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Transient suppression of processing during rapid serial visual presentation: Acquired distinctiveness of probes modulates the attentional blink

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The attentional blink is revealed in studies of rapid serial visual processing, in which observers view a stream of letters presented sequentially at the same location in a visual display. Reporting the identity of a specially marked letter (the target) amidst distractors causes a transient loss of accuracy for detection of another prespecified symbol (the probe). In two experiments, observers viewed lists of letters, identified a randomly selected letter as a target, and detected the presence of a probe from a different category (a digit or a Greek letter). After several days of training, probe detection following a target had improved markedly. Posttarget probe detection was again impaired when the distractor set included members of the probe set. These results are compatible with an explanation of the attentional blink as an act of suppression aimed at the current set of distractors, but additional mechanisms are needed to account for the effects of training.

Rapid serial visual presentation (RSVP) is one method for investigating attention in visual information processing. In RSVP, visual events are presented to the observer at a rapid rate, but in the same spatial location. Observers are able to efficiently detect or identify a single target item in an RSVP stream, but when the task involves multiple targets, performance suffers (Broadbent & Broadbent, 1987; Weichelsgartner & Sperling, 1987). For example, Raymond, Shapiro, and Arnell (1992) presented lists of letters (11.1 letters/sec). One letter, the target, was highlighted. On half the trials, a probe (the letter X) appeared at one of eight posttarget positions. In control sessions, the observers only detected the presence or absence of the probe; in experimental sessions, the observers also reported the identity of the target letter. Probe detection during control sessions was nearly perfect, but probe detection during experimental sessions was impaired for about a half second following the target. Raymond et al. likened this transient loss in detection to an attentional blink (AB).

Research on the AB has provided some knowledge about the conditions responsible for "triggering" the blink. Raymond et al. (1992) found that the first posttarget distractor was critical for producing the AB. Probes that immediately followed the target without an intervening distractor were well detected, and replacing the first posttarget distractor with a blank interval attenuated the AB. (However, replacing a later preprobe distractor with a blank had no effect.) Shapiro, Raymond, and Arnell (1994) also found that detection of a dot-pattern target in the midst of letter distractors was sufficient to trigger an AB, whereas detection of a temporal-gap target eliminated the AB, as did requiring a discrimination between target gaps of different duration. As a group, these findings suggest that the AB requires that the target and the immediately following blink-inducing distractor be visual patterns, and that the AB is not just another manifestation of the psychological refractory period (see Shapiro & Raymond, 1994).

As Raymond et al. (1992) noted, the characteristics of stimuli that are and are not affected by the AB should provide important clues regarding the nature of the mechanism responsible for the AB effect.[1] Shapiro, Raymond, and Taylor (1993) manipulated the nature of the probe in order to provide some information on this matter. The targets and distractors were letters, as before. In one condition, the probes were different-colored squares, and the observers' probe task was to report the probe's color. In another condition, the probes were different geometric shapes, and the observers' task was to report the probe's shape. The shape discrimination showed the AB effect, but the color discrimination did not. These results suggest that the AB might be specific to the requirement for extracting visual pattern information from targets as well as probes (see also Shapiro et al., 1994).

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The present research was motivated by the finding that the effects of AB are substantially diminished when distractors are physically dissimilar from the targets and probes (Chun & Potter, 1992; Maki & Frigen, 1993) and focuses on probe/distractor similarity. We anticipated that any procedure that causes probes to become highly discriminable from distractors should reduce the susceptibility of the probes to the AB. In the present research, targets, probes, and distractors were all characters and thus were all within the domain of visual patterns. We employed a consistent mapping technique (Schneider & Shiffrin, 1977) and extensive practice to make the probes distinct from the distractors. In previous studies of the AB (Raymond et al., 1992; Shapiro et al., 1994), data were collected in a few hundred trials during one or two sessions. In the present research, we studied changes in performance during several thousand trials over the course of many sessions. Thus, the present research also provides new information on how the AB effect is altered by practice.

The observers in our study practiced the RSVP task illustrated in Figures 1A and 1B. In each RSVP trial, the observer first studied a randomly selected probe digit and then viewed a list of characters presented at 11.7/sec. The target letter was highlighted. In half of the trials, the probe was omitted (Figure 1A). In the other half of the trials, the probe digit occurred at one of the eight possible serial positions following the target (Figure 1B). At the end of each trial, the observers attempted to recall the target and also reported on the presence or absence of the probe.

