Temporary Suppression of Visual Processing in an RSVP Task: An Attentional Blink?

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Through rapid serial visual presentation (RSVP), we asked Ss to identify a partially specified letter (target) and then to detect the presence or absence of a fully specified letter (probe). Whereas targets are accurately identified, probes are poorly detected when they are presented during a 270-ms interval beginning 180 ms after the target. Probes presented immediately after the target or later in the RSVP stream are accurately detected. This temporary reduction in probe detection was not found in conditions in which a brief blank interval followed the target or Ss were not required to identify the target. The data suggest that the presentation of stimuli after the target but before target-identification processes are complete produces interference at a letter-recognition stage. This interference may cause the temporary suppression of visual attention mechanisms observed in the present study.

During the course of many visual activities such as reading or scanning a visual scene, the eyes alternately fixate an area of the visual field and make a saccade to a different location. Because visual processing is suppressed during the rapid saccadic eye movement (for a review, see Volkman, 1986), this oculomotor behavior presents a rapid succession of brief, complex images to the perceptual processing system. The limits governing the brain's ability to process such a stream of stimuli can be studied in the laboratory with rapid serial visual presentation (RSVP). In this paradigm, stimuli such as letters, digits, words, or pictures are presented briefly in the same location and in rapid succession, usually in the same location (from 6 to about 20 items/s). Typically one item in the stimulus stream, the target, is differentiated in some way (e.g., presented in a different color), and the subject's task is to identify it. It is commonly known that processing a single briefly exposed target is substantially easier than processing the same stimulus embedded in a stream of complex stimuli (Lawrence, 1971). In this sense, RSVP tasks may be viewed as visual search tasks operating in the temporal rather than the spatial domain. Just as visual search studies have been useful in investigating how visual attention may be distributed spatially (e.g., Triesman & Gelade, 1980), the RSVP proce-

dure may be used to examine the temporal characteristics of perceptual and attentional processes.

Single-task RSVP experiments (in which only one target is identified) have provided data with regard to the temporal characteristics of the processes involved in the identification of a single target item (e.g., Lawrence, 1971) and thus have been useful in developing theories of the attentional and perceptual mechanisms that mediate such a task (e.g., Mc-Lean, D. E. Broadbent, & M. H. P. Broadbent, 1982). We review these studies and theories in the following. In addition to single-task experiments, there are a number of studies that have used a multiple-task RSVP procedure (in which two or more targets are identified). The latter studies have demonstrated that the cost of identifying the first target in a multiple-task RSVP experiment is a temporary but relatively long-lasting deficit in the identification of stimuli presented after the first target (D. E. Broadbent & M. H. P. Broadbent, 1987; Kanwisher, 1987; Kanwisher & Potter, 1989, 1990; Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987). The purpose of the present article is to explore further the nature of this posttarget processing deficit by determining (a) if perceptual or attentional factors underlie the reported deficits, (b) whether such deficits are observed in a simple detection task as opposed to the more complex identification tasks previously studied, and (c) what role other items in the RSVP stream (especially those in close temporal proximity to the target) play in producing the posttarget deficit.

RSVP procedures can be categorized on the basis of the information available to the subject for identification of the target(s). In studies that use target-identification tasks (as opposed to detection tasks), targets are partially (as opposed to fully) specified and are described by both a target-defining characteristic and a to-be-reported characteristic. For example, after the presentation of an RSVP stream of letters, each with a different color, a subject might be required to supply the letter name of the only red letter in the stream. The target-defining characteristic in this example is featural, the color *red*. The to-be-reported feature is the letter name.

Single-task RSVP studies have shown that even with very rapid stimulus presentation rates, subjects are able to identify

the target on a significant proportion of trials (Gathercole & D. E. Broadbent, 1984; Lawrence, 1971; McLean et al., 1982). When target-identification errors are made, however, they tend to be systematic. Analysis of such errors has been useful in modeling the processes involved in target identification. Depending on the stimuli, presentation rate, and target-defining characteristics, target-identification errors tend to be of two types: pretarget intrusions, that is, naming the to-be-reported feature from an item immediately preceding the target by n items (designated as $-n$ errors), or posttarget intrusions, that is, naming the to-be-reported feature from an item succeeding the target by n items ($+n$ errors).

When the target-defining characteristic is featural (e.g., "name the red letter"), subjects typically produce posttarget intrusion errors only (Lawrence, 1971; McLean et al., 1982). The prevalence of $+n$ errors suggests that processing of features in the target to an output stage extends beyond the time during which the target is physically present by n times the stimulus onset asynchrony (SOA). The occurrence of posttarget intrusion errors has been interpreted to indicate that target identification in filtering tasks involves two stages: an initial (early selection) stage in which the target-defining feature is detected and a subsequent stage in which the to-be-reported feature is identified from items in the available sensory store (D. E. Broadbent & M. H. P. Broadbent, 1986, 1987; Gathercole & D. E. Broadbent, 1984; Lawrence, 1971; McLean et al., 1982). If the to-be-reported feature is identified when posttarget letters are present in the store, a posttarget intrusion error may occur. To the extent that posttarget intrusion errors can be used to indicate target processing time, RSVP studies consistently suggest that target identification is complete on most trials in approximately 100 ms for both word and letter stimuli (Gathercole & D. E. Broadbent, 1984; Lawrence, 1971; McLean et al., 1982).

An alternative explanation for posttarget intrusion errors is a late-selection two-stage model in which codes associated with target-defining and to-be-reported features in each item develop concurrently but at different rates (Keele & Neill, 1978). Posttarget intrusions would occur when the target's code for the target-defining feature and a posttarget item's code for the to-be-reported feature arrive simultaneously for attentional coordination and are integrated into one percept. McLean et al. (1982) tested this possibility by using RSVP tasks with different target-defining features. First, color was used as the target-defining feature, and target name was used as the to-be-reported feature. In the second experiment, which used the same presentation rate, the roles were reversed. A predominance of posttarget intrusions was found for both conditions, which indicates that differential speed of code development alone cannot explain intrusion errors in feature-selection RSVP tasks.

This conclusion, however, cannot be applied equally to categorical selection tasks. McLean et al. (1982) reported that RSVP tasks that use categorically defined targets produce a pattern of adjacency intrusions; that is, both 1 and -1 intrusions were equally likely. Subjects were asked to name the color (to-be-reported feature) of a numeral (target-defining category) in a stream of colored letters and found adjacency errors. McLean et al. (1982) suggested that categorically de-

fined targets may not provide enough specificity to define the target for successful operation of the detect-then-identify model. They proposed that in such a situation, a late-selection mechanism may be used in which the codes for both target-defining and to-be-reported characteristics develop in parallel with active codes being integrated at a later stage.

Intraub (1985) found adjacency errors by using a single-task picture RSVP paradigm. The pattern of errors was found to be related to the speed of target detection. Rapidly detected targets were associated with pretarget intrusion errors, and slower target detection was associated with posttarget intrusion errors.

The results of single-task RSVP tasks clearly indicate that (a) target identification requires the conjoining of the target-defining characteristic with the to-be-reported feature, (b) feature conjunction in this task takes approximately 100 ms, and (c) the processing of such information requires attention. One might assume that once a target is identified, the perceptual and attentional mechanisms would be free to begin analyzing subsequent stimuli. Multiple-task RSVP research, however, strongly suggests that this is not the case. Rather, it appears that after target identification is presumably complete, large deficits in the processing of subsequent stimuli are found for up to 700 ms later.

