Journal of Experimental Psychology:
Human Perception and Performance
1995, Vol. 21, No. 3, 653–662

0096-1523/95/$3.00

Similarity Determines the Attentional Blink

Jane E. Raymond, Kimron L. Shapiro, and Karen M. Arnell
University of Calgary

When participants are required to respond to a target letter imbedded in a stream of rapid serially presented letters, perception of a 2nd target letter is impaired if the interval between the 2 targets is less than about 450 ms. This attentionally based posttarget suppression in visual processing, referred to as the *attentional blink* (AB), is not found when there is a brief pause in the stream immediately after the 1st target. To investigate the importance of posttarget stimulation in AB production, the categorical, featural, and spatial similarity of the immediate posttarget item to other items in the stream was manipulated. Although featural and spatial dissimilarity produced significant attenuation of the AB effect, categorical dissimilarity did not. Significant AB effects were found in all conditions, suggesting that the presentation of any patterned stimulus in close temporal proximity to the target provokes the AB.

A number of previous studies have indicated that the allocation of visual attention is nonuniformly distributed over time. Support for an episodic characterization of attention has been found in experiments in which participants viewed stimuli presented in rapid serial visual presentation (RSVP) and were required to identify or detect two targets embedded in the stimulus series (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994; Weichselgartner & Sperling, 1987). In dual-task procedures, the first target is used to focus attention on a single item, and the second target, referred to here as the *probe,* is presented at a variable interval after the first target and is used to assess temporal changes in visual processing mechanisms. The general result of such experiments is that when target and probe are presented in close temporal proximity, the processing of the probe is impaired. When the target–probe interval is greater than about 450 ms, responding to the target has no deleterious effect on detection of the probe. This effect was first demonstrated with words (Broadbent & Broadbent, 1987) and more recently with letters (Raymond et al., 1992; Shapiro et al., 1994).

Using a dual-target RSVP task, we previously explored this temporary deficit in visual processing by asking participants to identify a single white letter (target) appearing in an RSVP stream of black letters and then to report whether a black *X* (probe) had been presented among items in the posttarget series (Raymond et al., 1992). We found that during an interval beginning 180 ms after the target and extending for about 270 ms, the probability of probe detection was reduced significantly compared with the probability of detecting probes presented later in the RSVP stream. The results of this study established two important points regarding the posttarget processing deficit.

First, the effect appears to have an attentional basis. When participants were told to ignore the first target and to detect only the probe, the probability of probe detection remained uniformly high (about 90%) for all serial positions of the probe, indicating that the posttarget processing deficit did not result from low-level sensory masking of the probe stimulus by a preceding or succeeding item. Because the reduction in probe detectability was observed only when an item (i.e., the target) in the series required attention, we labeled the posttarget reduction in probe detection the *attentional blink* (AB; Raymond et al., 1992).

Second, we determined that the AB did not reflect the time required to switch from one task to the other. This conclusion was drawn after conducting an experiment in which we replaced the +1 item (the plus sign indicates that the item was presented after, not before, the target, and the number indicates its serial position relative to the target) with a blank interval, leaving all other items as in the original experiment (Raymond et al., 1992). This manipulation produced a uniformly high probability of probe detection (i.e., no AB), even when the probe was presented 180 ms after the target, demonstrating that participants were able to switch from the target task to the probe task within a short interval. Replacing the +2 item with a blank interval and presenting a letter at all other serial positions, including the +1 position, restored the AB. This result indicates that the blank interval per se was not responsible for eliminating the AB and refutes the suggestion that the AB results from a response bottleneck or a psychological refractory period of some type.

One explanation for the AB effect, referred to here as the *inhibition model,* is that the rapid appearance of the +1 item immediately after the target produces the potential for perceptual confusion during target identification processes. This potential causes inhibition of subsequently presented

Jane E. Raymond, Kimron L. Shapiro, and Karen M. Arnell, Department of Psychology, University of Calgary, Alberta, Canada.

Correspondence concerning this article should be addressed to Jane E. Raymond, who is now at the School of Psychology, University of Wales, Bangor, Gwynedd LL57 2DG United Kingdom.

stimuli so that further potential confusion may be minimized (Raymond et al., 1992). The term *perceptual confusion* refers to the inadequate processing, inappropriate conjoining, or both of letter names and luminance values (black or white) of the target and +1 item. In this explanation, presentation of the target initiates an attentional episode (or opens an "attentional gate") allowing the processing of the target and, by virtue of its temporal proximity, the +1 item as well. The potential for perceptual confusion among the attributes of these two items provokes an active inhibition of subsequent visual processing and thus produces an AB. We use the word *potential* here because the AB is measured only on trials in which the target is correctly identified (i.e., on trials in which the +1 item has not interfered with the processing of the attended target, at least not to a degree that disrupts identification).

A second explanation for the AB effect is that it results from interference occurring after the selection of critical items from the RSVP series (Shapiro et al., 1994). In this model (described more fully in the *Discussion* section and referred to here as the *interference model*), a perceptual description of each item presented in RSVP is produced, but only some items compete successfully for access to a visual short-term memory (VSTM) buffer. In elaborating this model, Shapiro and Raymond (1994) suggested that at least four items—the target, the probe, and the items immediately following each of these stimuli, that is, the +1 item and the item just after the probe (p + 1 item)—typically compete for entry into VSTM. The AB occurs when there is interference in retrieval of the correct item out of the VSTM buffer.

At the heart of both inhibition and interference models is the idea that similarity among items in the series is necessary to produce the AB effect. The inhibition model suggests that similarity between the target and the +1 item is the critical factor, whereas the interference model predicts that similarity between the probe and any of the other three critical items is a necessary condition. In the current experiments, we investigated the role of stimulus similarity by manipulating the categorical, featural, and spatial similarity of the +1 item to the other critical items in the RSVP series. Our goal was to test the two models just described and to investigate the stimulus attributes that are particularly important in similarity relationships.