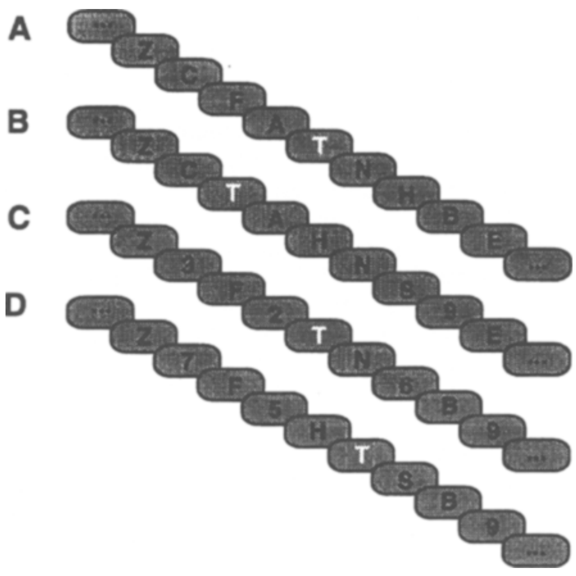

Figure 1. Events during rapid serial visual processing (RSVP) trials. Each RSVP list contained 17–25 characters. Only the stimuli including and surrounding targets and probes are illustrated. Target and probe identities varied from trial to trial. In these examples, the target is the letter T and the probe is the digit 9. The baseline task is illustrated in panels A (probe absent) and B (probe present). Panel C contains an example of the whole-list mixing condition, in which some distractors throughout the list were replaced by members of the probe set. Panel D shows an example of the pretarget mixing condition, in which only pretarget distractors were replaced by members of the probe set.

The probe and distractor sets were mutually exclusive, so stimuli were consistently mapped onto responses. Consistent mapping (CM) is a necessary condition for perceptual and attentional learning (Shiffrin & Schneider, 1977). With extensive practice, CM stimuli come to automatically attract attention, and the effects of automatic attention attraction are particularly noticeable under dual-task conditions (Czerwinski, Lightfoot, & Shiffrin, 1992). The experimental condition in the AB paradigm (Figure 1B) is a dual-task condition in that it requires performance of both target identification and probe detection. Thus, we expected that our observers would learn to discriminate the set of probe digits from the set of distractor letters because of CM training. We reasoned that the probes would become psychologically distinct, perhaps by acquiring the property of automatic attention attraction. We predicted that the AB effect, as manifested in the difference between probe detection in control and experimental sessions, would be attenuated.

Another purpose of this research was to explore the conditions under which the AB effect might be reinstated. Our observers were tested with lists like those illustrated in Figure 1 (C and D). In both these conditions, elements of the probe set appeared as distractors, either throughout the entire list (Figure 1C) or only prior to the target (Figure 1D). Because the probe and distractor sets overlapped, the sets were no longer discriminable. The category cue (digits vs. letters) was thereby rendered invalid, but (presumably) the CM-trained probes would still automatically attract attention. Thus, the question was whether the signs of the AB would again be reflected as a transient, posttarget reduction in probe detection.

METHOD

Subjects

The subjects were 7 undergraduate and graduate students who were paid $5 per day. Two of the subjects (S1 and S2) had participated in exploratory research and thus were experienced with the RSVP task; the other subjects (S3–S7) had had no previous experience with RSVP tasks. Five subjects (S1–S5) were first trained using the whole-list mixing procedure described below. Four subjects (S1, S3, S6, and S7) were later trained using the pretarget mixing procedure.

Stimulus Materials

The subjects sat about 50 cm in front of an IBM-compatible personal computer equipped with a color VGA monitor (36-cm diagonal screen, 70-Hz refresh cycle). The letters and digits were presented in 40-column mode at the center of the display and subtended a visual arc of approximately 0.54°. The background of the screen was normally light gray (text background color 7). Distractors and probes were presented in dark gray (text color 8), and the target was presented in white (text color 15). The distractor set contained all uppercase letters other than X. Probe sets contained either nine digits, 1–9, or nine Greek letters, α Γ Σ Φ θ Ω δ ϕ ε (ASCII codes 224, 226, 228, 232, 233, 234, 235, 237, 238).

Procedure

Baseline task. The subjects worked through two sessions each day. In experimental sessions, the subjects were instructed to attend to both the target and the probe. In control sessions, target recall was not required, and the subjects were explicitly instructed to ignore the target. Each session contained 16 types of trials; each trial was classified by posttarget probe position (1–8) and presence versus absence of the probe. Trials were ordered according to a 16 × 16 (trial type × replications) Latin square created independently for each session. An extra, practice block of 16 trials preceded each session. Within each day, experimental and control sessions were randomly ordered.