Through the use of a multiple-task RSVP procedure, D. E. Broadbent and M. H. P. Broadbent (1987) asked subjects to identify two different target words (defined by uppercase letters or flanking hyphens) that were embedded at different serial positions within a stream of lowercase words. The number of items between the target words was varied. They found that when the two targets were temporally adjacent (with an SOA of 80 ms), subjects could produce a correct response to either the first or the second target but not both. As SOA was increased and other items were presented between the two targets, the probability of correctly identifying the second word when the first word was correct remained at a minimum of .1 for SOAs up to 400 ms, rising again to an asymptote of .7 with SOAs of 720 ms. Not only were subjects unable to correctly identify the second target during the 400-ms interval after the first target, they frequently reported being unaware that it had been embedded in the stimulus stream.

A similar observation that uses a multiple-task RSVP procedure, called *repetition blindness* (RB), has been reported. Subjects viewed a stream of words that form a sentence or a stream of letters that form a word. On half the trials, one of the items in the stream was presented twice. Subjects were asked to report the sentence or word. It was found that when an item had been repeated, the subjects tended to omit the second repetition of the item in their response (Kanwisher & Potter, 1989, 1990). In other studies, a stream of unrelated words was presented and subjects were required to indicate the word they thought had occurred twice in the list (Kanwisher, 1987). Kanwisher reported that for word-presentation rates between 5.4 and 8.5 words/s, subjects showed a low probability of reporting word repetitions if 1-4 intervening words were presented between the first and second presentation of the repeated item (i.e., with SOAs of 185-741 ms). The RB effect was also found when the repeated item differed in case from the first instance (Kanwisher, 1987), when omis-

sion of the second occurrence of the repetition greatly reduced the grammaticality of the sentence to be reported (Kanwisher, 1987), and when the repeated word shared orthographic identity but had a different meaning or pronunciation than that of the first instance (Kanwisher & Potter, 1990). The effect was not found when items were presented auditorily at the same rate in compressed speech (Kanwisher & Potter, 1989) or for visually presented synonym pairs (Kanwisher & Potter, 1990). RB was found at the level of letter groups when words were the perceptual unit in a given task and at the level of letters when letters were presented one at a time in RSVP to spell words (Kanwisher & Potter, 1990).

Through another variant on the multiple-task RSVP procedure, Reeves and Sperling (1986) and Weichselgartner and Sperling (1987) observed large deficits in the processing of posttarget items. In Weichselgartner and Sperling's experiments, highly practiced subjects were presented with an RSVP stream of digits and asked to identify a highlighted or boxed digit (target) and to name the first three posttarget digits. They found that subjects' reports generally consisted of the target, the first posttarget item, and items presented about 300 and 400 ms after the target. The item presented in the interval between 100 and 300 ms posttarget was rarely reported. With this complex response requirement, it is not clear whether subjects were unable to process the item perceptually during this interval or whether they were unable to store or retrieve its memory for later recall. In either event, a deficit in the ability to process posttarget items to an output stage was reported.

The three types of multiple-task RSVP studies outlined all indicate that the allocation of visual attention to an item in an RSVP stream produces a temporary but relatively long-lasting suppression of visual processing. These data suggest that the mechanisms involved in target identification are temporally shut down after use. It is as if the perceptual and attentional mechanisms blink. Eyeblinks produce a dramatic brief reduction in pattern vision and are only initiated after important stimuli are viewed. The results of multiple-task RSVP studies suggest that sensory and attentional mechanisms may undergo a covert analog to this overt ocular process.

Is this suppression due to attentional or sensory factors? Although the data from the RB studies suggest an attentional basis, the tasks in the RB studies are substantially different from those in the other two multiple-task RSVP studies described here. In the studies that involve identification of a visually distinct target, the posttarget processing deficit could result from sensory processes, such as visual masking of the probe by adjacent stimuli regardless of the subject's attentional state, rather than from attentional factors related to target identification. In the present study, we explore the basis for the posttarget processing deficit, either attentional or sensory. To anticipate, the present data indicate that the posttarget processing deficit does result from attentional factors.

The first experiment reported here attempts to replicate one of the experiments reported by Weichselgartner and Sperling (1987). This study was conducted to determine if our stimuli and temporal parameters are able to produce a posttarget processing deficit. In the second experiment we used a

simplified multiple-task RSVP procedure somewhat similar to that of D. E. Broadbent and M. H. P. Broadbent (1987) so that visual processing following target identification could be probed systematically. In one condition, subjects were asked to identify a target letter in a letter stream; in a control condition with identical stimuli, subjects were told to ignore the target color and that identification was not required. In both conditions, subjects were also asked to detect the presence or absence of a fully specified letter presented at various intervals after the target. This experiment was performed to determine whether passive sensory versus active attentional processing of the target produced the posttarget processing deficit and whether this effect could be obtained with a simple posttarget detection task as opposed to the more complex identification tasks used by D. E. Broadbent and M. H. P. Broadbent (1987), Weichselgartner and Sperling (1987), and in the RB studies. In the third and fourth experiments, we used a procedure similar to that of the second experiment to investigate the role of immediate posttarget stimulation on the production of the posttarget processing deficit.

Experiment 1

The purpose of the present experiment was to replicate one of the experiments reported by Weichselgartner and Sperling (1987) with different stimuli (letters rather than digits) and slightly faster presentation rates (11 items/s rather than 10 items/s) to determine whether such stimuli could indeed produce a posttarget processing deficit. The subject's tasks were to identify a white target letter embedded in a stream of black letters and to identify the three letters presented immediately after the target letter.

Method

Subjects. Five University of Calgary (Alberta, Canada) students and staff members (3 women, 2 men) ranging from 22 to 39 years of age volunteered to participate in the experiment. All subjects had from 90 to 180 trials of practice prior to participation. All subjects had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to participation for subjects in all of the experiments reported in this article.

Apparatus. The stimuli for this and all subsequent experiments were generated by an Apple Macintosh II computer with custom software and displayed on an Apple 13-in. (32.5-cm) 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 chinrest. Responses were reported verbally and were recorded by an experimenter with the aid of a second computer. The experimenter was unaware of the correct responses for all trials in this and all experiments.