We used the dual-task RSVP procedure described in Experiment 2 of Raymond et al. (1992), including the same target (i.e., white letter), distractors (i.e., black letters), and probe stimulus (i.e., black *X*). In the first experiment, the +1 item was a number (categorical dissimilarity), in the second experiment the +1 item was a random-dot pattern (featural dissimilarity), and in the third experiment the +1 item was a letter, as in the original experiments, but it was displayed just to the right of the location at which all other items in the stream were presented (spatial dissimilarity). To anticipate the results, we found an AB effect in all conditions but observed that the magnitude of the effect was attenuated with featural and spatial, but not categorical, dissimilarity.

General Method

Apparatus

The stimuli were generated by an Apple Macintosh II computer using custom software and were displayed on an Apple 13-in. color monitor. Participants viewed the display 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. The experimenter was unaware of the correct responses for all trials.

Procedure

The stimuli and procedure were similar to those previously described in Experiment 2 of Raymond et al. (1992). Each volunteer participated in two sessions consisting of 140 RSVP trials each. Both sessions were conducted on the same day with an intervening rest break. The order in which conditions were tested was counterbalanced across participants. Each trial consisted of a series of successively presented simple, block-style alphanumeric characters (with one exception in Experiment 2). Each character was presented for 15 ms with an interstimulus interval (ISI) of 75 ms, producing a presentation rate of 11.11 characters per second. Each character was displayed singly at the same location (except in Experiment 3) in the center of a uniform gray field (9.1 cd/m^2), which subtended 16.3° × 12.5°. Characters were 0.82° in height and approximately the same width. All characters appeared black with the exception of the target item, which was white (32.9 cd/m^2). The uniform gray field was viewed during the ISI. The participant initiated a trial when ready by depressing the mouse button. Each trial began with a 180-ms presentation of a small, white fixation dot. The number of pretarget items was randomly chosen by the computer on each trial and varied between 7 and 15. Letters preceded only the target. The target was a white letter randomly chosen from the alphabet but was never an *X, I, O,* or *Q*. The stimulus presented immediately after the target (i.e., in the first posttarget serial position) was designated as the +1 item and was varied in each experiment. The probe stimulus in all experiments was a black *X*. In half of the trials, the probe was present at one of Serial Positions +2 through +8, and in the remaining trials a probe was not presented. A probe was never presented prior to the target and never appeared twice within a single stream. The probe was presented 10 times at each of the seven possible serial positions, yielding 70 probe-present trials per session.

The participant's task was to identify the target letter and to determine whether the probe was present or absent. Participants reported their responses aloud at the end of each RSVP stream. They received 10 practice trials in each condition prior to data collection. One-minute rest breaks were given every 60 trials within a session.

Experiment 1

The purpose of the first experiment was to determine whether categorical dissimilarity of the +1 item to other items in the stream would attenuate or eliminate the AB. To test this possibility, we created RSVP streams, as described in the General Method section, and always presented a randomly selected number in the +1 serial position.

Method

Design. In this study we used a two-variable design with condition (experimental vs. control) as a within-subjects variable and relative serial probe position (Positions 2–8) as a repeated measures variable.

Participants. Ten healthy university students and staff members (8 women and 2 men), aged 18–24 years, volunteered to participate in the experiment. In this and all subsequent experiments, informed consent was obtained from all participants.

Procedure. In both conditions, the +1 item was a black number between 2 and 9 that was randomly chosen by the computer. Number stimuli shared the same size and general features as letter stimuli. All other stimuli were letters as described in the General Method section. In the experimental condition (the number condition), the participant was required to name the white letter and to detect the presence or absence of the probe.

In the control condition, the participant was told to ignore the white letter and to simply judge whether an *X* was present or absent in the series. This single-task control condition was used to provide a baseline of probe detectability in an RSVP letter series in which a number had been imbedded. To control for the dual-task aspect of the experimental condition, we compared probe detection performance within the experimental condition for probes presented early in the posttarget serial positions with that for probes detected late in the posttarget series (i.e., well after the AB effects had dissipated).

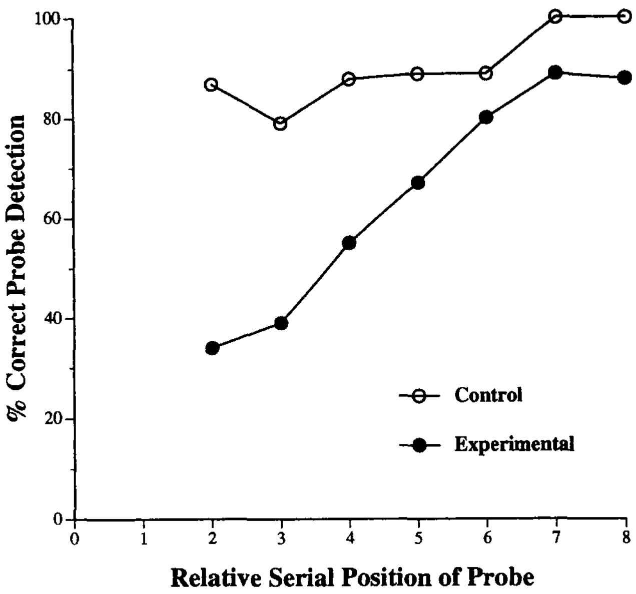

Figure 1. The group mean probability of correct probe detection when a probe was presented as a function of the relative serial position of the probe in Experiment 1. Open symbols represent data from the control condition (probe detection task only), and closed symbols represent data from the experimental condition (target identification and probe detection tasks). In both conditions the +1 item was a number, whereas all other items in the stimulus stream were letters.

Results

Probe detection. The group mean percentage of trials in which the probe was detected correctly when presented is plotted as a function of the relative serial position of the probe for the experimental and control conditions in Figure 1. (Note that using this measure, chance performance is not at 50% correct unless the false-alarm rate is also at 50%. Moreover, percentage correct probe detection can approach 0%. False-alarm rates and d' measures are reported in detail.) Means for the experimental condition were calculated using only those trials in which participants identified the target correctly.

