target. The uniform gray field was viewed during the ISI. The subject initiated a trial by depressing the mouse button. Each trial began with a 180-ms presentation of a small, white fixation dot. In the present experiment the subject's first task was to identify the white letter (target), which was chosen randomly from trial to trial from among the three letters, *B, G,* and *S.* The subject's second task was to report whether the letter *X* (i.e., the probe) was present or absent in the posttarget stream. The computer randomly chose the pretarget and posttarget letters to be presented from the remaining 22 letters in the alphabet (*B, G, S,* and *X* were exempt), with the condition that no letter was presented twice within a trial. Subjects were told in the preexperiment instructions that the target would be one of the letters *B, S,* or *G* but were not cued as to which letter would appear.
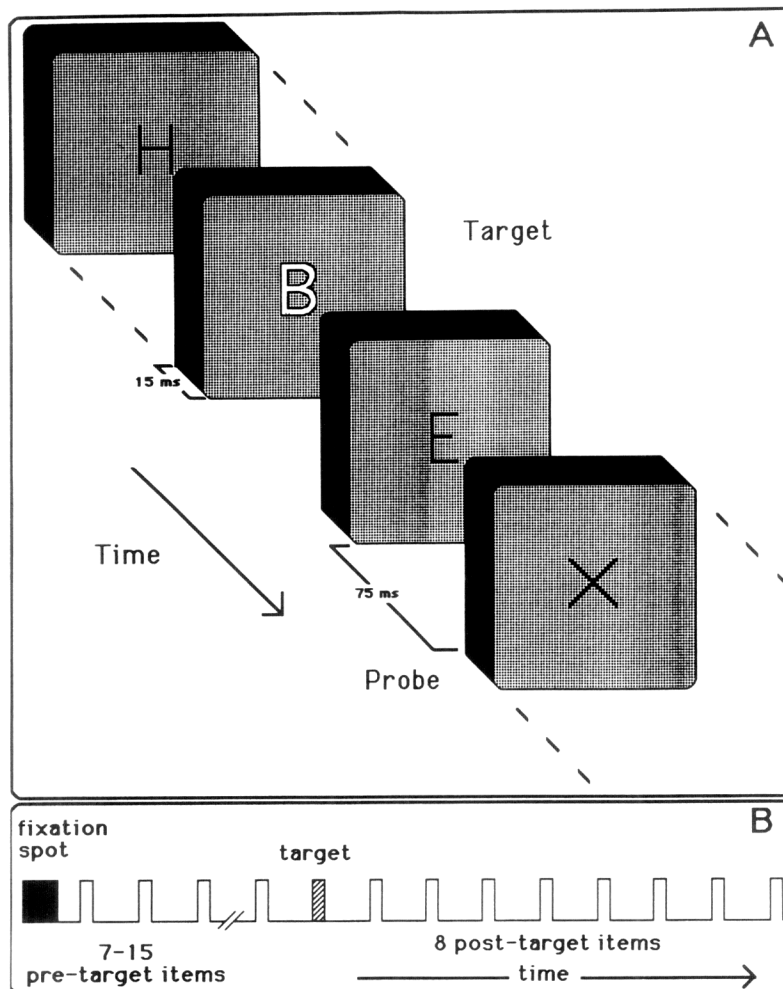

Figure 1. Panel A: An illustration of the stimuli used in the generic rapid serial visual presentation paradigm used in all the experiments. The target, embedded in the stimulus stream, was in the majority of experiments a white letter but could be a black letter, white dots, or the absence of a letter, depending on the particular manipulation. The probe in all experiments was a black *X* presented at a variable serial position after the target. Panel B: An illustration of the same stimuli shown in Panel A in the temporal order used in all experiments. See individual experiments for details.

In half of the randomly presented trials, a probe was present at one of the serial positions 1 through 8 and in the remaining trials a probe was never presented. A probe was never presented prior to the target. The probe was presented 10 times at each of the possible serial positions yielding 80 probe-present and 80 probe-absent trials. Whereas subjects in the control group performed the same probe detection task as their counterparts in the experimental group, they were not required to perform the target identification task and were instructed to ignore the white letter target.

Results and Discussion

Probe detection. The group mean percentage of trials in which the probe was detected correctly for both the control and the experimental groups is plotted as a function of the relative serial position of the probe in Figure 2. Means were calculated using only those trials in which subjects identified the target correctly. A two-factor analysis of variance (ANOVA) with condition (experimental vs. control) as a between-subjects factor and probe relative serial position (Positions 1–8) as the repeated measures factor revealed a nonsignificant main effect of condition, a significant main effect of probe relative serial position, $F(7, 77) = 2.16$, $p < .05$, and a significant Condition $\times$ Probe Relative Serial Position interaction, $F(7, 77) = 2.33$, $p < .05$. Multiple comparisons using Scheffé's method revealed significant posttarget processing deficits in the experimen-
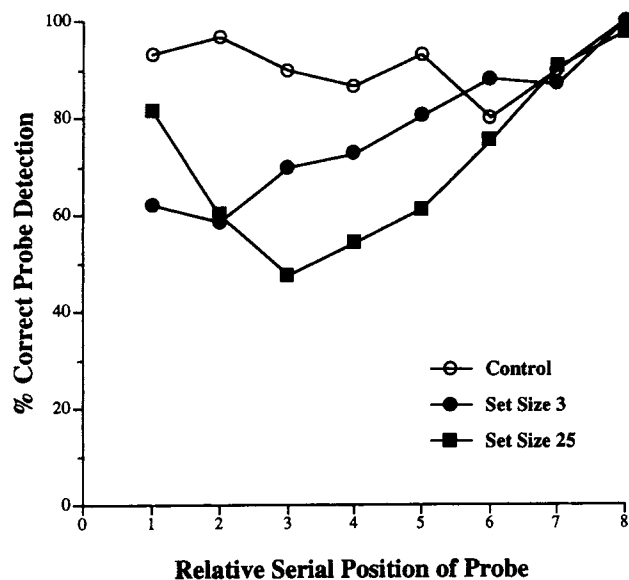

Figure 2. Experiment 1: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open circles represent data obtained in the control condition, in which subjects were told to ignore the target letter. Filled circles represent data obtained in the experimental condition, in which subjects were told to identify which of three possible target letters had been presented (Set-Size 3) and filled squares represent data obtained in the comparable experimental condition of the report by Raymond, Shapiro, and Arnell (1992, Experiment 2), where the target could be any one of 25 letters (Set-Size 25).

tal group for the probe when it occurred in the posttarget serial Positions 1 through 3, corresponding to the posttarget interval occurring between 0 and 270 ms. In the control group, subjects correctly detected the probe on 80% or better of trials for all probe relative serial positions. However, for the experimental condition, the percentage of correct detection dropped to approximately 60% for the posttarget interval between 0 and 270 ms. The group mean false-alarm rate for the probe in the experimental condition was 13.1% (ranging from 2.5% to 37.5%) and in the control condition was 6.7% (ranging from 2.5% to 13.7%). A *t* test between these two conditions showed no difference in the false-alarm rates ($p > .05$).

In order to assess the difference between the present experiment and Experiment 2 of Raymond et al. (1992) to determine whether a set-size effect exists, a two-factor ANOVA with set-size (3 vs. 25) as the between-subjects factor and probe relative serial position (Positions 1–8) as the repeated measures factor was performed; the data are shown in Figure 2. This analysis revealed a nonsignificant main effect of set-size, a significant main effect of probe relative serial position, $F(7, 126) = 11.09$, $p < .01$, and a significant Set-Size $\times$ Probe Relative Serial Position interaction, $F(7, 126) = 2.75$, $p < .05$. Though multiple post hoc comparisons using Scheffé's method revealed no significant differences between set sizes at any of the serial positions,[3] we nevertheless concede that a small set-size effect does likely exist and the implications of this are discussed in the General Discussion section.