Procedure. Each subject participated in one experimental session that consisted of 90 RSVP trials. In this and all experiments, each trial consisted of a series of successively presented simple, block-style upper case letters, as shown in Figure 1. The computer randomly chose the letters to be presented from the 26 letters in the alphabet with the condition that no letter be presented twice within a trial. 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/m^2) that subtended 16.3° × 12.5°. Letters
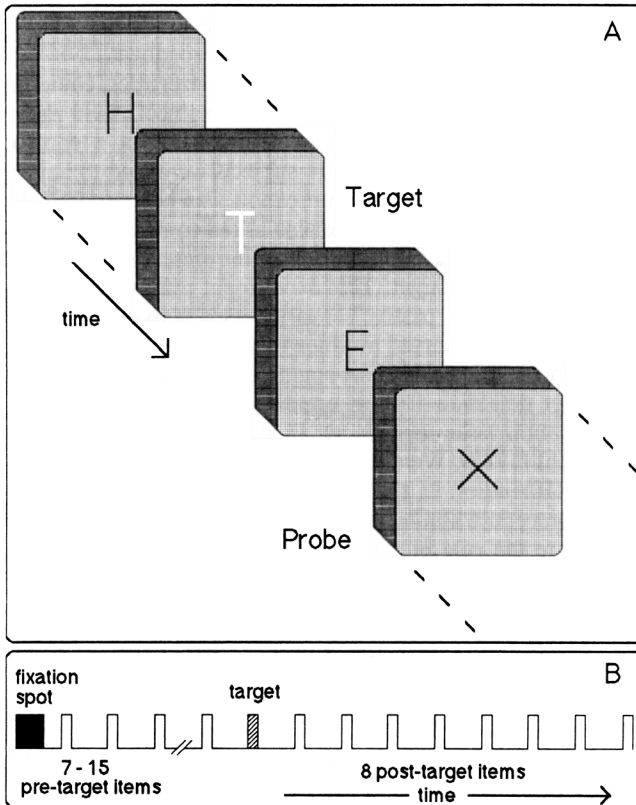
Figure 1. Panel A depicts an illustration of the rapid serial visual presentation stimuli presentation used in all of the experiments. (The target, embedded in the stimulus stream, was a white letter that subjects were required to identify in some experiments. The probe was used in Experiments 2–4. It was always a black X presented at a variable serial position after the target [except in Experiment 2, where it was also presented as the target on some trials].) Panel B depicts a diagram of the temporal arrangement used in stimulus presentation. (See text for details.)

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. Eight letters always succeeded the target. The uniform gray field was viewed during the ISI. Each trial began with a 180-ms presentation of a small white fixation dot. The subject initiated a trial when ready by depressing the mouse button. In this experiment, the subject was instructed to report the name of the white letter and the name of the next three letters in the stream as in the procedure used by Weichselgartner and Sperling (1987).

Results and Discussion

The group mean probability of reporting a letter anywhere in the response string is plotted as a function of the serial position of the letter in relation to the target in Figure 2. On the horizontal axis in this figure and all others like it, the target was assigned a relative serial position of 0; items preceding the target are given negative values and items succeeding the target were assigned positive values. A repeated meas-

ures analysis of variance (ANOVA) on the probability of reporting a letter revealed a significant main effect of relative serial position, $F(10, 40) = 69.53$, $p < .01$. Panel A of Figure 2 shows that the target letter and the last letter in the stream were reported with the highest and about equal probability (.8). Items presented at +1, +5, +6 and +7 serial positions were reported with about equal probability (.35), whereas post hoc multiple comparisons through the Scheffé method show that the +2 and +3 items were reported with significantly less probability ($p < .05$) than the former items. Subjects rarely reported items presented prior to the target. These data replicate the posttarget processing deficit reported by Weichselgartner and Sperling (1987), indicating that in this situation the effect is maximal during the interval between 180 and 270 ms posttarget.
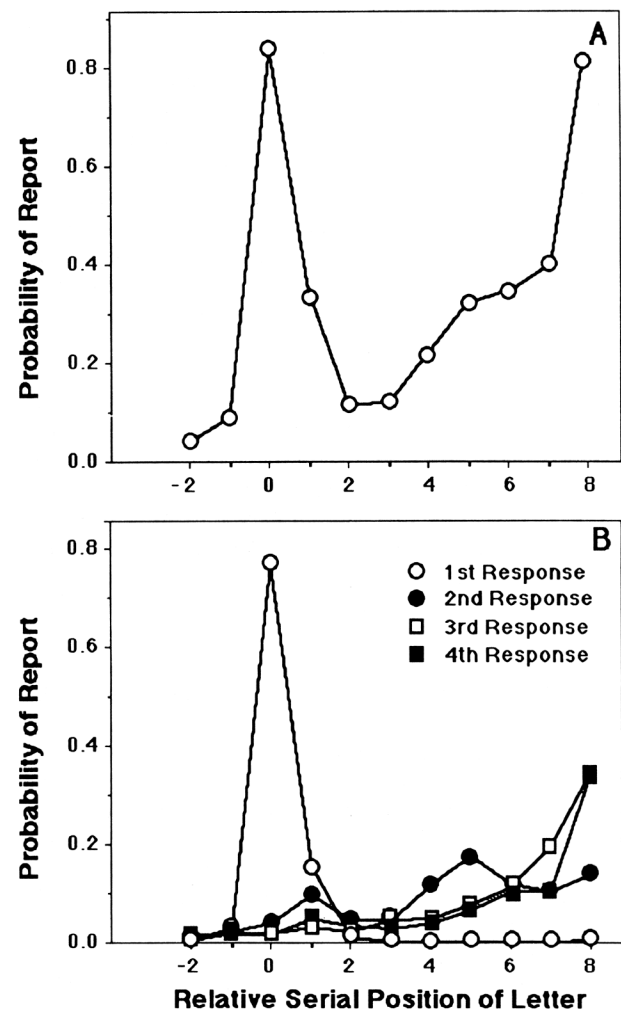
Figure 2. Panel A depicts the group mean probability of reporting a letter anywhere in the response string as a function of the letter's relative serial position in the stimulus stream. (The target's serial position is denoted as 0. Positive serial position values indicate posttarget stimuli, and negative values indicate pretarget stimuli.) Panel B depicts the group mean probability of reporting a letter at a specific position in the response string as a function of relative serial position in the stimulus stream.

Panel B of Figure 2 illustrates the probability of reporting an item at a specific location in the response string as a function of its actual serial position in the stimulus stream. Three points are of interest. First, there was a high probability (.77) that the target was reported as the first item in the response string. The +1 item, however, was occasionally reported as such, demonstrating that +1 posttarget intrusion errors were made on average on 16% of trials. Second, the second item in the response string was most frequently the +5 item and was rarely the +2 or +3 item. Third, items reported as the third and fourth response were drawn predominantly from the last three items in the stream, which indicates that the order of item presentation was not well preserved in the verbal report, a finding consistent with previous research (Reeves & Sperling, 1982; Weichselgartner & Sperling, 1987).

The results demonstrate that a posttarget processing deficit was found with less-practiced subjects than those of the Weichselgartner and Sperling (1987) study and with slightly different stimuli and temporal parameters.

Experiment 2

The purpose of Experiment 2 was to answer two questions. First, would performance on a simple posttarget probe-detection task, as opposed to the complex posttarget identification task used in Experiment 1, be negatively affected by a prior target-identification task? Second, if so, is the posttarget processing deficit mediated by sensory or attentional factors?

Previous research demonstrating posttarget processing deficits probed the posttarget period by asking subjects to identify words (D. E. Broadbent & M. H. P. Broadbent, 1987; Kanwisher, 1987; Kanwisher & Potter, 1989, 1990) or a string of items in an RSVP stream (Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987) after identifying a partially specified target. From the word-identification studies, it is unclear whether the posttarget processing deficit reported in these studies affects the mechanisms involved in word identification or acts at a lower level interfering in some way with perception of letters. Similarly, in the Weichselgartner and Sperling (1987) study, it is not possible to disentangle the role of memory or attentional or sensory factors in the posttarget processing deficit. In the present experiment, the posttarget period was probed by asking the subjects to detect a fully specified item, that is, a black X. If a posttarget processing deficit is found with this detection task, then the level of operation must be at least as low as a letter-recognition stage and is unlikely to be the result of memory-encoding difficulties or response demands.