A two-variable (Condition × Relative Serial Position of Probe) repeated measures analysis of variance (ANOVA) revealed a significant main effect of condition, $F(1, 54) = 56.95$, $p < .01$, a significant main effect of probe relative serial position, $F(6, 54) = 26.65$, $p < .01$, and a significant Condition × Relative Serial Position interaction, $F(6, 54) = 11.58$, $p < .01$. Multiple post hoc comparisons using Scheffé's method revealed that the group mean percentage probe detection for the experimental condition was significantly lower ($p < .05$) than the corresponding point for the control condition when probes were presented at Serial Positions +2, +3, +4, and +5, indicating a significant AB for the interval between 180 and 450 ms posttarget. For the control condition, participants correctly detected the probe on 79% or better of trials for all probe relative serial positions. However, for the experimental condition, percentage correct detection dropped to a minimum of 40% for probes appearing at the +2 serial position.

By comparing within the experimental condition the mean probability of probe detection for each serial positions just after target presentation (i.e., +2, +3, and +4) with the mean of the last three serial positions (i.e., +6, +7, and +8), evidence of an AB can be obtained. The last three serial positions were used to define a baseline of probe detection in a dual task. Previous experiments had indicated that the AB effect was fully attenuated for probes presented at these posttarget serial positions and thus could provide a reasonable estimate of baseline probe detection without contamination from the effects of having to perform the target task. It is, of course, a conservative measure of probe detectability because of the assumption that AB effects are fully attenuated by the +6 position. Testing for the presence of an AB by comparing probe detectability for the +2, +3, and +4 serial positions against this baseline also is a conservative test. Using Scheffé's method to make such comparisons, we found a significant decrement in performance for probes presented in close temporal proximity to the target in the experimental condition, but not in the control condition. This method of establishing the presence on an AB was used in subsequent experiments, thereby eliminating the need for the single-task control condition.

The group mean false-alarm rate for probe detection in the experimental condition was 15.1% (ranging from 1% to 36%); for the control condition it was 9.0% (ranging from 1% to 21%). A *t* test between these two conditions indicated that the difference in the false-alarm rates in the two conditions was nonsignificant. To evaluate probe detection performance using a criterion-free measure, we redid the analyses described earlier using d' measures of sensitivity to the probe and found results consistent with the analysis of the percentage correct measures. An ANOVA on these data revealed a significant main effect of condition, $F(1, 54) = 48.55$, $p < .01$, a significant main effect of probe relative serial position, $F(6, 54) = 25.11$, $p < .01$, and a significant Condition × Relative Serial Position interaction, $F(6, 54) = 2.59$, $p < .05$.

We quantified AB magnitude 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 detection of the probe at each serial position for each participant and then summing the values obtained for posttarget Serial Positions 2–8. Using this method, higher numbers reflected a larger AB magnitude. The mean AB magnitude for the number (experimental) condition was 248.0 (SE = 26.3) and was nonsignificantly different from that obtained from Experiment 2 of Raymond et al. (1992) using a similar calculation (M = 231.6, SE = 35.0). (Note that only values obtained for posttarget Serial Positions 2–8 were used to calculate this number.) In the current Experiment 3, a comparable dual-target condition in which all items including the +1 item were letters (nondisplaced condition) was tested. The mean AB magnitude measured here was 260.9 (SE = 28.4). The similarity of these latter two estimates of AB magnitude to that obtained in the number condition indicates that the categorical dissimilarity of the +1 item to other items in the stream had no effect on the magnitude of the AB effect.

Target identification. In the experimental condition, participants made a target identification error on 12.1% of the trials. This number is about half that found in Experiment 2 of Raymond et al. (1992) using a similar task but with black letters in the +1 relative serial position. In that experiment, it was reported that in trials in which the probe was presented at any serial position other than the +1 position (as was the case in all the current experiments), participants made target identification errors on 22% of trials. Half of these errors were +1 intrusions, whereas the remaining errors were nonsystematic. In the current experiment, participants were unable to make +1 intrusions because naming a number as the target would constitute an inappropriate response. Thus, the actual error rate found here was highly similar to the nonsystematic error rate found in the Experiment 2 of Raymond et al.

Discussion

Presenting participants with a dual-target RSVP task in which the +1 item was categorically dissimilar from other items in the stream produced a large AB effect on probe detection. The difference between the single-task control group and the dual-task experimental group provides evidence that the temporary deficit in processing found after target identification has an attentional basis, thus replicating Experiment 2 in Raymond et al. (1992).

The results of the current experiment fail to provide obvious support for either the inhibition model or the interference model. The inhibition model predicts that dissimilarity between the target and the +1 item should reduce the AB effect. Because this did not occur, one can conclude that either the model is inadequate or that the hypothesized perceptual confusion occurring during processing of the target and the +1 item occurs at an early stage of visual processing (i.e., prior to a number vs. letter categorization stage).

The interference model also predicts that dissimilarity between the probe and the +1 item should decrease the magnitude of the AB effect. As with the inhibition model, the current results can be taken to indicate either an inadequacy in the theory or that the interference effects are also occurring at a stage prior to letter versus number categorization.

Another possibility is that similarity of the +1 item to either target or probe has little to do with AB magnitude and that as long as a patterned visual stimulus is presented immediately after the target, an AB effect is produced. In Experiment 2, we explored this possibility by manipulating a featural characteristic of the +1 item.

Experiment 2

In this experiment, a black nonletter dot pattern similar in spatial scale to the letter stimuli was presented in the +1 relative serial position. If presentation of a patterned visual stimulus in the +1 serial position is all that is required to produce a posttarget deficit in probe detection, then presenting a letter or a nonletter stimulus in the +1 position should have the same effect on AB magnitude. However, if featural similarity of the +1 item to either target or probe is necessary to produce the AB, then this manipulation should attenuate or eliminate the effect.