Prior to each trial, the distractors, probe, and target were randomly selected; selection was subject to the constraint that no stimulus was ever repeated within a trial. Each trial began with the presentation of the probe. The subject then pressed a key to initiate the rest of the trial events. The trial consisted of a warning signal ("+") for 500 msec, followed by a sequence of single letters (55-msec duration, 30.7-msec interstimulus interval). The number of pretarget distractors (8–15) was determined randomly. Eight distractors always followed the target. On half the trials, one of the posttarget distractors was replaced by the probe digit. At the end of each trial in experimental sessions, the subject first recalled the identity of the target by typing a letter and then made a decision regarding the presence/absence of the probe by typing "y" or "n." Trials in control sessions ended only in the query about the probe.

Whole-list mixing. The 2 experienced subjects (S1 and S2) and 3 naive subjects (S3–S5) practiced the baseline task with digits as probes; the 3 naive subjects practiced for an average of 9.7 days (range: 9–11). The final 3 days constitute the baseline. The subjects were then transferred to a mixed distractor task for 3 days, in which some digits appeared as distractors. On each trial of both the control and experimental sessions, eight letters were dropped from the distractor set and were replaced by the eight digits not scheduled to appear as the probe. Thus, as is illustrated in Figure 1C (for a trial from an experimental session), elements of the probe set appeared throughout the list. During the final 3 days (recovery), the subjects were returned to the baseline task, in which only letters appeared as distractors.

Pretarget mixing. Two inexperienced subjects (S6 and S7) practiced the baseline task for 17 and 28 days. Probes were digits for S6, and probes were Greek letters for S7. Two subjects (S1 and S3), who had previously been tested with the whole-list mixing procedure, practiced the baseline task for 3 days; S3 had been retrained with Greek letters as probes in another experiment. Then all 4 subjects were transferred to a mixed distractor task for 3 days. Elements of the probe set (digits or Greek letters, as appropriate for the subject) that were not scheduled to appear as the probe replaced some of the pretarget distractors in both control and experimental sessions. Thus, as is illustrated in Figure 1D for a trial from an experimental session, elements of the probe set appeared only prior to the target. The subjects then practiced for another 3 days on the baseline task, with only letters as distractors (recovery phase).

RESULTS

Two results are of most interest. First, the AB effect was attenuated as a consequence of practice on the baseline task. Second, the AB effect was amplified by mixing probe and distractor sets.

Practice Effects

Figure 2 shows probe detection performance averaged across the 5 subjects who were inexperienced at the start of the research.[2] In experimental sessions, probe detection was conditionalized on correct recall of the target for trials in which the probe was present. During the first 3 days of practice on the baseline task (Figure 2, left panel), performance during control sessions was high, averaging over 90% correct. During experimental sessions, however, when the target identification task was also performed, probe detection accuracy showed a transient deficit. Probe detection accuracy was substantially diminished when the probe occurred within the window of about 100–500 msec after the target. Thus, we replicated the results of Raymond et al. (1992) with digits as probes. We also discovered that extended training attenuated the AB effect. During the last 3 days of practice on the baseline task, after an average of 15.2 days (range: 9–28), all the subjects showed a much smaller difference between control and experimental sessions (Figure 2, right panel).

The reliability of these observations was confirmed by repeated measures analyses of variance (ANOVAs) performed on percentages of correct probe detection re-

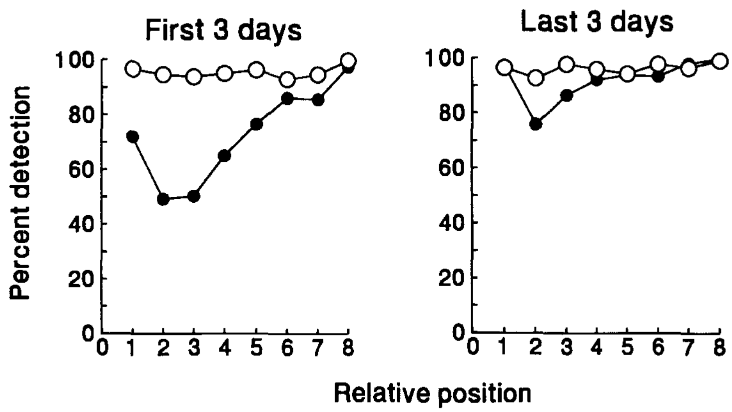

Figure 2. Changes in the attentional blink effect with practice. Percentage of correct probe detection is plotted as a function of position of the probe relative to the target. Data from experimental sessions are plotted with filled circles; data from control sessions are plotted with open circles. For experimental sessions, percentage of detection was conditionalized on correct recall of the target. Data are averaged for 5 subjects (S3–S7) who were inexperienced at the start of the experiment. The left panel displays performance during the first three sessions, and the right panel shows performance during three sessions after an average of 15.2 days of practice.