Two conditions were conducted in this experiment. The experimental condition required subjects first to identify a white letter (target) embedded in a letter stream of black letters and subsequently to respond whether an X (probe) had been presented in the posttarget letter stream. In the control condition, subjects were told to ignore the target color and that identification was not required and simply to respond whether the X had been presented in the posttarget letter stream. This control condition was conducted to determine whether posttarget processing deficits were due to either the generation of passive sensory transients (as in masking) by

the novel white target or the active attentional demand of having to identify the target.

Method

Subjects. Ten University of Calgary students (7 women, 3 men) ranging from 19 to 37 years of age ($M = 25$) volunteered to participate in the experiment. All subjects were naive to the purpose of the study and participated in both experimental and control conditions within a single 60-min session. The order of conditions tested was counterbalanced.

Procedure. For each condition, 180 RSVP letter streams (trials) were presented. The letter streams were generated the same as those for Experiment 1 except as noted in the following. In half of the trials, an X was present at one of Serial positions 0–+8; in the remaining trials, an X was never presented. An X was never presented prior to the target and never appeared twice within a single stream. When the probe was presented as the target, it appeared to be white. The probe X was presented 10 times at each of the possible serial positions, yielding 90 probe-present trials. In the experimental condition, the subject was asked to name the white letter and to say whether an X was present or absent. In the control condition, the subject was instructed to ignore the white letter and to determine whether an X was present or absent. Subjects received 10 practice trials in each condition prior to data collection. One-minute rest breaks were given every 60 trials, and a longer rest was permitted between conditions.

Results and Discussion

Probe detection. The group mean percentage of trials in which the probe was correctly detected is plotted as a function of the relative serial position of the probe for both conditions in Panel A of Figure 3. We calculated means for the experimental condition by using only those trials in which subjects identified the target correctly. For the control condition, subjects correctly detected the probe on 85% or better of trials for all probe serial positions. For the experimental condition, however, the detection of the percentage correct dropped below 60% for the posttarget interval from 180 to 450 ms.

A two-variable (Condition × Probe Serial Position) repeated measures ANOVA revealed a significant main effect of condition, $F(1, 72) = 35.23, p < .01$, a significant main effect of probe serial position, $F(8, 72) = 8.34, p < .01$, and a significant Condition × Probe Serial Position interaction, $F(8, 72) = 6.33, p < .01$. Multiple post hoc comparisons that used Scheffé's method revealed that the group mean percentage of probe detection for the experimental condition was significantly lower ($p < .05$) than the corresponding point for the control condition for items +2, +3, +4, and +5, indicating a significant posttarget processing deficit for the posttarget interval occurring between 180 and 450 ms. The group mean false-alarm rate for the experimental condition was 12.6% (ranging from 0% to 34%), and for the control condition it was 11.3 (ranging from 1% to 28%).

Target-identification errors. An analysis of target-identification errors in the experimental condition revealed that the position of the probe influenced the pattern of target errors. Panel B of Figure 3 shows the group mean probability of reporting an item as the target as a function of the relative serial position of the reported letter. These probabilities are illustrated separately for trial types in which the probe was
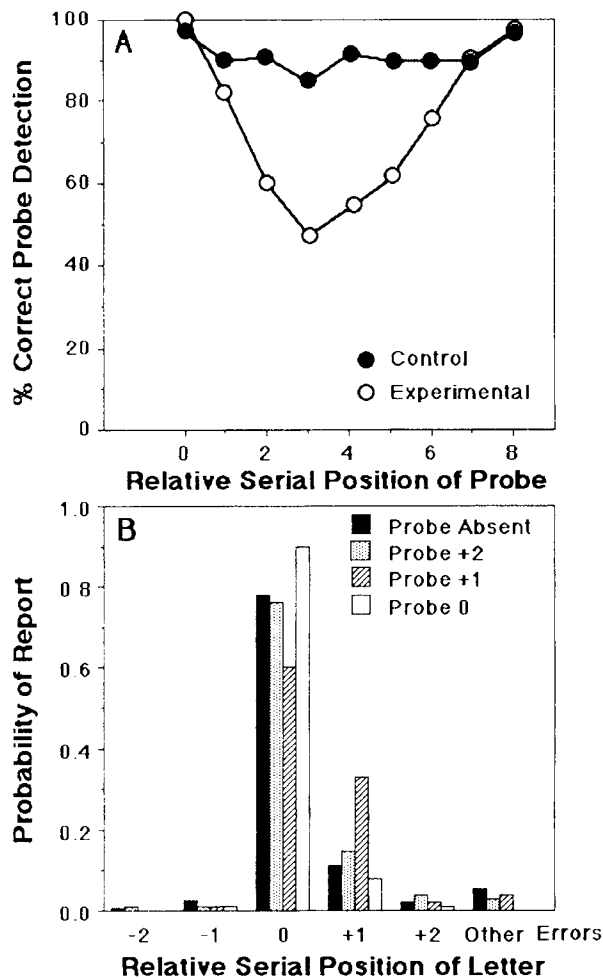
Figure 3. Panel A depicts the group mean percentage of trials in which the probe was correctly detected, plotted as a function of the relative serial position of the probe. (Closed symbols represent data obtained in the control condition in which subjects were told to ignore the target letter. Open symbols represent data obtained in the experimental condition in which subjects were told identify the target letter.) Panel B depicts the group mean probability of reporting a letter as the target as a function of the letter's relative serial position. (The solid bars represent data for trials in which the probe was absent from the stimulus stream. The hatched and stippled bars represent data for trials in which the probe was presented as the first and second item after the target, respectively. Open bars indicate the data from trials in which the probe was presented as the target item.)

presented as the target, the +1 item, the +2 item, or was absent. A two-variable repeated measures ANOVA on the probability of reporting an item as the target for these trial types revealed a significant main effect of relative serial position of the letter identified as the target, $F(4, 96) = 148.53$, $p < .01$, and a significant interaction effect of relative serial position of the letter identified as the target with the relative position of the probe in the stream, $F(9, 81) = 6.63$, $p < .01$.

For probe-absent trials, target-identification errors were made on 22% of trials on average. Subjects made +1 intrusion errors on 50% of these error trials or on 11% of all probe-

absent trials. This number is comparable to the 16% +1 intrusion errors found in Experiment 1. The probability of +2 errors was .02, which indicates that the target-identification task was completed in less than 180 ms, because the to-be-reported feature (letter name) from a +2 item was unlikely to be conjoined with the target-defining feature (white color). A similar probability of +2 errors was found for probe-present trials, which indicates that the duration of target-identification processes were not extended because of the probe's presence.

When the probe was presented as the +1 item, +1 intrusion errors were significantly more frequent ($p < .05$) than for any other trial type. When the X was in +1 position, +1 errors accounted for 82% of the 40% total errors. Thus for this condition, +1 intrusions were made on 33% of trials, which is triple the rate of the probe-absent trials. Target-identification errors for trials in which the X was presented as the target were made only 10% of the time, which was significantly lower ($p < .05$) than for any other trial type. Eighty percent of such errors were +1 intrusions. For all other probe-present trials (probe presented at Serial Positions +2–+8), target-identification error rates did not differ significantly from those in the probe-absent trials.