We presented participants with an RSVP stream in which the +1 item was an array of four black dots randomly positioned within the area typically occupied by a letter. All other items in the stream were letters, including the target and probe. In this condition (the dots condition) the same dot pattern was used in all trials so that not only was the +1 item featurally distinct from the target, it was also predictable in its pattern and temporal (relative to the target) characteristics. To control for the effect of this type of predictability, we used a second experimental condition (the same-letter condition) in which the +1 item was the same black letter on all trials. In both conditions, the participant was required to identify the white target letter and to detect the presence or absence of the probe.

Method

Design. We used a two-variable design with condition (dots vs. same letter) as a within-subjects variable and relative serial probe position (Positions 2–8) as a repeated measures variable.

Participants. Ten university students and staff members (7 women and 3 men), aged 25–36 years, volunteered to participate in the experiment. None of these participants had previously participated in a dual-task RSVP experiment.

Procedure. In the dots condition, the +1 item was an array of four black dots randomly positioned within the area normally occupied by a letter (see Figure 4). Each dot was a 0.12° square that was one third larger than the width of a letter bar. The same number of pixels were blackened for the dot pattern as were blackened for most letter stimuli. In the same-letter condition, the +1 item was always a black *S* and, in both conditions, the target was never a white *S* nor was an *S* ever presented in the distractor stream. All other stimuli in both experiments were the same as described in the General Method section. Participants were required to name the white letter and to detect the presence or absence of the probe.

Results

Probe detection. The group mean percentage of trials in which the probe was detected correctly when presented is plotted as a function of the relative serial position of the probe for the two conditions in Figure 2. Means were calculated using only the trials in which participants identified the target correctly.

A two-variable (Condition × Relative Serial Position of Probe) repeated measures ANOVA revealed a significant main effect of condition, $F(1, 54) = 24.40$, $p < .01$, a significant main effect of probe relative serial position, $F(6, 54) = 21.19$, $p < .01$, and a significant Condition × Relative Serial Position interaction, $F(6, 54) = 2.29$, $p < .05$.

To determine whether a significant AB effect would be found in each condition, we used multiple post hoc tests

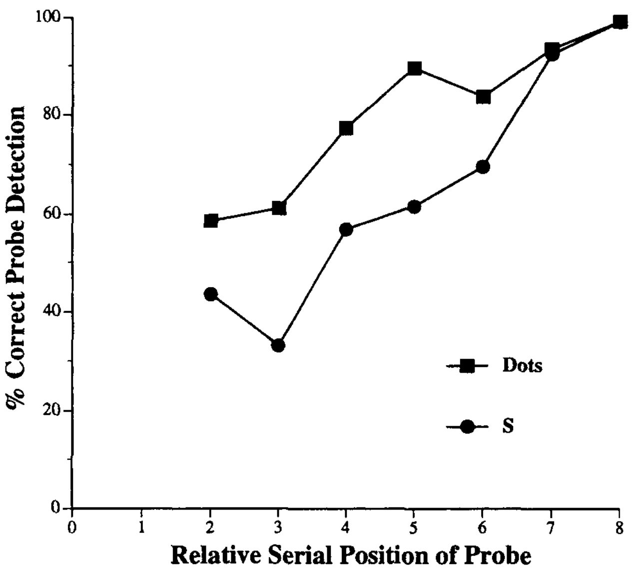

Figure 2. The group mean probability of correct probe detection when a probe was presented as a function of the relative serial position of the probe in Experiment 2. Squares represent data from the condition in which the +1 item was a random-dot pattern, and circles represent data from the condition in which the +1 item was always a black *S*. In both conditions, the participant was required to identify a white target letter and to detect the presence or absence of the probe stimulus.

using Scheffé's method to compare the mean of the probability of probe detection in the last three serial positions with the probability of probe detection for Serial Positions +2, +3, and +4 for each condition. For the dots condition, the group mean probability of detecting the probe at Serial Positions +2 and +3 was significantly ($p < .05$) less than that of the mean for the last three serial positions, indicating the presence of a significant AB effect. For the same-letter experimental condition, such differences were significant for the +2, +3, and +4 serial positions.

The group mean percentage probe detection for the dots condition was significantly higher ($p < .05$) than the corresponding point for the same-letter condition for items at the +3 and +5 positions. In the dots condition, the minimum percentage correct detection of the probe was 59%, whereas in the same-letter condition the minimum was 33%. Group mean blink magnitude was calculated as in Experiment 1. The mean AB magnitude for the dots experimental condition was 137.8 ($SE = 17.4$) and was significantly smaller in magnitude ($p < .01$) than that obtained in the same-letter condition ($M = 244.8$, $SE = 31.4$). These observations indicate that featural dissimilarity of the +1 item from other items in the stream attenuated the magnitude of the AB effect. The AB appeared to be not only deeper but also slower to recover in the same-letter condition than in the dots condition.

The group mean false-alarm rates for probe detection for the dots condition (14.8%, range = 3–31%) and the same-letter condition (11.3%, range = 7–21%) were not significantly different. However, to more carefully consider probe detection performance, we reanalyzed the data using d' measures. An ANOVA revealed a significantly greater d' for the dots versus the same-letter condition, $F(1, 9) = 4.73$, $p = .05$, a significant main effect of probe relative serial position, $F(6, 54) = 27.04$, $p < .01$, but, unlike the previous ANOVA, a nonsignificant interaction between relative serial position and condition.

Target identification. In the dots condition, participants made target identification errors on 5.8% of the trials, on average ($SD = 4.6\%$), whereas in the same-letter condition, the group mean was 22.9% ($SD = 14.5\%$). A correlated *t* test showed that this difference was significant, $t(9) = 4.94$, $p < .01$. For the same-letter condition, this number was consistent with the target letter identification performance found in Experiment 2 of Raymond et al. (1992), suggesting that predictability of the +1 item plays no part in facilitating the target identification task. In the dots condition, participants were unable to make +1 intrusions because the dot pattern could never be mistakenly named as the target. The error rate in this condition was lower than the target identification error rate found in the number condition in Experiment 1 ($p < .01$) and lower than that found in Experiment 2 of Raymond et al. when +1 intrusions were excluded.