It should be noted that the blink observed in the group receiving set-size 3 lasted for the same duration as that found in the group receiving set-size 25 in Raymond et al. (1992, Experiment 2), but the former group's blink onset and offset occurred earlier by one serial position. This is the only condition in the present report where such a difference in onset of the blink occurs. Observation of the data from individual subjects in this condition suggests one or two outliers may have accounted for this difference.

Target identification. Analyzing target identification errors in the group receiving the reduced target set revealed a mean error rate of 5.9%. There was a mean of 5.5% errors on probe-absent trials and a mean of 6.1% on probe-present trials, revealing no statistical difference between target errors on probe-present versus probe-absent trials ($p > .05$). This error rate is far less than would be expected by chance ($p < .01$) and suggests subjects were able to perform the target task in the present experiment with considerable accuracy and were unlikely to be trading off target accuracy for the modest, though statistically nonsignificant, increase in probe detection.

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[3] Whereas the significant Set-Size $\times$ Probe Relative Serial Position interaction indicates a significant difference between the two set-sizes in at least one probe serial position, there are no differences obtained without producing an orthogonal comparison by averaging treatment means. A trend analysis reveals a linear trend in the set-size 3 condition, whereas a quadratic function is necessary to describe the set-size 25 condition.

The results of this experiment reveal the AB effect following successful target identification like that shown in a similar experiment by Raymond et al. (1992, Experiment 2). The presence of a significant but small set-size effect suggests that either attentional demands of the target have only a marginal effect on the production of the AB or that both set-sizes overloaded the limited capacity mechanism sufficiently to produce a blink (see the General Discussion section for a further treatment of this issue).

According to the detect-then-identify model (D. E. Broadbent and M. H. P. Broadbent, 1987), the target task requires an attentionally demanding identification process that extends beyond the time of the target's appearance. Raymond et al. (1992) suggested that the AB effect results from the attentional system attempting to reduce confusion that arises during this identification process. If the attentional demand of the target requires only simple *detection* and little or no identification, the detect-then-identify model would predict that performing the target task should therefore not interact with the occurrence of the first posttarget stimulus and not produce an AB.

Experiment 2

The purpose of the second experiment was to investigate whether a target detection task imposes a different attention demand than a target identification task. We attempted to create a target detection, rather than identification, task by having subjects detect merely the presence or absence of a white target occurring in an RSVP stimulus stream identical to that used in Experiment 1. Subjects were then required to detect the presence or absence of the probe in the posttarget stream (also as in Experiment 1).

Method

Design. The present study used a two-factor design with condition (target present vs. target absent) as a within-subjects variable and relative serial probe position (Positions 1–8) as a repeated measures variable.

Subjects and apparatus. Ten university students (1 man and 9 women), ranging in age from 18 to 24 years ($M = 20.5$), volunteered to participate in the experiment. The apparatus was identical to that described for Experiment 1.

Stimuli and procedure. Each subject participated in one experimental session, which consisted of 320 RSVP trials. The stimuli and temporal parameters in this experiment were the same as in Experiment 1, except for those differences noted below. Subjects in this experiment were required to perform two tasks: The first, or target task (which differed from the previous experiment) was to detect if a target was present or absent (in Experiment 1 they had to identify the target). The subject was repeatedly told that the identity of the target letter was unimportant and not to attempt to identify it. The second task (which was identical with a task in Experiment 1) was to determine if a probe (i.e., the black letter X) was present or absent. As before, the target was distinguished from the other items in the stimulus stream by its color (white). The target could be any letter of the alphabet except X. Half the randomly presented trials had a target present and the other half did not, yielding 160 trials in each condition, i.e., target-present and target-absent. In half of the target-present

trials and half of the target-absent trials, the probe was presented 10 times at each of the possible posttarget serial Positions 1 through 8, yielding 80 probe-present trials in each condition. The remaining trials contained no probe and served as catch trials.

Results and Discussion

Probe detection. The group mean percentage of probe-present trials in which the probe was detected correctly is plotted as a function of the relative serial position of the probe for target-present and target-absent conditions in Figure 3. Means were calculated using only those trials in which subjects detected the target's presence or absence correctly. A two-factor (Condition × Probe Relative Serial Position) repeated measure ANOVA revealed a significant main effect of condition, $F(1, 9) = 25.98, p < .01$, a significant main effect of probe relative serial position, $F(7, 63) = 15.34, p < .01$, and a significant Condition × Probe Relative Serial Position interaction, $F(7, 63) = 8.78, p < .01$. Multiple comparisons using Scheffé's method revealed that the group mean percentage probe detection for the target-present condition was significantly lower ($p < .05$) than the corresponding point for the target-absent condition for posttarget probe positions 2, 3, and 4, indicating a significant posttarget processing deficit for the posttarget interval occurring between 90 and 360 ms. For the target-absent condition, subjects correctly detected the probe on 79% or more of trials for all probe relative serial positions. However, for the target-present condition, the percentage of correctly detected probes dropped to an average of 47% for the posttarget interval between 90 and 360 ms. The group mean false-alarm rate for probe detection in the
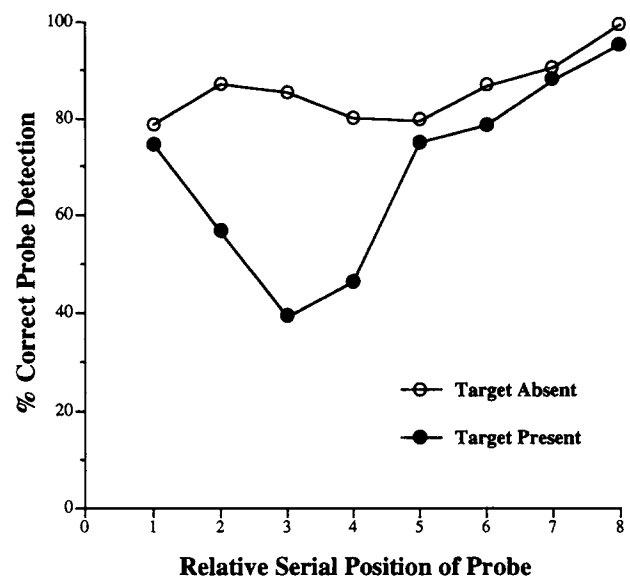

Figure 3. Experiment 2: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open symbols represent data obtained in the control condition, in which no target was presented. Filled symbols represent data obtained in the experimental condition on trials in which subjects correctly detected the target as being present for the condition where the target was any one of 25 (white) letters of the alphabet.

Table 1

Mean Probability of Target Hits and False Positives (Probe-Present Trials) and Target d' Values by Experiment

Experiment no.	Probability of hit	Probability of false positive	Target d'
2	.94	.06	3.93
3A	.98	.02	4.54
3B	.91	.10	3.03
4	.98	.03	4.40
5A	.79	.05	2.78
5B (short gap)	.59	.24	.94
5B (long gap)	.76	.42	

target-present condition was 8.9% (ranging from 1.25% to 25%) and in the target-absent condition was 10.6% (ranging from 0% to 26%), with no statistical difference between these two conditions ($p > .05$).

Target detection. The mean probability of a successful target detection (probe-present trials only) was 0.94 and the mean probability of a false positive (probe-present trials) was 0.06. These error rates are reported in Table 1 and reveal that subjects were correctly identifying the target with a high degree of success while at the same time keeping their false positive rates low. A mean d' for target detection on probe-present trials was calculated to be 3.93 ($SE = 0.36$).

The results of this experiment suggest that an AB occurs after a target detection task, like that found after the target identification task in Experiment 1 of the present study and in similar experiments by Raymond et al. (1992). Whereas it is tempting to conclude that the results of this experiment invalidate the detect-then-identify account of why the blink is produced, this may be premature. It is possible that subjects were identifying the target even though they were instructed not to do so; in other words, letter identification may occur involuntarily. In the next experiment we sought to create a target task that required target detection but would not prompt target identification.