The results of Experiment 2 indicate two important points. First, the probe-detection data from the experimental condition provide evidence that the posttarget processing deficit previously reported to affect the identification of words (D. E. Broadbent & M. H. P. Broadbent, 1987; Kanwisher, 1987; Kanwisher & Potter, 1990) and letter strings (Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987) also affects the detection of a fully specified item. This observation suggests that the deficit operates at a relatively early stage of processing. Second, comparison of probe-detection data obtained in the experimental and control conditions demonstrate that the posttarget processing deficit is attentional. In both control and experimental conditions, the subject's visual system was stimulated with a novel white target midway through the stream of black letters. Because there was no evidence of a posttarget processing deficit in the control condition, the temporary posttarget reduction in probe detection found in the experimental condition cannot be due to low-level visual transients produced by the target. Rather, reduced performance in detecting a posttarget X must stem from attentional processes arising from the target-identification process.

A possible explanation for the effect is that failure to detect the probe in the posttarget interval in the experimental condition was due to subject's neglecting the probe-detection task to enhance accuracy on the target-identification task. Nevertheless, subjects were able to detect the probe when presented at Serial Position 1 on 80% of trials, which indicates that switching tasks could be accomplished in a short period of time. Moreover, identification errors in the experimental condition provide evidence that subjects were more readily prepared to select Xs than any other letter. In the experimental condition, the rate of +1 intrusion errors was three times as great for trials in which the probe was the +1 item than it was for probe-absent trials. Moreover, when the target was an X, +1 intrusion errors were significantly less than for other trial types. If it can be assumed that target identification involves the conjunction of the target-defining feature (white color)

with the to-be-reported feature (letter name), then these data strongly suggest a preference to select Xs from the available sensory store. During the critical posttarget interval (180–450 ms), however, it appears that such a top-down selection mechanism fails to operate, possibly because lower level attentive mechanisms are suppressing input.

Experiment 3

The results from Experiment 2 suggest that the posttarget processing deficit is initiated by events related to target identification, that it is mediated by an attentional mechanism, and that this mechanism acts at a relatively early stage of visual processing. The purpose of this experiment was to investigate whether the action of the attentional suppression mechanism is ballistic once it is initiated, that is, nonadaptive to posttarget events, or alternately whether it depends on the nature of posttarget stimulation. The experiment was designed so that if a ballistic mechanism were found, it could be determined whether it was time- or event-dependent.

Through the same RSVP procedure with both of the experimental and control conditions as in Experiment 2, posttarget stimulation was manipulated by inserting a uniform field (blank interval) of variable duration between the target and the posttarget letter stream. We reasoned that if the attentional suppression mechanism is ballistic and time-dependent, then the insertion of a blank interval between the target and the posttarget letter stream containing the probe should yield attenuated probe detection for specific posttarget times, as was seen in the experimental condition of Experiment 2. On the other hand, if suppression is ballistic but event-related, then detection of probes presented at the +2, +3, +4, or +5 positions should remain attenuated in spite of the insertion of the blank interval.

In contrast to these two possibilities, the suppression mechanism could be adaptive (i.e., sensitive) to posttarget events. If so, suppression might be initiated and maintained only when posttarget events interfered with target identification. When posttarget events do not interfere with target identification, as might be the case with a blank interval, then activity of the suppressive mechanism is not necessary, and the posttarget processing deficit can be eliminated.

Method

Subjects. Ten University of Calgary students (9 women, 1 man) ranging from 17 to 19 years of age (M = 18) volunteered to participate in the experiment. All subjects participated in both experimental and control conditions, which were conducted in two separate 60-min sessions. The order of conditions tested was assigned randomly.

Procedure. For each condition, 440 RSVP letter streams (trials) were presented. Stimuli and procedures were identical to that used in Experiment 2 except that in some trials a blank of variable duration was presented at the offset of the first posttarget ISI period and before the first posttarget stimulus. This is illustrated in Panel A of Figure 4. Blank intervals of 0, 90, 180, and 270 ms were used. (Note that for the 0-ms blank conditions, a 75-ms posttarget ISI of blank stimulation was still presented, as in the previous experiments.) One hundred trials that contained each interval type were presented in a random order. Only half of these trials contained a probe in the posttarget
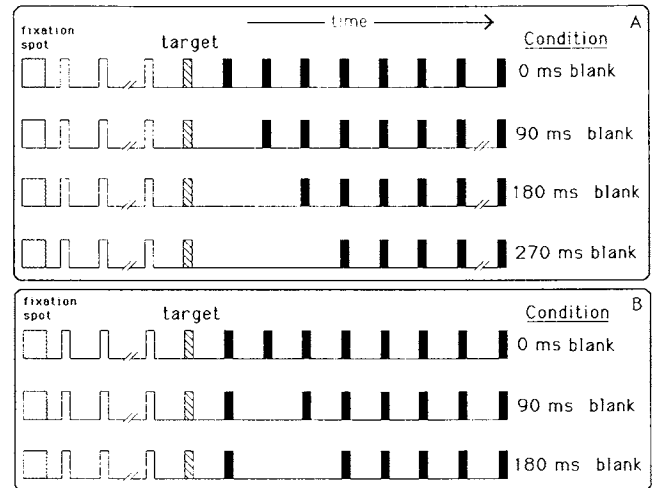

Figure 4. Diagram describing temporal characteristics of stimulus presentation in Experiments 3 (Panel A) and Experiment 4 (Panel B). (The filled rectangles indicate serial positions in which probes could be presented. There were eight posttarget letters presented in all conditions for Experiment 3 and eight, seven, and six posttarget letters presented in the 0-, 90-, and 180-ms blank conditions, respectively, of Experiment 4.)

letter stream. The probe was either the +1, +2, +3, +4, or +7 posttarget event. Ten trials were presented for each combination of blank duration and probe position. This set of stimulus conditions allows the comparison of probe-detection performance for items presented at either a specific interval after the target or after a specific number of events. In addition to the trial types described earlier, 40 additional trials were presented in random order among the trials described earlier, 20 with blanks of 450 ms and 20 with blanks of 540 ms. When present (on 50% of trials), probes were presented at either the +1 or +2 serial position. These trial types were used to test for probe detection with blank intervals longer than the posttarget processing deficit found in Experiment 2. In the experimental condition, the subject was asked to name the white letter and to say whether an X was present or absent. In the control condition, the subject was instructed to ignore the white letter and to determine whether an X was present or absent. Practice and rest breaks were given as in Experiment 2.