Discussion

The observation that an AB was produced in both the same-letter and the dots conditions indicates that temporal and featural predictability of the +1 item does not itself alleviate the AB. The pattern of results obtained in the dots condition indicates that a significant AB effect can be found when the +1 item is featurally dissimilar from all other items in the stream.

An interesting result of this experiment is that the magnitude of the AB was significantly attenuated in the dots versus the same-letter condition. This attenuation was accompanied by a reduction in target error rate. Such a pattern of results might suggest that the target was ineffectively masked by the dot pattern, making the target easier to process. If difficulty of target processing explains the AB effect, then reducing target task difficulty should attenuate the blink, as we observed. However, there are three reasons why this account is inadequate. First, the target error rate observed in the dots condition was highly similar to that reported in Experiment 3 of Raymond et al. (1992), wherein the +1 item was a blank interval (target error rate = 4.0%). In this condition, no AB effect was observed, yet target task difficulty was apparently the same as in the current condition. Although this supports the idea that the dot pattern may not have masked the target, a comparison of the AB effect in the two conditions indicated that masking of the target could not explain the production of an AB effect in the dots condition. Second, the correlation between target error rate and AB magnitude among participants in the dots condition ($r^2 = .25$) or the *S* condition ($r^2 = .12$) was nonsignificant, suggesting that target task difficulty and AB magnitude are unrelated. Third, Shapiro et al. (1994) demonstrated that manipulation of the target item to produce a wide range in target error rates had no effect on AB magnitude when all other items in the RSVP series were kept constant. These observations suggest that the degree to which the target may be masked by the +1 item does not directly affect the magnitude of the AB.

An alternative explanation for the difference in the magnitude of the AB effects observed in the current conditions may lie in the featural dissimilarity of the +1 item in the dots condition to other items in the RSVP stream. A similarity-based explanation can be couched in terms of the inhibition or the interference models outlined earlier.

The inhibition model hypothesizes that errors in conjoining letter color with letter name triggers the inhibition resulting in the AB (Raymond et al., 1992). With the dot stimulus as the +1 item, letter–name conjunction errors would be impossible (at least at the report level), and the model predicts that AB effects should be eliminated. As can be seen in Figure 2, such a result was not obtained. Indeed, the low target error rates in this condition suggest that perceptual confusion between the target and the +1 item at any stage was minimal. The observation of a significant, albeit reduced, AB effect is thus inconsistent with a perceptual confusion-based account of the AB.

The interference model predicts that if any one item among the four critical items thought to be consistently selected from the RSVP series is dissimilar from the others, then the AB effect should be attenuated but not necessarily eliminated. Thus, this model predicts the attenuated AB effect in the dots condition observed here. However, to evaluate the interference model as an adequate explanation, we consider the results of a previous experiment.

Shapiro et al. (1994) conducted a dual-target RSVP experiment (similar to the current one) in which the target was a white dot pattern embedded in a series of black letters (see Figure 4). The probe was a black *X* and the +1 item was a black letter, thereby producing featural and contrast dissimilarity between the target and the +1 item, as was the case in the current dots condition. In the Shapiro et al. (1994) experiment, unlike the current one, this manipulation also produced a dissimilarity between the target and the probe. Shapiro et al. reported a significant AB effect. We compared the AB magnitude obtained in their study with that obtained in the current experiment, using the method described earlier and calculated using only the data obtained for posttarget Serial Positions +2 through +8. The AB magnitude for the dots-as-target experiment yielded a significantly ($p < .05$) higher AB magnitude (group mean = 224.6, $SE = 36.9$) than for the current experiment. Moreover, Shapiro et al. reported that the AB magnitude measured in their dots condition was nonsignificantly different from that obtained in another dual-task condition in which no such dissimilarity was present (i.e., all items in the RSVP series were letters). This is inconsistent with the significant attenuation of the AB effect found here between the dots condition and the same-letter condition. Perhaps an explanation for the lack of AB attenuation reported in the Shapiro et al. experiment lies in the temporal contiguity of the dissimilar item (dot pattern) and the probe. The temporal contiguity between +1 item and probe is greater than that between the target and probe. Less interference with the probe task may result when the +1 item is dissimilar from it (dots-as-+1 experiment) than when the target is dissimilar from it but the +1 item is highly similar (dots-as-target experiment). These results suggest that the relationship between the +1 item and the probe may be particularly critical in producing the AB effect. In the next experiment we examined whether spatial dissimilarity of the +1 item would affect the magnitude of the AB.

Experiment 3

We created RSVP series in which all items were featurally and categorically similar (i.e., all items were letters), but in this experiment the +1 item was distinguished by its spatial location. Keele, Cohen, Ivry, Liotti, and Yee (1988) investigated the role of spatial location on intrusion errors in single-target RSVP tasks. They presented items in RSVP alternating between two locations and found that +2 intrusions errors were more likely to occur than +1 intrusion errors. In other words, illusory conjunctions of target-defining and response features were more likely to occur for items that shared the same spatial location but have larger temporal separations than items that are spatially disparate but presented with greater temporal proximity. These results indicate that the attentional mechanism that determines how features are to be integrated relies on spatial (i.e., location) coordination cues rather than temporal coordination cues.

Such results are consistent with previous studies of the spatial relationships between asynchronously presented target and nontarget stimuli (Gathercole & Broadbent, 1987). Assuming location-based integration of stimulus features, presenting a +1 item that is spatially displaced from the other items in the RSVP series should reduce target error rates, reduce the potential for confusion between target and +1 item, and, according to the inhibition model, produce an attenuation of the AB effect. The interference model would predict an attenuation of the AB effect only if the unique location "tag" of the +1 item were retained at least until the presumably later stage, where interference effects occur.

Repetition blindness (RB) experiments have shown that when letters (Kanwisher, 1991) or words (Kanwisher & Potter, 1989) presented in RSVP are displayed at displaced spatial locations, no decrement in the magnitude of the RB effect is observed compared with that measured with successive stimuli displayed at the same location. Because RB and AB may reflect different mechanisms (Ward, Duncan, & Shapiro, 1992), these data do not necessarily predict that spatial displacement of the +1 position should have no effect on the magnitude of AB effects.