sponses (hits); the analyses included position (of probe relative to the target), task (experimental vs. control), and practice (first 3 days vs. last 3 days) as factors. All 5 subjects improved with practice [$F(1,4) = 16.19$, $MS_e = 248.13$, $p < .05$]. This practice effect was evident in the experimental sessions [$F(1,4) = 27.83$, $MS_e = 267.40$, $p < .01$], but not in the control sessions ($F < 1$). The AB effect, measured by differences in probe detection rates between control and experimental sessions, varied with probe position, as was indicated by significant task × position interactions during both the first three sessions [$F(7,28) = 8.44$, $MS_e = 79.30$, $p < .001$] and the last three sessions [$F(7,28) = 8.64$, $MS_e = 12.56$, $p < .001$]. Importantly, the AB effect was attenuated with practice; the task × position × practice interaction was reliable [$F(7,28) = 4.88$, $MS_e = 35.28$, $p < .01$].

Distractor-Probe Mixing Effects

Figure 3 shows probe detection performance for the 5 subjects who performed in the whole-list mixing condition (top row) and for the 4 subjects who performed in the pretarget mixing condition (bottom row). Probe detection was again conditionalized on correct recall of targets in experimental sessions. Figure 3 shows that the AB effect, though small, was present in the baseline phases before and after the mixing manipulations. However, the AB effect was enlarged when elements of the probe set appeared as distractors (middle panels in each row). In both mixing conditions, accuracy of probe detection during control sessions was slightly disturbed, but a substantial drop in accuracy was observed during experimental sessions.

The reliability of these observations was confirmed by within-subjects ANOVAs that included position (of probe relative to the target), task (experimental vs. control), and phase (baseline, mixing, baseline recovery) as factors. Because probe detection rates were not significantly different between the baseline and recovery phases, the data from these phases were averaged and used as a baseline against which to evaluate the effects of mixed