Results and Discussion

Probe detection. Figure 5 shows the group mean percentage of trials in which the probe was correctly detected, plotted as a function of probe presentation time after the target for the four blank durations for the experimental condition (Panel A) and for the control condition (Panel B). We calculated means for the experimental condition by using only those trials in which subjects identified the target correctly. In the control condition, subjects correctly detected the probe on 75% or better of trials for all probe serial positions. In experimental condition trials in which the blank duration was 90 ms or longer, the probe was also detected at least 75% of the time or better for all probe positions. For experimental trials containing no blank interval (replication of Experiment 2), however, probe detection dropped to below 60% for probes
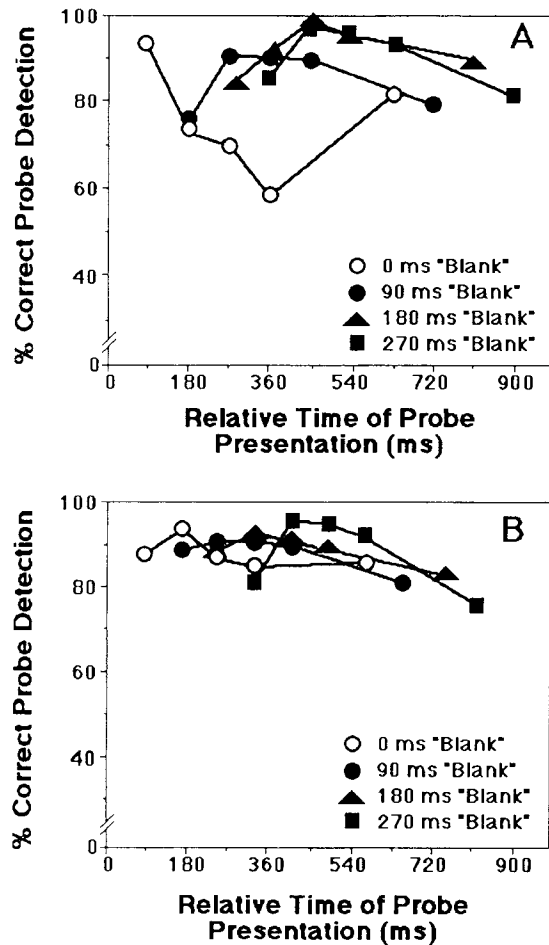
Figure 5. The group mean percentage of trials in which the probe was correctly detected in the experimental conditions (Panel A) and for the control conditions (Panel B), plotted as a function of the time of probe presentation after the target. (Open circles represent data obtained for the 0-ms blank conditions. Closed symbols represent data obtained for the 90-ms [closed circles], 180-ms [closed triangles], or 270-ms [closed squares] blank conditions.)

presented 360 ms after the target, a result comparable to that of Experiment 2. Probe detection on trials with long blank durations (450 and 540 ms) was 85% or greater for all probe serial positions.

A three-variable (Condition × Blank Duration × Probe Serial Position) repeated measures ANOVA revealed significant main effects for blank duration, $F(3, 108) = 7.40$, $p < .01$, and probe serial position, $F(4, 108) = 3.85$, $p = .01$. The ANOVA also showed a significant Condition × Blank Duration interaction, $F(3, 108) = 12.17$, $p < .01$, a significant Blank Duration × Probe Serial Position interaction, $F(12, 108) = 5.25$, $p < .01$, and a significant three-way Condition × Probe Serial Position × Blank Duration interaction $F(12, 108) = 2.13$, $p < .02$. The mean false-alarm rate for the experimental condition was 5.9% (ranging from 3% to 10%); for the control condition, it was 4.0% (ranging from 1% to 9%) and did not vary as a function of blank interval duration.

Post hoc tests with the Scheffé method compared probe detectability in experimental versus control conditions for probes presented at 360 ms posttarget. Results revealed that differences were significant only for the 0-ms blank condition ($p < .05$). In addition, Scheffé tests that compared probe detectability in experimental versus control conditions for probes presented as the +4 letter regardless of its posttarget presentation time revealed that only the difference for the 0-ms blank condition was significant ($p < .05$).

This pattern of results indicates that the attentional mechanism mediating the suppression of posttarget processing is not ballistically generated by events related to the target-identification task. In accounting for their RSVP results, Weichselgartner and Sperling (1987) proposed that the target initiates both a transient and a sustained attentional response. They proposed that the transient response had a rapid buildup and decay and that the sustained response had a slow buildup. They suggested that the posttarget processing deficit occurred during the interval after the transient attentional response had decayed and before the sustained response was built up, leaving the system without an attentional mechanism. Nakayama and Mackeben (1989) proposed a similar mechanism. The results of our Experiment 3 fail to provide any evidence for this idea. Rather, the data suggest that the suppressive mechanism is sensitive to posttarget stimulation and raise the possibility that attentional suppression occurs only when posttarget stimulation interferes with target identification. Trials with a posttarget blank interval might relieve the visual system of having to process a novel stimulus immediately after the target. This would allow target-identification processes to be completed in an unencumbered fashion, thus eliminating the need to invoke a suppression of subsequent visual input.

Target-identification errors. For 0-ms blank duration trials, subjects made target-identification errors on 32% of trials. +1 intrusion errors were made on about 15% of trials, a rate consistent with that found in Experiment 2. For trials with longer blank durations, target-identification errors dropped to 4% of trials, which indicates that target identification was significantly eased by reducing stimulation in the immediate posttarget period. Such a finding supports the conjecture that the initiation of attentional suppression results from interference in the target-identification task.

Experiment 4

Experiment 3 demonstrated that if a blank interval of at least 90 ms was inserted after the first posttarget ISI and before the first posttarget letter, no evidence of a posttarget processing deficit was obtained. These data suggest that an attentional suppressive mechanism is used only when posttarget stimulation interferes with target identification. If so, then presentation of a single posttarget item immediately following the target should be enough to elicit the suppression. In Experiment 4 we tested this possibility by repeating the experimental conditions of Experiment 3 but with blank intervals inserted between the +1 and +2 items rather than between the target and the +1 item as in Experiment 3.

Method

Subjects. Ten University of Calgary students (7 women, 3 men) ranging from 20 to 37 years of age ($M = 26$) participated in the experiment to fulfill a course requirement. All subjects were naive to the purpose of the study. Each participated in a single 60-min session.

Procedure. Each subject viewed 380 RSVP letter streams (trials). Stimuli and procedures were similar to those used in the experimental conditions of Experiment 3 except that when present, the variable-duration blank intervals were presented after the offset of the ISI following the +1 letter and before the onset of the +2 letter, as shown in Panel B of Figure 4. Control conditions were not conducted in the experiment. Blank intervals of 0, 90, and 180 ms were presented (the 270-ms interval was not used). One hundred sixty trials were presented with 0-ms blank durations, 120 trials were presented with 90-ms blank duration, and 100 trials were presented with 180-ms blank durations presented in a random order. Half of the trials for each duration contained a probe in the posttarget letter stream; the remaining trials did not. For 0-ms blank duration trials, the probe, when present, appeared in one of the eight posttarget positions. For the remaining probe-present trials (i.e., those with blanks inserted), the probe was presented at one of the postblank letter positions and was never presented either as the target or in the +1 position. For blank durations of 90 and 180 ms, the number of postblank letters presented was five and four, respectively. Ten trials were presented for each combination of blank duration and probe position. For all trials, subjects were instructed to report the identity of the white letter and state whether the probe had been presented.