We presented participants with an RSVP stream in which the +1 item was a black letter displaced by one letter width (0.82°) to the right of the spatial location occupied by all other items in the stream (the displaced condition). With a displacement of this size, the letter was well within the limits of visual resolution for this degree of eccentricity (Jacobs, 1979). Moreover, because LaBerge (1983) demonstrated that in letter categorization tasks the spatial extent of attention includes about one letter width on either side of the target letter, it is most likely that the displaced +1 item used in the current study fell within the spatial extent of attention directed at the remaining items in the RSVP stream. Volunteers also participated in another experimental condition in which the +1 item was a black letter presented at the same location as all other items in the stream (the nondisplaced condition). This is a replication of the Raymond et al. (1992) Experiment 2, except that in the current experiment probes were never presented in the +1 position.

Method

Design. We used a two-variable design with condition (displaced vs. nondisplaced) as a within-subjects variable and relative serial probe position (Positions 2–8) as a repeated measures variable.

Participants. Ten university students and staff members (7 women and 3 men), aged 18–24 years, volunteered to participate in the experiment. None of these volunteers had participated previously in a dual-target RSVP experiment.

Procedure. In both the displaced and nondisplaced conditions, the letter presented in the +1 serial position was always a black *S*. Neither the target nor any other distractor stimulus was ever an *S*. In both conditions, all items (except the +1 item) were presented 0.41° to the left of the fixation spot (presented at the beginning of each series). In the displaced condition, the +1 item was presented 0.41° to the right of the fixation spot (i.e., in a location that was immediately adjacent but not overlapping with the area occupied by all other letters in the stream). In the nondisplaced condition, the +1 item was presented in the same spatial location as all other items. All other stimuli in both experiments were as described in the General Method section. In both conditions, the participant was required to name the white letter and to detect the presence or absence of the probe.

Results

Probe detection. The group mean percentage of trials in which the probe was correctly detected when presented is plotted as a function of the relative serial position of the probe for the two conditions in Figure 3. Means were calculated using only the trials in which participants identified the target correctly. A two-variable (Condition × Relative Serial Position of Probe) repeated measures ANOVA revealed a significant main effect of condition, $F(1, 9) = 47.86, p < .001$, a significant main effect of probe relative serial position, $F(6, 54) = 29.64$, $p < .001$, and a significant Condition × Relative Serial Position interaction, $F(6, 54) = 6.11, p < .001$. For the nondisplaced condition, the percentage correct detection of the probe dropped to a minimum of 33% when it was presented in the +2 serial position, indicating the presence of a large AB effect. However, for the displaced condition the effect was smaller and short-lived, with the probability of probe detection reaching a minimum of 61%.

To determine whether there was an AB in the two conditions, the mean probe detection found in the +2, +3, and +4 positions in each condition was compared with a baseline measure of probe detection performance. As in Exper-

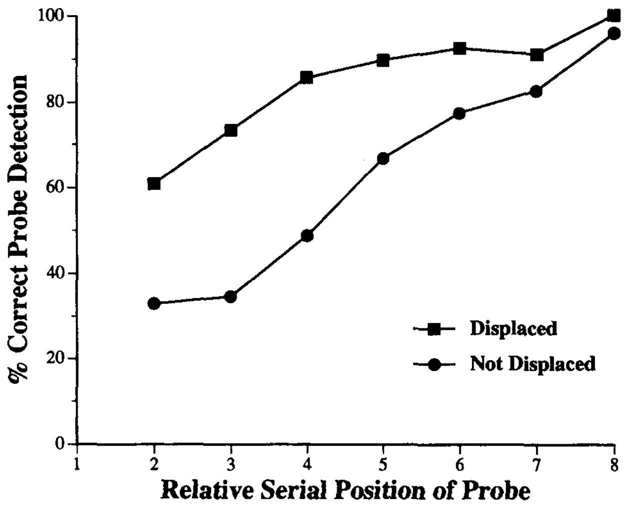

Figure 3. The group mean probability of correct probe detection when a probe was presented as a function of the relative serial position of the probe in Experiment 3. Squares represent data from the condition in which the +1 item was displaced just to the right of the spatial location occupied by all other letters in the stream. Circles represent data from the condition in which the +1 item was presented in the conventional location. In both conditions, the participant was required to identify a white target letter and to detect the presence or absence of the probe.

iment 2, this was obtained by calculating the mean probability of probe detection for relative Serial Positions +6, +7, and +8. Multiple post hoc comparisons using Scheffé's method revealed that the probability of probe detection was significantly depressed ($p < .05$) for the +2, +3, and +4 serial positions for the nondisplaced condition and that it was significantly depressed for the +2 and +3 serial positions only for the displaced condition.

Group mean blink magnitude was calculated as in Experiment 1. The mean AB magnitude for the displaced condition was 106.7 (SE = 18.1) and was significantly less ($p <$ .01) than that obtained in the nondisplaced condition (M = 260.9, SE = 28.4). These observations indicate that positional dissimilarity of the +1 item from other items in the stream attenuated the magnitude of the AB effect.

The group mean false-alarm rate for the displaced condition was 9.6% (range = 1–24%) and for the nondisplaced condition was 9.9% (range = 1–21%). A correlated t test between these two conditions indicated that the difference in the false-alarm rates in the two conditions was nonsignificant. As in the previous two experiments, we again performed the analyses using d' measures of sensitivity to the probe. An ANOVA on these data revealed a significant main effect of condition, $F(1, 54) = 11.42$, $p < .01$, a significant main effect of probe relative serial position, $F(6, 54) = 31.42$, $p < .01$, and a nonsignificant Condition × Relative Serial Position interaction. This lack of interaction effect resulted from a small but consistent difference in d' at Serial Positions +6, +7, and +8.