Experiment 3A

The major purpose of the third experiment was to try to create a detection task that had no identification component in order to test the detect-then-identify model discussed previously. Thus in the present experiment, we used a target with the same identity from trial to trial (i.e., the same letter), thereby attempting to remove any propensity for subjects to attempt to identify it.

Method

Design. The present study used a two-factor design with condition (target present vs. target absent) as a within-subjects variable and relative serial probe position (Positions 1–8) as a repeated measures variable.

Subjects and apparatus. Ten university students (6 men and 4 women), ranging in age from 18 to 22 years ($M = 19.0$), volunteered to participate in the experiment. The apparatus used in this experiment was identical to that used in the previous experiment.

Stimuli and procedure. Each subject participated in one experimental session, which consisted of 320 RSVP trials. The stimuli and stimulus parameters in this experiment were the same as in Experiment 2, except that the white target could be only the letter *S*. As in the previous experiment, half the randomly presented trials were target-present and the other half were target-absent (condition variable). The probe *X* was presented 10 times at each of the possible posttarget serial Positions 1 through 8, yielding 80 probe-present with a corresponding 80 probe-absent trials for each of the target-present and target-absent conditions. The subject was instructed to simply detect whether a white target was present or absent and then to detect whether an *X* was present or absent. The subject was told that the identity of the target letter was the same on each trial and not to attempt to identify it.

Results and Discussion

Probe detection. The group mean percentage of trials in which the probe was detected correctly is plotted as a function of the relative serial position of the probe in Figure 4. Means were calculated using only those trials in which subjects detected the presence or absence of the target correctly. A two-factor (Condition × Probe Relative Serial Position) repeated measures ANOVA revealed a significant main effect of condition, $F(1, 9) = 20.04$, $p < .01$, a significant main effect of probe relative serial position, $F(7, 63) = 18.54$, $p < .01$, and a significant Condition × Probe Relative Serial Position interaction, $F(7, 63) = 5.00$, $p < .01$. Multiple comparisons using Scheffé's method revealed that the group mean percentage probe detection for the target-present con-
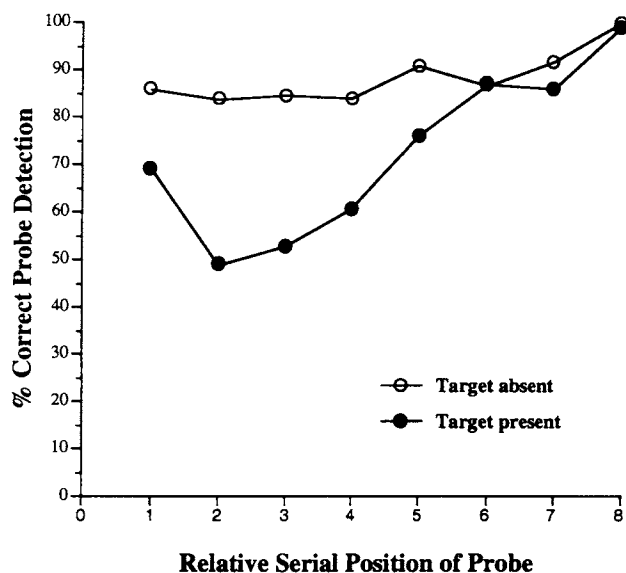

Relative Serial Position of Probe

Figure 4. Experiment 3A: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open symbols represent data obtained in the control condition in which no target was presented. Filled symbols represent data obtained in the experimental condition on trials in which subjects correctly detected the target as being present for the condition where the target was the white letter *S*.

dition was significantly lower ($p < .05$) than the corresponding point for the target-absent condition for posttarget serial positions 2, 3, and 4, indicating a significant posttarget processing deficit for the posttarget interval occurring between 90 and 360 ms. For the target-absent condition, subjects correctly detected the probe on 84% or better of trials for all probe relative serial positions. However, for the target-present condition, the percentage of correctly detected probes was 61% or less for the posttarget interval between 90 and 360 ms. The group mean false-alarm rate for the probe in the target-present condition was 10.0% (ranging from 0% to 26%) and for the target-absent condition was 12.1% (ranging from 4% to 27%), with no statistical difference between these two conditions ($p > .05$).

Target detection. The mean probability of a successful target detection (probe-present trials only) was 0.98 and the mean probability of a false positive on probe-present trials was 0.02. These error rates are reported in Table 1 and reveal that subjects were correctly identifying the target with a high degree of success while at the same time keeping their false positives low. A mean d' for target detection on probe-present trials was calculated to be 4.54 ($SE = 0.19$).

The results of this experiment reveal an AB following successful target detection like that shown in Experiments 1 and 2 of the present report and in similar experiments by Raymond et al. (1992). Once again, it is tempting to deny the contribution of the identification process, combined with the confusion resulting from the first posttarget item, to the production of the AB. Although such a conclusion is somewhat more credible than before, it still cannot be ruled out that subjects were identifying the target. The higher d' value revealed in Experiment 3A as opposed to Experiment 2 suggests that subjects were indeed easily performing the target task and that the constant identity of the target in the present, as opposed to the previous, experiment made the task that much easier. In the next experiment, we took a different tack in examining the contribution of target task identification to the production of the blink; we sought to determine whether a more difficult target identification task would effect any greater degree of an AB than did the ostensible target detection task of Experiment 3A.

Experiment 3B

The purpose of this experiment was to enable a comparison between the outcome of the previous experiment to that of a task where the target is differentiated from the background stream by identity, rather than by a feature (i.e., the color white). Such a manipulation provides another opportunity to examine the relationship of target task difficulty to the magnitude of the AB effect. Thus, whereas Experiment 3A required the subject to detect the presence or absence of a highly discriminable feature (i.e., a white S) from the background stream of black letters, the present experiment required the subject to identify each letter and determine whether the black letter S was present or not. We anticipated finding an AB of greater magnitude in the present condition than we found in Experiment 3A.

Method

Design. The present study used a two-factor design with condition (target present vs. target absent) as a within-subjects variable and relative serial probe position (Positions 1–8) as a repeated measures variable.

Subjects and apparatus. Ten university students (8 men and 2 women), ranging in age from 18 to 19 years ($M = 18.5$), volunteered to participate in the experiment. The apparatus used in this experiment was identical to that used in the previous experiment.

Stimuli and procedure. Each subject participated in one experimental session that consisted of 320 RSVP trials. The stimuli and stimulus parameters in this experiment were the same as in Experiment 3A, except that the target was the black letter S. As in the previous experiment, half the randomly presented trials were target-present and the other half were target-absent (condition variable). The probe X was presented 10 times at each of the possible serial Positions 1 through 8, yielding 80 probe-present with a corresponding 80 probe-absent trials for each of the target-present and target-absent conditions. The subject was instructed to detect whether a black S was present or absent and then to detect whether an X was present or absent.