Results and Discussion

Probe detection. Figure 6 shows the group mean percentage of trials in which the probe was detected correctly, plotted as a function of the time of probe presentation after the target. We calculated means for Figure 6 by using only those trials in which the subject identified the target correctly. We conducted a two-variable (Blank Duration × Probe Serial Position) repeated measures ANOVA on the data obtained for trials in which probes were presented 360 ms posttarget and later, because probes were presented at these times for all blank conditions. This analysis revealed a significant main effect of probe serial position, $F(4, 72) = 17.90$, $p < .01$, a marginally significant main effect of blank duration, $F(2, 72) = 4.76$, $p < .05$, and a nonsignificant interaction effect, which indicates that probe presentation time affected probe detection equally for all blank duration conditions. Scheffé post hoc tests revealed that performance on the probe-detection task averaged across probe presentation time was slightly but significantly greater for the 180-ms blank duration condition than for the 90-ms blank duration condition ($p < .01$). Post hoc tests also revealed that performance on the probe-detection task, averaging across blank duration condition, was significantly worse when probes were presented 360 ms after the target than the average performance for probes presented 540, 630, and 720 ms after the target ($p < .01$). For all three blank durations, probes presented 360 ms after the target were correctly detected on less than 65% of trials. This result is comparable to results shown for the experimental conditions of Experiments 2 and 3 (no blank condition) and constitutes a posttarget processing deficit. When probes were presented 540 ms or more after the target, however, on average they
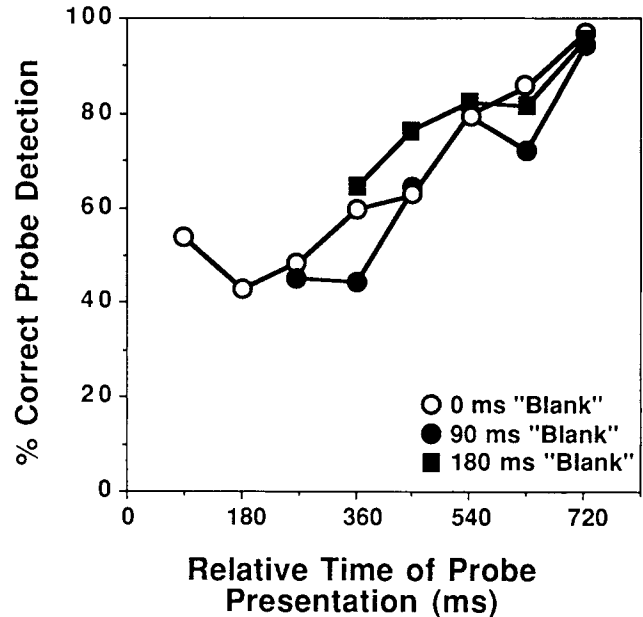

Figure 6. The group mean percentage of trials in which the probe was correctly detected (experimental conditions), plotted as a function of the time of probe presentation after the target. (Open circles represent data obtained for the 0-ms blank conditions. Closed symbols represent data obtained for the 90-ms [closed circles] and 180-ms [closed squares] blank conditions.)

were correctly detected on greater than 85% of trials. The group mean false-alarm rate for all conditions was 11.4% (ranging from 3.2% to 21.6%) and did not vary as a function of blank interval duration.

Target-identification errors. The rates of target-identification errors were similar for the three blank durations, ranging from 17% (no blank condition) to 24% (90-ms blank duration condition). The rate of +1 intrusion errors was also similar for all blank durations, ranging from 7% for the no-blank condition to 10% for the 90-ms blank duration condition. These error rates are consistent with those obtained in Experiment 2 and for the no-blank condition in Experiment 3 and are approximately double the rate found in any of the conditions in Experiment 3 containing a significant blank interval.

Unlike the results of Experiment 3, the results of this experiment demonstrate that a significant posttarget processing deficit can be produced when prolonged intervals (> 90 ms) lacking in visual input are inserted into the posttarget stimulus stream. In Experiment 3, the blank intervals were presented immediately after the target, whereas in the present experiment, the identical-duration blank intervals were presented after the +1 letter. The difference in the results obtained indicates that the posttarget processing deficit must result from the presentation of a letter stimulus immediately after the target. This finding strongly suggests that the attentional suppression mediating the posttarget processing deficit is only initiated when posttarget stimuli are presented with

enough temporal proximity to the target to interfere with its identification.

These data also suggest that once initiated, the attentional suppression acts ballistically and is nonadaptive to levels of stimulation during the posttarget period. If the suppressive mechanism were sensitive to the nature of posttarget stimulation in effect during suppression, then there should have been a significant interaction between blank duration condition and time of probe presentation. Because the magnitude of the deficit for probes presented 360 ms after target presentation did not differ for the short and long blank durations, it can be concluded that the mechanism mediating the posttarget suppression is insensitive to stimulation presented after the +1 item.

General Discussion

In Experiment 1, which used the RSVP paradigm of Weichselgartner and Sperling (1987), subjects were asked to report a partially specified target letter and the first three items following the target. Letters presented at the +2 and +3 relative serial positions were reported with a very low probability, and letters presented later in the stimulus stream were reported with a significantly greater probability. Experiment 2 explored this selective neglecting of posttarget items by maintaining the same target-identification task but simplifying the task requirement after target identification by asking subjects to detect a single fully specified letter (probe). Three main points should be noted with regard to the data obtained in Experiment 2.

First, target-identification errors (experimental condition) were made in 22% of trials; 50% of these errors were +1 intrusion errors. (The bulk of the remaining target-identification errors were random naming of letters, which suggests an overall lapse of attention during those trials.) Target-identification errors for Experiments 3 (0-ms blank experimental conditions) and 4 (all conditions) were similar both quantitatively and qualitatively. The preponderance of +1 intrusion errors indicate that the to-be-reported feature of the +1 item and the target-defining feature of the target were conjoined incorrectly on a significant proportion of trials. These data suggest that target-identification processes remain somewhat sensitive to incoming stimuli for about 105 ms (the time of offset of the +1 item) and that target-identification processes in this task are complete in less than 180 ms (the time of the onset of the +2 item) in at least 89% of trials.

Second, detection of the probe was significantly and dramatically suppressed for 450 ms after the target had been presented in the experimental (identify target) condition. This suggests that the deficit in posttarget identification and report seen in Experiment 1 results from a suppression in visual processing operating at a relatively early detection stage, as opposed to a later identification stage, as has been suggested by previous research (D. E. Broadbent & M. H. P. Broadbent, 1987).

Third and most important, the posttarget processing deficit was not found in the control (ignore target) condition. This finding clearly shows that the posttarget processing deficit results from attentional factors instead of sensory factors such

as masking. In the control condition, the white target letter failed to produce any masking effects of immediately subsequent (+1) probes. Moreover, because probe detection in the control condition was greater than 85% for all probe locations, detection of probes presented later in the posttarget stream was obviously not masked by immediately preceding or succeeding items.

The results reported here provide a dramatic demonstration of an attentional blinklike process. The loose analogy of this effect to an eyeblink is based on its temporal characteristics. First, the lid closure during an eyeblink is accompanied by visual suppression lasting about 150 ms (Volkman, Riggs, & Moore, 1980). The duration of the posttarget processing deficit was 180 ms for Experiment 1, and when found in Experiments 2–4, was between 180 and 270 ms. Second, an eyeblink is typically initiated after information in a scene is acquired. Similarly, in the RSVP task, the drop in probe detectability seen in Experiment 2 becomes significant for probes presented after target identification is complete.[1] Third, like an eyeblink, the attentional blink appears to be ballistic.

In Experiments 3 and 4, short blank intervals were embedded in the posttarget letter stream to determine whether the attentional blink was initiated by the presentation of the target per se or by the posttarget stimuli interfering with target identification. The explanation offered by Weichselgartner and Sperling (1987) for the posttarget processing deficit was that it does not result from any sort of suppression but rather reflects the interval between a rapid automatically cued attentional response and a slower, more controlled attentional response, both of which occur in response to the target. The results of the present experiments do not support this explanation. Rather, our data show that if visual input is eliminated for 165 ms after target offset (a blank interval is inserted in which the +1 item would have been), a posttarget processing deficit is not produced. If a similar-duration blank interval is inserted in place of the +2 item (Experiment 4), however, a large posttarget processing deficit is produced. These results suggests that an attentional blink is initiated only if novel visual input occurs before target-identification processes are complete.