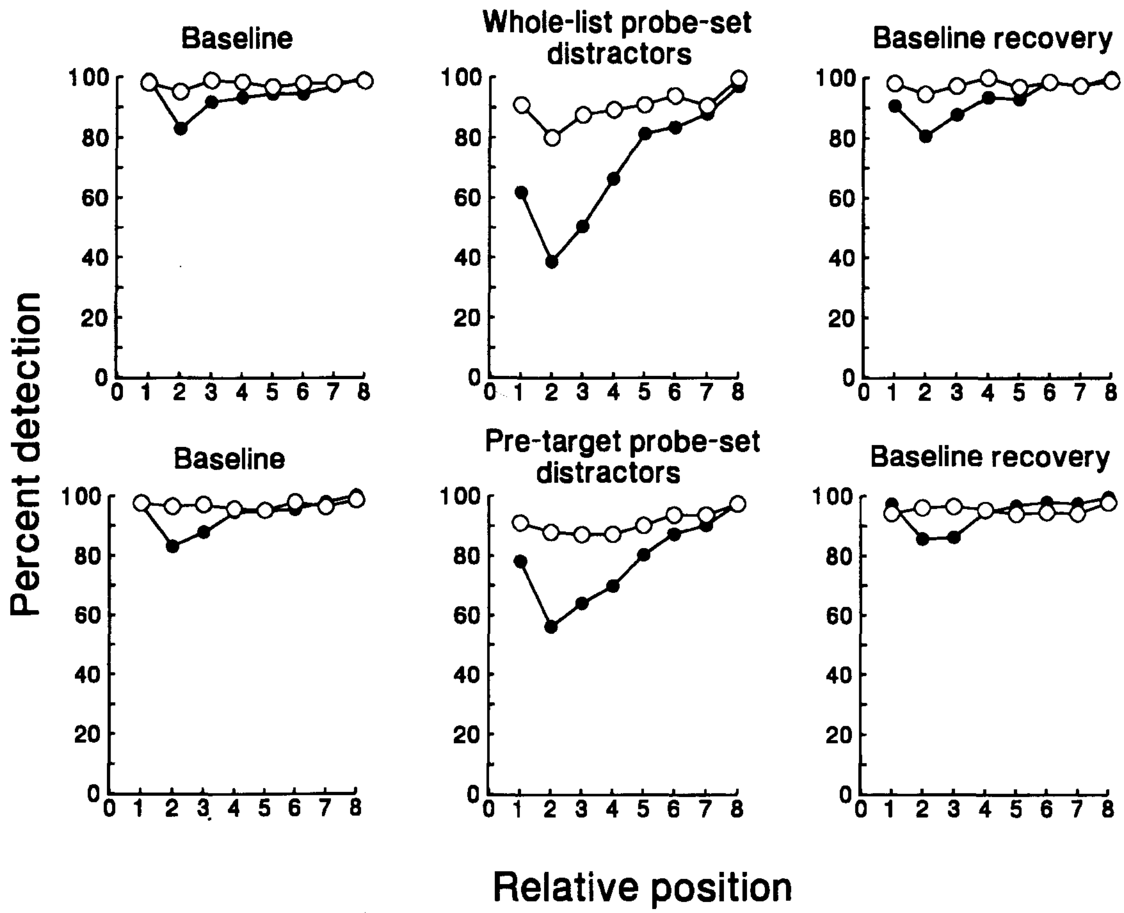

Figure 3. Changes in the attentional blink effect caused by mixing probes with distractors. Data from experimental sessions are plotted with filled circles; data from control sessions are plotted with open circles. For experimental sessions, percentage of detection was conditionalized on correct recall of the target. Data are averaged for 5 subjects who performed in the 3 days of the whole-list mixing condition (top center) and for 4 subjects who performed in the 3 days of the pretarget mixing condition (bottom center). The left column of panels shows the baseline performance during the 3 days immediately prior to the mixing manipulations, and the right column of panels shows the recovery of the baseline performance during the 3 days subsequent to the mixing manipulations.

distractors. Reliable AB effects were noted in the baseline phases surrounding both the whole-list and the pretarget mixing phases, as was evidenced by significant task × position interactions [$F(7,28) = 4.71$, $MS_e = 22.40$, $p < .01$, and $F(7,21) = 3.95$, $MS_e = 16.06$, $p < .01$, respectively]. The AB effects during both whole-list and pretarget mixing phases also were reliable; both task × position interactions were significant [$F(7,28) = 9.49$, $MS_e = 61.98$, $p < .001$, and $F(7,21) = 6.28$, $MS_e = 35.73$, $p < .001$, respectively]. Both three-way interactions were reliable, indicating that the AB effect was significantly larger in the whole-list mixing sessions than during surrounding baseline sessions [$F(7,28) = 7.59$, $MS_e = 21.24$, $p < .001$] and that the AB effect was also significantly larger during the pretarget mixing sessions than during surrounding baseline sessions [$F(7,21) = 2.67$, $MS_e = 13.44$, $p < .05$].

DISCUSSION

The present study resulted in two main findings. First, the set of probe characters was rendered resistant to the AB as a consequence of practice under CM conditions in which probes and distractors were drawn from different symbol sets. Second, when the probe and distractor sets were intermingled, and thus became functionally less distinct, the AB effect was increased. The results are congruent with our original conjecture about probe/distractor discriminability as a modulator of the AB effect. The results are also consistent with our prediction of an attenuated AB effect consequent to CM training. However, restoration of the AB effect by the mixing of probe and distractor sets makes the explanation of the entire pattern of results more complicated. Some alternative explanations are considered below.

Automatic Attention Attraction

We initially suspected that CM training would make the probe stimuli automatic attractors of attention. The effects of CM training shown in Figure 2 are consistent with our prediction. But it is not clear what to make of the reappearance of the AB effect in the mixing condition from the standpoint of present views of the acquisition and expression of automaticity (e.g., Czerwinski et al., 1992; Logan, 1988). If the probes automatically attracted attention, then they should have continued to do so in the mixing conditions, and the AB effect should not have reappeared. This is especially true of the pretarget mixing manipulation in which the stimulus conditions surrounding the probe were the same as those in the baseline conditions. One could appeal to conditioning-like processes and argue that the relatively frequent appearance of members of the probe sets as distractors served to extinguish the automatic attraction "response." However, inspection of the first block of trials during the mixing conditions suggests that the AB effect reappeared almost immediately.[3] Moreover, the AB effect was quickly diminished during the recovery sessions (rightmost panels of Figure 3). In order to accommodate these observations, an explanation couched in terms of automatic attention attraction would need to let such attraction be under strategic control to the extent that the subject could elect to use it or ignore it on the basis of very little experience. The same arguments can be applied to other possible outcomes of CM training, like learned category codes (Czerwinski et al., 1992). Hence, automaticity may be important for the acquired distinctiveness of the probes, but it cannot be the whole story.