Results and Discussion

Probe detection. The group mean percentage of trials in which the probe was detected correctly is plotted as a function of the relative serial position of the probe in Figure 5. Means were calculated using only those trials in which subjects detected the presence or absence of the target correctly. A two-factor (Condition × Probe Relative Serial Position)
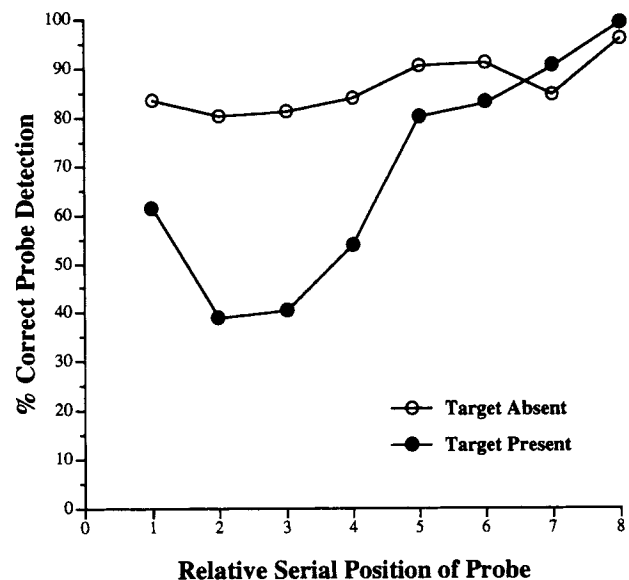

Figure 5. Experiment 3B: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open symbols represent data obtained in the control condition in which no target was presented. Filled symbols represent data obtained in the experimental condition on trials in which subjects correctly detected the target as being present for the condition where the target was the black letter S.

repeated measures ANOVA revealed a significant main effect of condition, $F(1, 9) = 42.08$, $p < .01$, a significant main effect of probe relative serial position, $F(7, 63) = 14.22$, $p < .01$, and a significant Condition × Probe Relative Serial Position interaction, $F(7, 63) = 7.47$, $p < .01$. Multiple comparisons using Scheffé's method revealed that the group mean percentage probe detection for the target-present condition was significantly lower ($p < .05$) than the corresponding point for the target-absent condition for posttarget serial positions 2, 3, and 4, indicating a significant posttarget processing deficit for the posttarget interval occurring between 90 and 360 ms. For the target-absent condition, subjects correctly detected the probe on 80% or better of trials for all probe relative serial positions. However, for the target-present condition, the percentage of correctly detected probes dropped below 54% for the posttarget interval between 90 and 360 ms. The group mean false-alarm rate for the probe in the target-present condition was 9.6% (ranging from 0% to 25.0%) and for the target-absent condition was 10.1% (ranging from 1.2% to 17.5%), with no statistical difference between these two conditions ($p > .05$).

It is important to determine whether there was any difference in the results of the two tasks confronting the subject in this and in the previous experiment (3A). A two-factor (Experiment × Probe Relative Serial Position) repeated measures ANOVA was conducted with two levels of the first between-subjects factor (white S vs. black S on target-present trials only) and 8 levels of the within-variable (posttarget positions 1–8). No main effect of condition was revealed, nor was there any interaction with the position variable. There was, as expected, a main effect of probe relative serial position, $F(7, 144) = 22.14$, $p < .01$, indicating the presence of the AB effect in both conditions.

Target detection. The mean probability of a successful target detection on target-present trials (probe-present trials only) was 0.91 and the mean probability of a false positive on probe-present trials was 0.10. These error rates are reported in Table 1 and reveal that subjects were correctly identifying the target with a high degree of success while at the same time keeping their false positives low, though not as low as in previously reported experiments. A mean d' for target detection on probe-present trials was calculated to be 3.03 ($SE = 0.33$).

The results of this experiment reveal an AB following successful target detection like that shown in all previous experiments of the present report. We did find a substantially lower d' value for the target task in Experiment 3B than in 3A, indicating that the task was more difficult, as predicted. However, the more difficult target task did not result in a blink of greater magnitude (see the General Discussion section for a quantification of blink magnitude). These first four experiments, taken as a whole, suggest that any target task that involves a letter stimulus, regardless of the set-size from which it is drawn or whether detection or identification is required, yields an approximately equal attentional deficit. Thus, there appears to be a lack of relationship between letter target task difficulty and the magnitude of the AB. However, we have yet to determine conclusively whether target identification is necessary for production of the AB. In the next

experiment we sought to create a target task in which letter identification was not possible.

Experiment 4

The purpose of the next experiment was to investigate the possibility that letters, regardless of the task requirement, were involuntarily identified and that such identification is necessary for the blink. The present experiment required the detection of a nonletter stimulus that contained pattern information of a similar spatial scale to that found in letter stimuli. Subjects in the present experiment were required to detect the presence or absence of a random dot pattern (target) occurring in the RSVP stimulus stream and then to detect the presence or absence of the letter X in the posttarget stream, as in previous experiments.

Method

Design. The present study used a two-factor design with condition (target present vs. target absent) as a within-subjects variable and relative serial probe position (Positions 1–8) as a repeated measures variable.

Subjects and apparatus. Ten university students (2 men and 8 women), ranging in age from 19 to 45 years ($M = 31.6$), volunteered to participate in the experiment. The apparatus was identical to that described for all previous experiments.

Stimuli and procedure. Each subject participated in one experimental session that consisted of 320 RSVP trials. The stimuli and temporal parameters in this experiment were the same as in all previous experiments, except for those differences noted below. Subjects in this experiment, as before, were required to perform two tasks: The first, or target task, was to detect whether a target was present or absent, and the second task was to determine whether a probe was present or absent. In the present experiment, the target was an array of five white dots randomly positioned within the area normally occupied by a letter. The same target was used in all target-present trials. The probe stimulus was identical to that used in previous experiments and required the subject to detect the presence or absence of the letter X in the posttarget stream. Half the randomly presented trials were target-present and the other half were target-absent, yielding 160 of each. For half of the target-present and half the target-absent trials, the probe X was presented 10 times at each of the possible serial positions 1 through 8, yielding 80 probe-present trials in each condition.

Results and Discussion

Probe detection. The group mean percentage of trials in which the probe was detected correctly is plotted as a function of the relative serial position of the probe for both levels of the condition variable (target-present vs. target-absent) trials in Figure 6. Means were calculated using only those trials in which subjects detected the target correctly. A two-factor (Condition × Probe Relative Serial Position) repeated measures ANOVA revealed a significant main effect of condition, $F(1, 9) = 19.69$, $p < .01$, a significant main effect of probe relative serial position, $F(7, 63) = 12.66$, $p < .01$, and a significant Condition × Probe Relative Serial Position interaction, $F(7, 63) = 8.19$, $p < .01$. Multiple comparisons
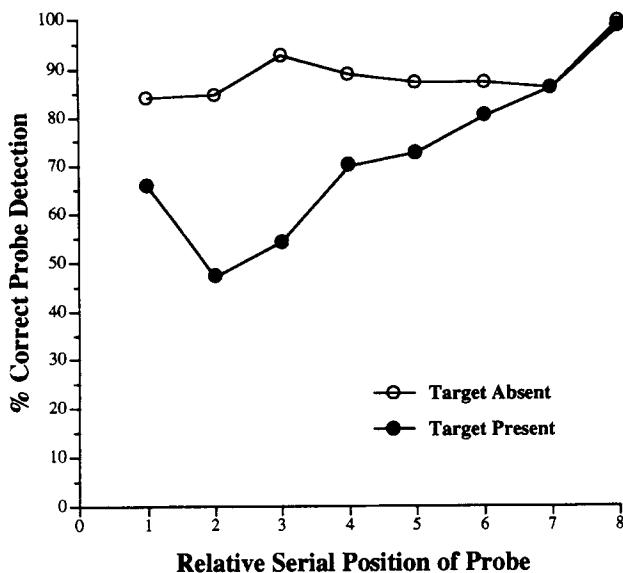
Figure 6. Experiment 4: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open symbols represent data obtained in the control condition in which no target was presented. Filled symbols represent data obtained in the experimental condition on trials in which subjects correctly detected the target as being present for the condition where the target was a randomly predetermined white dot pattern.

using Scheffé's method revealed that the group mean percentage for probe detection for the target-present condition was significantly lower ($p < .05$) than the corresponding point for the target-absent condition for posttarget probe positions 2 and 3, indicating a significant posttarget processing deficit for the posttarget interval occurring between 90 and 270 ms. For the target-absent condition, subjects correctly detected the probe on 84% or better of trials for all probe relative serial positions. However, for the target-present condition, less than 50% were correctly detected for the posttarget interval between 90 and 270 ms. The group mean false-alarm rate for probe detection in the target-present condition was 11.3% (ranging from 1% to 35%) and in the target-absent condition it was 11.0% (ranging from 2% to 31%), with no statistical difference between these two conditions ($p > .05$).