A Model for the Attentional Blink

On the basis of these data obtained in the four experiments described here, we can postulate that the following sequence of events may lead to an attentional blink. During the presentation of the RSVP stream of letters, the white color of the target is detected preattentively. This information is then used to initiate an attentional response to facilitate target identification. If attention is allocated episodically, as suggested by Sperling and Weichselgartner (1990), then target identification may involve the opening and closing of a gate to regulate the flow of postreceptoral visual information to recognition

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[1] Although not systematically measured in the present experiments, oculomotor measurements of subjects participating in other highly similar experiments were conducted and revealed that subjects do inhibit eyeblinks during the viewing of an RSVP stream.

centers of the brain (Reeves & Sperling, 1986). According to this model, an attentional episode begins (i.e., the gate opens) when the target-defining feature is detected and continues until target identification is complete. The presentation of a new item (+1 item) immediately after the target but before the termination of the attentional episode will result in features of the +1 item being processed along with features of the target item. This possibility is supported by the observation that probes presented in the +1 position were detected on an average of 82% of trials in experiments in which attentional blinks were found. The availability of features from both the target and the +1 item in the sensory store, however, will provide the identification mechanism with confusing information: two letter colors and two letter names. Extrapolating from visual search research, similarity theory (Duncan & Humphreys, 1989) suggests that the greater the similarity between the target and the +1 letter (distractor), the greater the potential for confusion. The serial report data of Weichselgartner and Sperling (1987) and in our own replication of that study show that the temporal order of information is not preserved, which supports this idea. Thus, the target color and the target name may be inappropriately matched on some occasions, resulting in Serial Position 1 intrusions.

This potential confusion is noted by the system and then used to initiate a suppressive mechanism to eliminate further confusion. When confusion is not present (i.e., target identification can reach completion without interference from new stimuli), the attentional gate is merely closed, and the next attentional episode can be initiated rapidly (i.e., probes can be readily detected at any time). When confusion is present, however, the attentional gate is both shut and locked, making the initiation of the next attentional episode a more time-consuming process than if a locking operation had not been conducted. The possibility of a shut-and-lock procedure when interference is present is supported by the finding (reported here) that once initiated, suppression of visual processing lasts for the same amount of time whether there is a steady stream of new stimulation being presented or not (Experiment 4). The extent of interference should depend on the temporal relationship between the target and +1 item (Experiments 3 and 4), the similarity between these two items, and the similarity between the +1 item and the other nontarget items in the stream (Duncan & Humphreys, 1989). Experiments to test the latter two possibilities are currently underway. In the blink analogy, the locking of the gate is like the closing of an eyelid.

Relationship to Other Multiple-Task RSVP Experiments, Including RB

Can this model be used to account for previous data in which posttarget processing deficits have been found? The RSVP experiments of Reeves and Sperling (1986), Weichselgartner and Sperling (1987), and D. E. Broadbent and M. H. P. Broadbent (1987) all involved the identification of a partially specified target as the initial task and the identification of one or more subsequent items. The shut-and-lock model suggests that the posttarget processing deficits reported in these studies result because the +1 item was presented before

identification of the target was complete. The close temporal proximity of the +1 item to the target caused interference in the target-identification task and thus produced an attentional blink. During the blink, items could not be detected easily and thus their identification was impaired. That detection and not identification was impaired in the D. E. Broadbent and M. H. P. Broadbent (1987) study is supported by their comment that subjects in this experiment were often unaware that a second target had been presented.

Application of the shut-and-lock model to the findings in RB experiments (Kanwisher, 1987; Kanwisher & Potter, 1989, 1990) is more problematic. There are two striking similarities between the RB results and those reported in the present article. First, the duration of the RB effect closely parallels the duration of the attentional blink. Kanwisher (1987) found that recall of a repeated word is significantly reduced in relation to nonrepeated words in an RSVP task if the repeated word is presented within about 500 ms of its first presentation. In the present experiments, probe detectability recovered to control levels about 540 ms after the target. Second, no RB was found for repeated items presented during the critical posttarget (first instance) interval if slow presentation rates were used, that is, if the SOA between the first presentation of a word and the next item in the string was 250 ms. Thus, in both the RB paradigm and the probe-detection procedure used in our studies, it appears that if recognition of an item can proceed without the occurrence of immediate novel stimulation, then difficulties in processing subsequent stimuli are eliminated.

Although the results of the RB studies and the present data bear a resemblance on the aforementioned points, there is a distinct difference in the two tasks. In Kanwisher's (1987) RB experiment, subjects were required to indicate which word had been repeated in an RSVP stream of randomly related words. In the later studies, the order of item presentation was constrained so that words constructed sentences or letters constructed words, and the subject's task was to report the sentence or the word (Kanwisher & Potter, 1990). These tasks, especially the latter, required subjects to identify each item in the stream. They may have used their attentional mechanisms in a mode quite different from that in multiple-task RSVP studies in which identification of a clearly demarcated target stimulus is the first task and stimulus items are unrelated to each other.[2]

Kanwisher and Potter (1990) explained their results by suggesting that each word in the stream is recognized as the first instance (token) of a specific stimulus (type). When a word is repeated, it is also recognized (typed), but it is not individualized from the first instance (i.e., it is not tokenized). Support for the idea that the repeated item is typed but not tokenized comes from the finding that subjects can recall the

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[2] It is interesting to note that Kanwisher and Potter (1990) conducted an RSVP experiment in which subjects were required to recall a stream of seven unrelated letters. They reported that subjects' performance was substantially worse on this task compared with conditions in which the sequence of letters was arranged so that a word was spelled. This indicates that if items are linked in some way, visual processing of RSVP stimuli is facilitated.

last word in an RSVP string with slightly greater accuracy when the last item is a repeated item (52%) than when it is a nonrepeated item (35%) and both are followed by a mask (Kanwisher, 1987).

Our shut-and-lock model accounts for these data by suggesting that an attentional episode is initiated with the presentation of each item because each must be recognized and therefore attended. The model further suggests that the attentional gate is closed and locked for about 400 ms after the presentation of the next item. How, then, is it that a nonrepeated item is recognized on about 80% of trials? Perhaps when subjects must attend to every item in the stream and are attempting to link items in a meaningful manner, the attentional gate behaves more like an attentional filter, that is, is more effective at locking out stimuli with high visual similarity to items previously processed than other items. When subjects need attend only to a stimulus that is highly localized in the temporal domain (i.e., a target) and do not need to relate information from one item to information in subsequent items, the gate may be less permeable, reducing detectability of all stimuli. Experiments are currently underway to determine the characteristics of stimuli screened out during an attentional blink and the relationship between the target task and the probe task.

The results of the experiments described here demonstrate that if attention has been allocated to a stimulus presented briefly at time $t = 0$, and if a distracting item has been presented while target identification of that stimulus is still underway, attention cannot be consistently reallocated to new stimuli presented during the interval of $t = 180$ ms to $t = 450$ ms. These data suggest that attentional mechanisms "blink," that is, transiently limit visual processing, when the flow of visual information interferes with an attention-demanding task.

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