Target identification. In the displaced condition, the group mean percentage of target identification errors was only 3.5% (SD = 1.6%), whereas in the nondisplaced condition, the group mean was 16.3% (SD = 11.1%). A correlated one-tailed t test revealed that this difference was significant, $t(5) = 2.47$, $p < .01$. For the nondisplaced condition, the target identification error rate was consistent with the target letter identification performance found in Experiment 2 of Raymond et al. (1992).

Discussion

The results of this experiment demonstrate that when the +1 item was presented to an adjacent but nonoverlapping region of the visual field, a significant but attenuated AB effect was observed. Because Kanwisher (1991) failed to find any attenuation in RB effects with displaced stimuli, our finding supports the claim of Ward et al. (1992) that different mechanisms generate AB and RB effects.

There are two possible explanations for the decrease in AB magnitude. First, it is possible that the displaced +1 item was ineffective at masking the target and that this resulted in an attenuated AB. As discussed in the previous experiment, such an explanation is likely to be inadequate. As in Experiment 1, the correlation between target error rate and AB magnitude was nonsignificant in both the displaced (r^2 = .003) and the nondisplaced (r^2 = .003) conditions, which supports the idea that target task difficulty and AB magnitude are not directly related. However, the low number of target identification errors in the displaced conditions is interesting in that, unlike in the dots or number conditions, participants could have named the +1 item as the target because it was in fact a letter. That they did not is consistent with the results of Keele et al. (1988) and indicates that the spatial location of the +1 item was sufficient to differentiate it from the target so that neither masking, metacontrast, or any other type of perceptual confusion between the target and +1 item occurred. Attentional (LaBerge, 1983) and psychophysical (Jacobs, 1979) data indicate that the eccentricity at which the +1 item was presented in the displaced condition was insufficient to significantly degrade its being visually processed.

A second, more plausible possibility is that the location information regarding the +1 item was sufficient to distinguish it from the probe on most trials, thus reducing interference. The low target error rate in the displaced condition suggests that the location "tag" was reasonably effective at disambiguating the +1 item from the target. That the AB effect was attenuated suggests that the location tag also was useful in disambiguating the +1 item from the probe.

General Discussion

In all experimental conditions reported earlier, participants viewed an RSVP stream of stimuli and were asked to identify a white letter (target) embedded in a stream of black letters and to report whether a black X (probe) had been presented. Throughout all of the experimental manipulations, the required responses and the target, probe, and distractor stimuli remained the same. The stimulus feature that distinguished each experiment was the item immediately succeeding the target (i.e., the +1 item). In Experiment 1, this item was a number; in Experiment 2, it was either the same pattern of black dots or the same black letter on every trial; and in Experiment 3, it was a randomly chosen black letter that was displaced spatially to the right by a letter width. In all cases, a significant AB was found (i.e., detectability of the probe was significantly reduced when the probe was presented in close temporal proximity to the target relative to when the target–probe interval was greater than 540 ms). Thus, despite categorical, featural, or spatial dissimilarity between the +1 item and other items in the RSVP stream, AB effects were still observed. Figure 4 shows the conditions and results of the current experiments as well as relevant experiments from previous articles.

Note that the magnitude of the AB effect varied across conditions. An ANOVA on the blink magnitudes measured in all of the experimental conditions revealed a significant main effect of condition, $F(4, 45) = 9.05$, $p < .001$. The blink magnitude in the dots and displaced conditions was significantly smaller than the same-letter, number, and nondisplaced conditions ($p < .01$). In summary, blink magnitude was greatest in conditions in which the +1 item was an alphanumeric symbol displayed at the same location as the other items in the series.

The significance of our results is that the magnitude of the AB effect was modulated successfully by manipulating

Experiment	Target	+1 item	+n item	Probe	Mean AB Magnitude
Raymond et al. (1992) Exp. 3	T		A	X	NA
Raymond et al. (1992) Exp. 2 Exp 3	T	A	A	X	231.6 (35.0) 260.9 (28.4)
Exp 1	T	2	A	X	248.0 (26.3)
Exp 1	"IGNORE"	2	A	X	68.0 (12.6)
Exp 2	T	S	A	X	244.8 (31.4)
Exp 2	T	⁘	A	X	137.8 (17.4)
Shapiro et al. (1994) Exp. 4	□□ □□	A	A	X	224.6 (36.91)
Exp 3	T	A	A	X	106.7 (18.1)

Figure 4. An illustration of the conditions and results of our and other relevant rapid serial visual presentation experiments (Exp). The *A* and 2 denote that a letter or number, respectively, was presented at the serial position indicated and that the item was chosen randomly from trial to trial from the set of distractor letters or numbers. The white *T* denotes that the letter presented as the target was chosen randomly from trial to trial from the set of target letters. The *S, X,* and dot patterns indicate that these stimuli were always presented at the serial position indicated. The numbers in parentheses indicate the standard error of the mean. AB = attentional blink; NA = not applicable.

stimulus attributes of the +1 item. In an effort to understand the mechanisms underlying the AB effect, we discuss the results of our experiments in terms of the two models previously proposed.

The Inhibition Model

Raymond et al. (1992) proposed that the AB is produced by potential perceptual confusion between the target and the +1 item that occurs during the target identification processes. This model hypothesizes specifically that the potential to conjoin erroneously a letter–color with a letter name triggers an inhibition mechanism that results in the AB. Such an explanation predicts that if the +1 item has no letter name, making it impossible to make name–color conjunction errors, no AB effects should be observed. However, in both the number and the dots conditions, name–color conjunction errors were impossible, yet significant AB effects were found. Thus, these data do not support the notion of inhibition provoked by potential, relevant conjunction errors.