Target detection. The mean probability of a successful target detection on target-present trials (probe-present trials only) was 0.98 and the mean probability of a false positive on probe-present trials was 0.03. These error rates are reported in Table 1 and reveal that subjects were correctly detecting the target with a high degree of success while at the same time keeping their false positives low. A mean d' for target detection on probe-present trials was calculated to be 4.40 ($SE = 0.24$).

The results of this experiment reveal an AB following successful target detection like that shown in all previous experiments of the present study and in experiments by Raymond et al. (1992). Thus it appears that detection of a meaningless patterned stimulus embedded in a letter stimulus stream can cause an AB and that such an attentional deficit

is not limited to situations requiring attentional allocation to letter targets embedded in a letter stream. Moreover, these results strongly suggest that identification of a target is not necessary for the production of the AB but that simple detection of a target in a continuous RSVP stream is sufficient. To be certain that the presence of pattern information and not identification versus detection is the important determinant of the blink, we conducted two additional target manipulations. Both target conditions were characterized by an absence of pattern information, but the first required detection, whereas the second required identification.

Experiment 5A

In the present experiment, subjects were required to detect whether a target was present or absent, though the target itself contained no pattern information of any kind. This was accomplished by requiring subjects to detect if a temporal gap in the stimulus stream had occurred.

Method

Design. The present study used a two-factor design with condition (target-present vs. target-absent) as a within-subjects variable and relative serial probe position (Positions 1–7) as a repeated measures variable.

Subjects and apparatus. Ten university students (2 men and 8 women), ranging in age from 19 to 33 years ($M = 23.2$), volunteered to participate in the experiment. The apparatus used in this experiment was identical to that used in the previous experiment.

Stimuli and procedure. Each subject participated in one experimental session, which consisted of 320 RSVP trials. The stimuli and stimulus parameters in this experiment were the same as in previous experiments except that the target-present condition consisted of the absence of a letter (i.e., a gap) in the same serial position as normally occupied by the target. The gap produced a 165-ms interval with no letter. (This interval consisted of the 75-ms ISI succeeding the last pretarget item, the 15-ms target interval, and the 75-ms ISI normally following the target.) In the target-absent condition, a black randomly chosen letter appeared in the position typically occupied by the target. As in the previous experiment, half the randomly presented trials were target-present and the other half were target-absent (condition variable). The probe X was presented 10 times at each of the possible posttarget serial positions 1 through 8, yielding 80 probe-present with a corresponding 80 probe-absent trials for each of the target-present and target-absent conditions. The subject was instructed to simply detect whether the gap was present or absent and then to detect whether an X was present or absent.

Results and Discussion

Probe detection. The group mean percentage of trials in which the probe was detected correctly is plotted as a function of the relative serial position of the probe for posttarget positions 1–7 in Figure 7.[4] Means were calculated using only those trials in which subjects identified the target correctly.

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[4] Since Position 8 reached 100% accuracy in both the target-present and target-absent groups, it was creating an artificial effect of position; thus, this position was removed from the analysis.
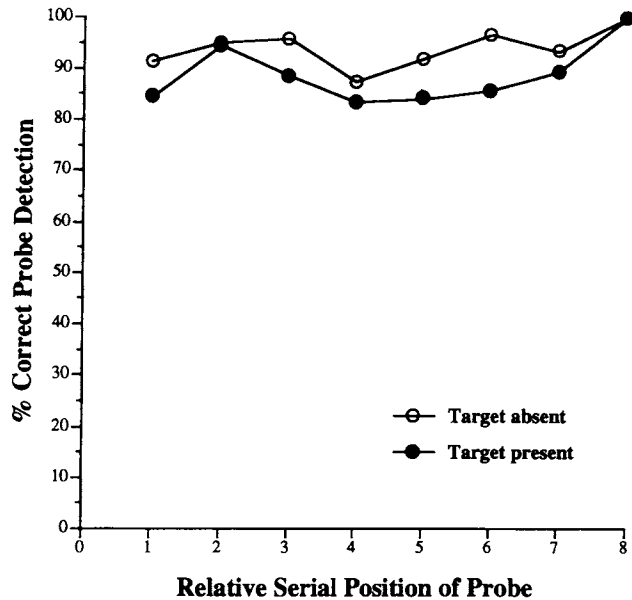
Figure 7. Experiment 5A: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open symbols represent data obtained in the control condition in which no target (i.e., "gap") was presented. Filled symbols represent data obtained in the experimental condition on trials in which subjects correctly detected the target as being present for the condition where the target was a single "gap."

A two-factor (Condition × Probe Relative Serial Position) repeated measures ANOVA revealed a significant main effect of condition, $F(1, 9) = 8.43$, $p < .01$, a nonsignificant main effect of probe relative serial position ($p > .05$), and a nonsignificant Condition × Probe Relative Serial Position interaction ($p > .05$). Whereas the significant effect of condition does indicate that there is a difference between target-present and target-absent trials, the lack of a probe relative serial position effect and the lack of a Serial Position × Condition interaction suggests that the AB per se is not revealed when the target is a gap. Moreover, probe detection in the target-present condition averaged approximately 89% across posttarget serial positions 2–4, which is higher by about 35% relative to the same posttarget positions in Experiments 1–4. The group mean false-alarm rate for the probe in the target-present condition was 6.25% (ranging from 0% to 14%) and for the target-absent condition it was 8.5% (ranging from 0% to 19%), with no statistical difference between these two conditions ($p > .05$).

Target detection. The mean probability of a successful target detection on target-present (i.e., gap) trials (probe-present trials only) was 0.79, and the mean probability of a false positive on probe-present trials was 0.05. These error rates are reported in Table 1 and reveal that subjects were correctly identifying the presence of the gap with a considerable degree of success, though lower than in previous experiments, while at the same time keeping their false positives low. A mean d' for gap detection on probe-present trials was calculated to be 2.78 ($SE = 0.33$).

The results of this experiment reveal the lack of an AB relative to all previous experiments in this report and including that reported by Raymond et al. (1992, Experiment 2). This suggests that targets not possessing visual pattern information fail to yield an AB. Although the random-dot presence versus absence judgment of Experiment 4 was intended to create a detection task, it cannot fully be discounted that subjects were attempting to "identify" the dot pattern, given its similarity in pattern information to letter stimuli used in previous target tasks. Thus, it is possible that the detection, as opposed to identification, characteristic of the target "gap" task was responsible for the absence of an AB effect. The next experiment sought to eliminate the contribution of identification per se to the production of the blink.

Experiment 5B

Experiment 5A revealed that when a single gap is a target, the AB effect appears to be eliminated. The possibility still remains, however, that identification, not pattern information, is the critical component of the target task necessary to produce the effect. This hypothesis was tested by requiring subjects to identify whether a short or a long gap was presented as the target. Thus the identification component was reinstated but the target did not possess any pattern information as in the previous target identification tasks.

Method

Design. The present study used a two-factor design with condition (experimental vs. control) as a within-subjects variable and relative serial probe position (Positions 1–7; see Footnote 4) as a repeated measures variable, as in Experiment 1. The condition variable was counterbalanced, with approximately half the subjects running in the control condition first and the remainder running in the experimental condition first.

Subjects and apparatus. Nine university students (four men and five women), ranging in age from 20 to 38 years ($M = 26.3$), volunteered to participate in the experiment. The apparatus used in this experiment was identical to that used in the previous experiments.