Retrieval Competition

Shapiro et al. (1994) have reinterpreted the AB in terms of an interference theory that emphasizes competition among items in visual short-term memory (VSTM): "the target and probe, and to a lesser extent the items immediately succeeding each of these, are competing for subsequent retrieval ... [and] this competition should be less severe when the target and probe are highly dissimilar" (p. 370). This account offers a potential explanation for the whole-list mixing results, if the similarity of the probe and distractors also contributes to competition in VSTM. The members of the probe set that functioned as distractors but that appeared in the temporal vicinity of the probe (Figure 1C) could have interfered with probe detection and thereby could have caused the magnification of the AB effect when probe and distractor sets were mixed. The results of the pretarget mixing manipulation, however, are not consistent with the interference hypothesis. In that procedure, members of the probe set sometimes appeared as distractors, but only prior to the target (Figure 1D). The interference hypothesis specifies the first few items after the target as the source of competition with the probe. Because members of the probe set never appeared after the target, the interference hypothesis incorrectly predicts no interference and thus no AB effect in the pretarget mixing sessions. Thus, although retrieval from VSTM might well be important to performance of visual search tasks, it too cannot be the whole story.

Distractor Suppression

Another interpretation of the present results begins by noting the generality of suppression of irrelevant information in a variety of cognitive and perceptual tasks (e.g., Chelazzi, Miller, Duncan, & Desimone, 1993; Connelly & Hasher, 1993; Gernsbacher & Faust, 1991, Neill, Terry, & Valdes, 1994). The AB might be another form of suppression of distractors. On this account, the AB itself is always triggered in trials of the experimental sessions. The suppression is directed at the current set of distractors and is time limited, perhaps extending as long as the duration of processing of the target. But the AB *effect* is diminished when the probes are removed from the focus of the suppression, either by making the probes and distractors physically dissimilar, or by providing training that allows probes and distractors to become perceptually segregated. The results we obtained with both of the mixing procedures are consistent with the view of the AB as suppression of the set of distractors. Once the probes had been discriminated from the distractors, the probes were no longer similar to the distractors and hence no longer susceptible to the blink. When the probes were explicitly included as members of the distractor set in the mixed conditions, then the probes were again subjected to the post-target suppression. Although this distractor suppression hypothesis provides a mechanism for the AB, it too is an incomplete account of our results in that it does not specify in any detail the processes and outcomes of the learning that occurs during CM training.

In view of the multiple processes underlying visual search tasks (Czerwinski et al., 1992), it should not be surprising that no single theoretical mechanism is capable of handling the full pattern of results presented here. Attempting to construct a coherent account of the AB and how its effects are modulated with training will reveal other important questions for which we do not yet have answers. Are the probes perceptually enhanced by CM training, or are the distractors more efficiently suppressed? Is the current set of distractors defined trial by trial, or is it defined by the subject's expectancies? Research on these matters is underway.

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NOTES

1. To disambiguate the term *attentional blink* (AB) with respect to the phenomenon and its underlying causes, we will refer to the empirical fact—the transient drop in posttarget probe detection—as the "AB effect." We will refer to the theoretical process or mechanisms responsible for that effect as the attentional blink, or AB.

2. False-alarm rates were low, averaging 3.8%, and did not vary systematically with any of the task manipulations (all *ps* > .05). Variations in accuracy of recall of the target letter also were slight. Recall improved steadily across the baseline, whole-list mixing, and recovery phases [94.8%, 95.8%, and 96.6%; $F(2,8) = 5.15$, $MS_e = 8.13$, $p < .05$]. Target recall averaged 94.3% during the pretarget mixing condition and surrounding baseline sessions, and variations across task manipulations were not reliable (*ps* > .05).

3. In each block of 16 trials, only 8 trials contained probes; with so few observations, the average for each subject is not a stable estimate of performance. In order to obtain enough data to estimate the AB effect, we averaged over both mixing conditions and over the first four and last four probe positions. In control sessions, probe detection averaged 92% and 100% during the first and last four positions, respectively. In experimental sessions, the corresponding means were 56% and 81%. Thus, as best as we can determine, the AB effect appeared very early during the mixing manipulations.

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