To explain these results, the model would have to be modified to posit that the potential for any confusion between target and +1 item evokes the inhibition response. However, even this modification may be inadequate, as evidenced by the relationship between target error rates and AB magnitude. Three conditions of the +1 item have been reported that produce uniformly low error rates: the blank +1 item (Raymond et al., 1992, Experiment 3), the dots condition, and the displaced condition. In the latter two conditions, significant AB effects were found, whereas in the "blank" condition no AB effect was reported. Moreover, there were a number of conditions in which the AB magnitude was uniformly high (the number condition, the same-letter condition, and the nondisplaced condition), yet the target error rates varied (from 12.1% to 22.9%). A similar result was reported by Shapiro et al. (1994). An additional point suggesting that interactions between the target and the +1 item do not directly determine the AB effect is that within the experiments reported here, correlations between target error rates and AB magnitude were nonsignificant.

Another way of viewing the relation between error rate and AB magnitude within the framework of the inhibition model is to speculate that low target error rates reflect the activation of a rapid and efficient inhibition mechanism that has suppressed processing of the +1 item. In this scenario, the AB magnitude would be either negatively correlated with target error rate or uniformly high, regardless of target error rate. However, neither result was obtained. An additional problem for this view is that, according to the inhibition model, inhibition is triggered by the presentation of the +1 item, not by the target itself. Thus, it is difficult to envision a mechanism capable of inhibiting a stimulus that itself caused the suppression. In summary, then, our experiments provide only marginal support for the inhibition model as it was originally expressed by Raymond et al. (1992).

The Interference Model

Shapiro et al. (1994) proposed that an interference model may better explain the AB effects than the inhibition model described earlier. Suppose that during the observation of an RSVP series, representations of several items are allowed to enter VSTM, from which two must be selected for report for the target and probe tasks. In an interference model of the AB, deficits in probe detection are thought to occur because an inappropriate item is selected out of VSTM for response to the probe task. In this model, which is based on an adaptation of similarity theory (Duncan & Humphreys, 1989), perceptual descriptions of each item are constructed and then matched against an internal template for target and probe. Depending on the goodness of the match, representations are assigned a weighting in VSTM in a manner similar to that proposed by Bundesen (1990). The total assignable weighting is limited, and weightings may degrade with the passage of time. The likelihood that a representation will be selected out of VSTM and passed on to a report stage may depend on its weighting assignment, the number of other items in VSTM, the similarity of items in VSTM, or a combination of these factors.

Shapiro et al. (1994) proposed that with such a mechanism in place, a dual-target RSVP stream of letters will compete for entry into VSTM in the following manner. First, the target item will gain heavily weighted entry into VSTM because of a close match to its template. By virtue of its close temporal proximity to the target, the +1 item will next gain access to VSTM, taking up a valuable resource. Following this, the probe is presented, and it will gain access into VSTM because of close congruence with the probe template. Although substantial, the probe's weighting may be limited by the remaining resource in VSTM. The item immediately succeeding the probe may also be included in the VSTM array. If the interval between target and probe is long (more than 500 ms), a greater weighting may be assigned to the probe because either the target's and +1 item's initial weighting values have been degraded with time, or these representations have been advanced to a report stage or otherwise eliminated from VSTM. If the interval is short, the target and +1 item persist in VSTM, and little resource is left over for the probe. When probe weighting assignment is insufficient, errors in selection will be made and AB effects will be observed.

The observation that manipulations of the +1 item affect the magnitude of the AB effect suggests that the +1 item does not gain entry in VSTM solely on the basis of its temporal proximity to the target. Rather, these data support the claim that the perceptual description of the +1 item also undergoes a template matching process to determine its likelihood of entering VSTM, its assigned weighting once in VSTM, and therefore its capacity to interfere with selection of items out of VSTM. Perhaps the +1 item is matched against a template of the probe rather than the target, because featural dissimilarity of the +1 item to the target is insufficient to attenuate the AB (Shapiro et al., 1994, Experiment 4), but featural dissimilarity of the +1 item and probe (the dots experiment) did reduce the AB. The observation that categorical dissimilarity did not attenuate the AB suggests that the matching mechanisms may be insensitive to such differences. Attenuation of the AB with featural and spatial dissimilarity suggests that the template matching process is able to use featural and spatial information available in the perceptual description of the +1 item.

In summary, our results indicate that the featural and spatial attributes of the +1 item play a significant role in determining the magnitude of the AB. Such results can be explained most parsimoniously by an interference model. An essential aspect of this model is that similarity between the +1 item and the probe stimulus acts to increase interference, resulting in the AB.

References

Broadbent, D. E., & Broadbent, M. H. P. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics, 42,* 105–113.

Bundesen, C. (1990). A theory of visual attention. *Psychological Review, 97,* 523–547.

Duncan, J. N., & Humphreys, G. (1989). Visual search and stimulus similarity. *Psychological Review, 96,* 422–458.

Gathercole, S., & Broadbent, D. E. (1987). Spatial factors in visual attention: Some compensatory effects of location and time of arrival of non-targets. *Perception, 16,* 433–443.

Jacobs, R. J. (1979). Visual resolution and contour interaction in the fovea and periphery. *Vision Research, 19,* 1187–1195.

Kanwisher, N. (1991). Repetition blindness and illusory conjunctions: Errors in binding visual types with visual tokens. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 404–421.

Kanwisher, N., & Potter, M. (1989). Repetition blindness: The effects of stimulus modality and spatial displacement. *Memory & Cognition, 17,* 117–124.

Keele, S. W., Cohen, A., Ivry, R., Liotti, M., & Yee, P. (1988). Tests of a temporal theory of attentional binding. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 444–452.

LaBerge, D. (1983). Spatial extent of attention to letter and words. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 371–379.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860.

Shapiro, K. L., & Raymond, J. E. (1994). Temporal allocation of visual attention: Inhibition or interference? In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory mechanisms in attention, memory and language* (pp. 151–187). San Diego, CA: Academic Press.

Shapiro, K. L., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in RSVP. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 357–371.

Ward, W., Duncan, J., & Shapiro, K. L. (1992, November). *The attentional blink does not require selection from among a nontarget stream.* Paper presented at the meeting of the Psychonomic Society, St. Louis, MO.

Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science, 238,* 778–780.

Received March 18, 1993
Revision received April 25, 1994
Accepted July 18, 1994 ■