Stimuli and procedure. Each subject participated in two sessions, as described above, which consisted of 160 RSVP trials each. The stimuli and stimulus parameters in this experiment were the same as in previous experiments, except for those differences noted below. In this experiment the "short target" present condition consisted of a gap in the same position as the target would normally occur (as in Experiment 5A), amounting to 165 ms. In the "long target" present condition, subjects experienced the absence of two temporal stimulus positions, amounting to an interval of 255 ms. Half the randomly presented trials were "short gap" and the other half were "long gap." The probe X was presented 5 times at each of the possible serial positions 1 through 8, yielding 40 probe-present with a corresponding 40 probe-absent trials for each gap-length target condition. In the experimental condition, subjects were instructed to identify only whether the gap was short or long and then to detect whether an X (probe) was present or absent. In the control condition, subjects were instructed to ignore the target (gap) but to detect whether an X (probe) was present or absent.

Results and Discussion

Probe detection. Before comparing the control and the experimental conditions, a comparison between the short- and long-gap target trials in the experimental condition was conducted. A two-factor ANOVA with gap length (short vs. long) as a within-subjects factor and probe relative serial position (Positions 1–7; see Footnote 4) as the repeated measures factor revealed a nonsignificant effect of gap length ($p > .05$), a nonsignificant main effect of probe relative serial position ($p > .05$), and a nonsignificant Gap Length × Probe Relative Serial Position interaction ($p > .05$). Thus the means for the short and long gap were averaged to produce one mean for the experimental gap condition.

The group mean percentage of trials in which the probe was detected correctly for both the control and experimental conditions is plotted as a function of the relative serial position of the probe in Figure 8. Means were calculated using only those trials in which subjects identified the target correctly. A two-factor ANOVA with condition (experimental vs. control) as a between-subjects factor and probe relative serial position (Positions 1–7; see Footnote 4) as the repeated measures factor revealed a nonsignificant main effect of condition ($p > .05$), a nonsignificant main effect of probe relative serial position ($p > .05$), and a nonsignificant Condition × Probe Relative Serial Position interaction ($p > .05$). The group mean false-alarm rate for the probe in the experimental short-gap condition was 1.5% (ranging from 0% to 2%), and in the experimental long-gap condition it was 1.4% (ranging from 0% to 1%). A t test between these two conditions showed no difference in the false-alarm rates ($p > .05$).
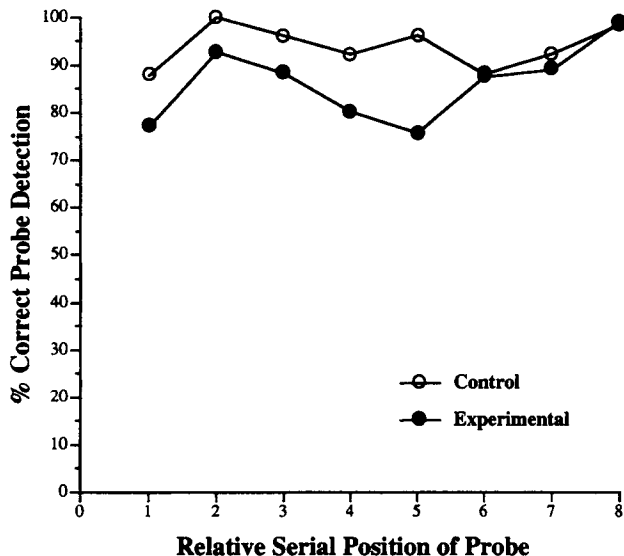

Figure 8. Experiment 5B: The group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. Open symbols represent data obtained in the control condition in which the target (i.e., a gap) was ignored. Filled symbols represent data averaged over both single and double "gap" experimental conditions for trials in which subjects correctly identified the target as being present.

Target identification. The mean probability of a successful short-gap identification (probe-present trials only) was 0.59 and the mean probability of a short-gap response on long-gap trials was 0.24. When analyzing for long-gap identification, the mean probability of a successful identification was 0.76 but the false-positive rate (i.e., the probability of a "long-gap" response on a short-gap trial) was 0.42. These error rates are reported in Table 1 and reveal that subjects were correctly identifying the target with a considerably lower degree of success and making many more false positives than in previous manipulations in the present report. A mean d' for both the short and the long gap was calculated to be 0.94 ($SE = 0.14$). Such a d' reveals that although the target task was considerably more difficult than in previous experiments in this report, an AB was not revealed.

The outcome of this experiment suggests that the absence of a blink in Experiment 5A does not represent merely the first time a "true" detection task was effected, that is, that the lack of an identification component accounts for the lack of a blink. Taken as a whole, Experiments 4, 5A, and 5B suggest that the blink must occur whenever a target containing pattern information is encountered in a continuous RSVP stream and that it is the presence of this pattern information and not the detection versus identification requirement of the target that contributes to the production of the AB.

General Discussion

Summary of Experimental Results

Before discussing the implications of the experiments described in the present article, it may be useful to review the methods and results. Some of the basic methodological features common to all experiments are that subjects performed a target task that required either identification (Experiments 1, 3B, and 5B) or detection (Experiments 2, 3A, 4, and 5A) of a featurally distinct (white) target from among a set of black temporally displaced distractor items. (The only exceptions were Experiment 3B, which required a black target to be detected, and Experiments 5A and 5B, which required a gap to be detected or identified, respectively.) After this task, subjects in all experiments were required to detect whether a probe stimulus (the letter X) was present or absent.

Experiment 1 required subjects to identify which of three possible letters constituted the target. The results of this experiment revealed an AB of slightly less magnitude but equal duration (≈ 300 ms) as shown when subjects had to identify which of 25 letters was the target (Raymond et al., 1992, Experiment 2). This result suggests that a reduced set-size and thus a likely decreased attentional load only marginally affects the magnitude of the blink.[5] The implications of this

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[5] It has been suggested by various investigators (e.g., Schneider & Shriffrin, 1977) that increasing target set-size has a harmful effect due to increased attentional load. Although we do not have a direct measure of attentional load for Experiment 1, we do know from other experiments in this report (see analysis following this

effect are discussed later in the section titled "Properties of the AB."

In Experiment 2 subjects were required merely to report whether a white target, which could be any letter of the alphabet (except X), was present or absent. An AB was revealed of equal duration, though beginning slightly earlier, to that just described, suggesting that detection alone (as opposed to identification) is sufficient to produce the blink. Although it appears that the magnitude of the blink did not change between Experiments 1 and 2, a quantitative analysis of blink magnitude was conducted to evaluate this possibility and will be presented in the section that follows.

Since subjects in Experiment 2 could have been identifying the target even though not required to do so, Experiments 3A and 3B enabled us to determine how well subjects performed when the target was either the same white letter from trial to trial and presumably did not engender identification (Experiment 3A) or was identical in feature (color) to the distractor set but nominally different (Experiment 3B), thus requiring identification.[6] The results of both these experiments demonstrated ABs of equal magnitude and equal duration to each other and to the experiments that preceded them. Though this outcome further substantiated the notion that both detection and identification each produce ABs of equal magnitude, the possibility that subjects may have been identifying the targets in both conditions of Experiment 3 cannot be eliminated.

In Experiment 4, we required a target detection task where letter identification per se was not possible. This task required subjects to judge the presence or absence of a white, patterned, nonletter, random-dot target. This target manipulation produced an AB of equal magnitude to those seen in previous experiments where *letter* stimuli were used. Thus it appears that any target containing pattern information produces an AB and that a letter stimulus is not necessary to produce such an attentional deficit.

Experiments 5A and 5B were conducted to verify the apparent necessity of the presence of a target containing at least some pattern information, as opposed to a detection or identification task per se. In Experiments 5A and 5B, a short or a short versus long temporal gap, respectively, defined the target. In Experiment 5A the subject was required to detect the presence or the absence of the gap, whereas in Experiment 5B the requirement was to identify whether a short or a long gap had occurred. Both experiments failed to reveal an AB even though the target identification task in the short-versus long-gap condition was significantly more attentionally demanding than in the single-gap condition.

Cross-Experiment Analyses

Prior to assessing the relationship between the magnitude of the AB and the difficulty of the target task for each experiment, we performed an analysis of all experimental conditions to validate further the claims made individually from

section) that there is no correlation between target difficulty and the magnitude of the AB.

each experiment in the present report and the set-size 25 condition from Raymond et al. (1992). A between-factor, Experiment (8 levels) by within-factor, probe position (8 positions) ANOVA yielded a significant main effect of experiment, $F(7, 71) = 3.84, p < .01$, a significant main effect of probe position, $F(7, 497) = 57.96, p < .01$, and a significant Experiment × Probe Position interaction, $F(49, 497) = 3.63$, $p < .01, MS_e = 249$. In examining the interaction, multiple comparisons using Scheffé's method revealed that the only conditions to differ significantly $(p < .05)$ from those revealing the AB effect were the two gap conditions (Experiments 5A and 5B) and just marginally the set-size 3 condition (Experiment 1). There was also a significant difference between the set-size 3 group and the two "gap" groups, with the former revealing the AB effect by virtue of a significant difference between posttarget positions 3, 4, and 5 and all other posttarget positions, whereas the latter condition revealed no such difference.

In order to examine directly the relationship between the magnitude of the AB and the difficulty of the target task, we correlated the d' value of the target's detectability in conditions revealing an AB to the magnitude of the blink.[7] A nonsignificant correlation $(r^2 = .001; p > .05)$ was obtained and mean group data is graphically represented in Figure 9. Even when the correlation for all target conditions (i.e., both those revealing a blink and those that did not) is analyzed, only a marginally significant correlation $(r^2 = .058; p = .0468)$ is obtained. The lack of a significant correlation supports our contention that the magnitude of the blink is not related to the difficulty of the target detection task per se, but it is related to the all-or-nothing demands imposed by an "object as target" task.

Properties of the AB

In our first article (Raymond et al., 1992), we were able to draw a number of conclusions regarding the AB. First, we determined that it occurs between 100–450 ms after identification of a target and is a robust phenomenon occurring in most subjects. Second, we concluded that the blink appears to be attentionally based and not due to sensory or memory limitations, as might have been concluded on the basis of earlier reports using a different procedure (e.g., Weichselgartner and Sperling, 1987). The attentional as opposed to sensory basis for this effect rests on the finding that the blink

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[6] It could be argued that the target in Experiment 3B required detection, rather than identification, since it was fully specified and could only be present or absent. Nevertheless, it is clearly the case that the specifying feature of 3B (a black S among other black letters) is a more difficult feature relative to its nontarget background than the specifying feature of 3A (a white S among the same black letters).

[7] The magnitude of the blink was quantified by calculating the area above the curve relating percentage correct probe detection to probe relative serial position. This was determined by calculating the difference between 100% and the percentage of correct detections of the probe at each serial position for each subject and then summing the values obtained for posttarget serial positions 1–8.
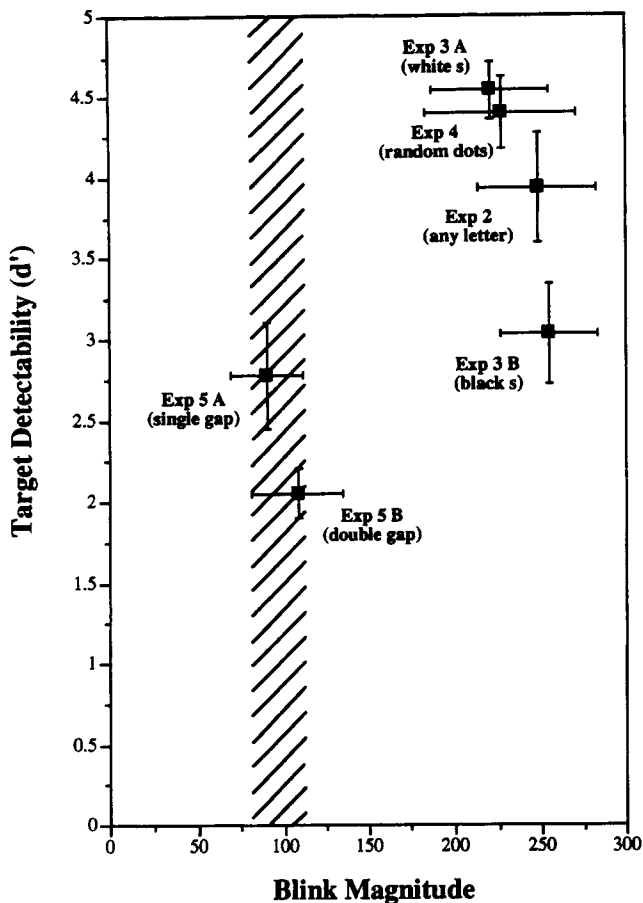
Figure 9. The magnitude of the blink (quantified by calculating the area above the curve relating percentage correct probe detection to probe relative serial position), plotted as a function of target detectability (d') for Experiments 2–5. Error bars revealing standard error of the mean are shown for the dimensions of both blink magnitude and d'. The shaded area depicts the blink magnitude 95% confidence interval for the mean performance of all control groups. (Exp = experiment.)

others. On the whole, the experiments replicate our earlier report of a marked deficit in visual information processing occurring after targets have been attended. However, the present article adds to our knowledge by suggesting that the presence or absence of the target but not its attributes per se is important in determining whether or not a deficit will occur. Specifically, only targets that constitute a physical "object" will cause an AB. Such a conclusion was drawn after finding that targets defined by a gap (i.e., a nonobject) in the temporal stream failed to produce the phenomenon. It is interesting to note that the presence of an "object" caused the AB even though the identity of the object was irrelevant to the task (i.e., only the luminance of the object was important). Such a finding is consistent with views (e.g., Duncan, 1984; Treisman, 1988) that humans attend to all aspects of an object when such an entity is selected for further action. The present series of experiments is further consistent with this notion in that attention to an object target yielded the same magnitude of blink, regardless of the attentional load imposed by it.

Challenging the conclusions drawn by Raymond et al. (1992) that target *identification* is a necessary precondition to produce the blink is the present finding that even the *detection* of a target-defining feature caused a deficit of approximately equal magnitude. This conclusion was perhaps questionable for those experiments in which detection of a letter target was required, given that identification may have been occurring involuntarily. However, such a conclusion becomes more substantiated when the detection task does not involve letters and becomes specific to object-based targets, as it was revealed that no blink occurs to targets defined by temporally based means.

It could still be argued that even nonletter stimuli such as random dot patterns invoke identification. The logical extension of such an argument, however, leaves little room to demonstrate conclusively that object detection can ever occur without identification, at which point our conclusion does become invalid. Nevertheless, our findings at the very least suggest that even the process of selecting a simple overlearned target for report yields a subsequent attentional deficit.

does not occur when the target task is omitted, though the sensory information remained the same. Limitations on memory are unlikely to be playing a role as well, since in Raymond et al. and in the present experiments the probe task required the detection of the presence or absence of a simple stimulus. Finally, Raymond et al. concluded that the AB is produced by the interaction of the demands of the target task and the occurrence of the first posttarget item; removing this item from the stimulus stream resulted in a complete attenuation of the phenomenon. Similar to others (e.g., D. E. Broadbent and M. H. P. Broadbent, 1987), our finding that reporting of the *first* posttarget item was the most frequently committed target error led us to conclude that processing of the target was incomplete by the time the first posttarget item occurred (≈ 100 ms).

The series of experiments reported in this article replicate and add to certain aspects of the findings reported by Raymond et al. (1992) while at the same time challenging

Accounts of the AB

Raymond et al. (1992) suggested that the AB results from confusion manifest by a limited capacity attentional mechanism attempting to identify a target while being confronted with additional competing stimuli before identification has been completed. In this model, target identification involves two stages. In the first stage, the target is likely preattentively differentiated from the nontargets by its featural difference (e.g., a white target among black nontargets). Second, attention is directed to this item in the stimulus stream in an effort to identify it. During this second stage, the first posttarget item arrives and leads to confusion due to a potential for a conjunction error—visual short-term memory (VSTM) contains two letters and two colors. The blink thus occurs when the system ceases to accept items into VSTM for ap-

proximately 300 ms, during which time it is attempting to conjoin the correct color with the correct identity.

The set of experiments reported in this article suggest that the attentional system's attempt to avoid a conjunction problem during the process of target identification need not be the root cause of the AB. This claim is supported by the present experiments where a blink of equal magnitude occurred when only target detection (i.e., a luminance discrimination) was required, as that revealed when the target task required identification. In spite of the results from Experiment 1 where a slight attenuation of the blink occurred when the target task's set-size was reduced,[8] we believe that the blink occurs in an "all-or-nothing" fashion as a result of the activation of an "object" analyzer by the presence of any object matching either the feature detection or target identification template. Such an account must argue that the pattern information (i.e., identity) contained in the target becomes analyzed even though only a featural aspect (i.e., luminance) is actually required for the judgment of presence or absence. Further experiments are underway to determine the minimum degree of pattern necessary to produce the blink (e.g., low as opposed to high spatial-frequency information, or the presence vs. absence of texture or motion).

Duncan and Humphreys (1989) suggest an account consistent with our data, which may serve as an alternative explanation to that proposed by Raymond et al. (1992). Duncan and Humphreys proposed that target selection in *spatial* visual search is more efficient to the extent that (a) target–nontarget similarity is decreased and (b) nontarget–nontarget similarity is increased. Their theory does not support a distinction either between serial and parallel search or between search for features and conjunctions (see, e.g., Treisman & Gormican, 1988), though their theory is able to account for experimental outcomes predicated on these distinctions.

To account for the results of the experiments presented in this article, Duncan and Humphreys's (1989) theory would have to be modified to include the importance of target–target similarity to the efficiency of search and to allow that *temporal* search operates in a fashion similar to that of spatial search.[9] The issue of target–target similarity was not required in their original formulation, since visual search experiments typically deal with only one target. However, the logic would dictate in the present context that one target can be selected more easily to the extent that it differs from a second target (e.g., probe), in much the same way as one target can be selected from a nontarget to the extent that they are dissimilar.

Such a mechanism is suggested to operate at the third of the three stages proposed by Duncan and Humphreys (1989), where information selected during Stage 2 now enters VSTM. According to Duncan and Humphreys's model, in Stage 1 a spatially scaled and structured perceptual representation of the entire visual field is constructed. In Stage 2 selection from among objects represented in Stage 1 is accomplished by matching input descriptions *from Stage 1 against an internal template of the informa-*tion required for current behavior (e.g., judging a target's

presence or absence). We are proposing the following scenario. First, a template is established for both the target and probe that provides each with a high weighting and likely entry in VSTM. Additionally, a lower but higher-than-baseline weighting is extended to the first posttarget (and postprobe) item, perhaps as a consequence of their temporal relationship to the respective targets that precede them. The reason for proposing a higher weighting to the first posttarget (and postprobe) item than for other nontarget items in the stream is derived from Raymond et al.'s (1992) demonstration that the first posttarget item is critical for the production of the blink and that a large proportion of target identification errors are first posttarget-item intrusions.[10]

A model based on competition in VSTM, such as that proposed by Duncan and Humphreys (1989), would suggest that the target and probe, and to a lesser extent the items immediately succeeding each of these, are competing for subsequent retrieval. According to our extension of Duncan and Humphreys's theory, this competition should be less severe when the target and probe are highly dissimilar and lead to better retrieval of each. This situation occurs in the case of the gap as target conditions of Experiments 5A and 5B and the lack of a blink in these conditions is taken as evidence in support of this view. Conversely, when the target and probe are similar as in the case of a letter as target task, the expectation is confirmed as a blink does occur. The result of the random dots as target experiment (Experiment 4), however, becomes somewhat problematic for this model. In this case, the target and probe are dissimilar on a featural basis and yet AB effects were found.

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[8] The small but significant reduction in blink magnitude when the set-size was reduced from 25 to 3 does indicate that target task difficulty and hence early-selection difficulty may play a role in production of the AB effect; this role is overshadowed by that played by late-selection mechanisms such as the one proposed subsequently in this article.

[9] Actually, Duncan and Humphreys (1989) do suggest that more elaborate templates would be required to differentiate multiple heterogeneous targets, as opposed to a single target, from nontargets.

[10] Further support for the view that items other than the target enter VSTM comes from a recent article by Botella and Eriksen (1992). These investigators found that they could manipulate the pattern of target errors (i.e., intrusions) in a single-target RSVP task by changing either the target task demands (i.e., featural vs. categorical) or altering the rate at which the stimuli were presented. The study by Botella and Eriksen was innovative in its use of a "menu" to allow subjects to indicate their choice of target, which then allowed these researchers to evaluate carefully the types of errors made as a function of the target task manipulations. The researchers found a changing pattern of intrusion errors, often including pretarget, as well as posttarget, items. The significant number of pretarget intrusions led them to favor a parallel processing account of target identification, as opposed to serial filter model (e.g., D. E. Broadbent, 1977; Gathercole & D. E. Broadbent, 1984). These investigators further argued that errors in target identification likely arise during the process of retrieval when there is a significant opportunity for confusion between items in VSTM.

Two possibilities within the framework of the similarity approach could account for these findings. First, the dot pattern (target) in this experiment shares enough critical features (e.g., spatial scale information) with the probe so that they appear effectively similar to the retrieval mechanism. A second possibility is that even though the target and probe may be dissimilar, similarity theory requires an evaluation of the relationship between the target(s) and nontarget items as well. In all experiments reported here, the first posttarget and the first postprobe items were highly similar to the probe (i.e., all were letters). Perhaps the similarity of the second target (probe) to the nontargets is more problematic for making a judgment regarding a probe's presence or absence when there is a featural target already present in VSTM (even when it only marginally resembles the probe), than when there is only one featural target (i.e., the probe alone), as occurs in the gap-target condition. Relieving competition in VSTM by eliminating and/or differentiating any of these items may be sufficient to allow for a high probability of probe detection. In the gap experiments, the target may not compete at the level of VSTM due to its temporal, rather than featural, character.

Two other aspects of our data are explained by such a theory. First, the finding that the probe is reported approximately 50% of the time with a low false-alarm rate is consistent with the probabilistic nature of its retrieval from VSTM according to the above model. In other words, the probe is selected for VSTM entry, but sometimes wins and sometimes loses in its competition with the target for retrieval. Second, our finding that the probe is readily available for retrieval when it occurs in posttarget Positions 5–8 is consistent with the notion of Duncan and Humphreys (1989) and others that VSTM may be flushed after sufficient time has passed with no demand made on it.

Before leaving these considerations, it seems important to contrast the theoretical account suggested by Raymond et al. (1992) to that suggested by Duncan and Humphreys (1989). Both serve to explain the inability of subjects to detect a probe occurring between approximately 100–450 ms after a patterned target has been identified. The former suggests that the AB results from confusion between the target and the *first posttarget* item resulting in a shutdown of processing (i.e., entry into VSTM). The latter account suggests the problem arises from the degree of similarity between items competing for retrieval from VSTM. The distinction between these two accounts resembles quite closely that between an "early-selection account" (e.g., Broadbent, 1957) and a "late-selection" model of attention (e.g., J. A. Deutsch & D. Deutsch, 1963; Norman, 1968).

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