

Timing attention: Cuing target onset interval attenuates the attentional blink

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Three experiments tested whether the attentional blink (AB; a deficit in reporting the second of two targets when it occurs 200–500 msec after the first) can be attenuated by providing information about the target onset asynchrony (TOA) of the second target relative to the first. Blocking the TOA did not improve second-target performance relative to a condition in which the TOA varied randomly from trial to trial (Experiment 1). In contrast, explicitly cuing the TOA on a trial-by-trial basis attenuated the AB without a cost to first-target identification (Experiments 2 and 3). The results suggest that temporal cues influence the allocation of attentional resources by adding temporal information to the perceptual description of the second target that can then be used to filter targets from nontargets, resulting in enhanced accuracy.

The visual system is remarkably efficient at picking up information from the outside world. For example, it takes only a fraction of a second for one to feel embarrassed when walking into the wrong room. Despite people's seemingly limitless ability to process information and the speed at which the gist of any given scene can be extracted, the ability to report the details of incoming information is severely restricted. Recent studies on a phenomenon called the *attentional blink* (AB; a deficit in reporting the second of two targets presented in rapid serial visual presentation [RSVP] when it occurs 200–500 msec after the first target; e.g., Raymond, Shapiro, & Arnell, 1992) have shown that incoming information can be processed up to the level of semantic analysis, but that there is a bottleneck in transferring the information into working memory and in consolidating it so that it can be consciously used for the control of behavior (e.g., Luck, Vogel, & Shapiro, 1996; Martens, Wolters, & van Raamsdonk, 2002; Rolke, Heil, Streb, & Hennighausen, 2001; Vogel, Luck, & Shapiro, 1998). The question addressed in the three experiments reported here concerns whether strategic information can be used to overcome temporal limitations in consolidating information in working memory.

Since Broadbent and Broadbent (1987; Experiment 3) first demonstrated the relatively long-lasting interference effect resulting from target identification that has come to be known as the AB (Raymond et al., 1992), the AB paradigm has been used to study the costs of divid-

ing attention over time in a variety of task conditions. The detection or identification of visual targets such as letters, digits, words, and pictures (e.g., Shapiro, Arnell, & Raymond, 1997), auditory targets such as tones, syllables, and words (e.g., Potter, Chun, Banks, & Muckenhoupt, 1998), and tactile targets varying in intensity, amplitude, frequency, and location (Hillstrom, Shapiro, & Spence, 2002) have been studied both within and between modalities (Arnell & Jolicœur, 1999; Duncan, Martens, & Ward, 1997; Soto-Faraco et al., 2002). The majority of these studies show a robust AB effect and suggest that attention is subject to resource limitations at a postperceptual stage in processing.

The restrictions in memory and attention as revealed by the AB highlight the importance of efficient selection of items occurring at different points in time. It is well known that spatial or symbolic cues can be used to enhance the selection of relevant information in space, as revealed by improvements in the accuracy and speed of detection or discrimination of stimuli presented at cued locations (e.g., Posner, 1980). Given the dynamic nature of the environment, it seems likely that cuing the time of occurrence of an event could also facilitate selection. Thus, it is plausible that not only information about *where*, but also information about *when* to expect an event may play an important role in directing one's attention to the external world. From the warning signal literature (for a review, see Niemi & Näätänen, 1981), it is known that performance can be improved when a warning signal is presented before an imperative stimulus (see, e.g., Bertelson, 1967; Bertelson & Tisseyre, 1968). Presumably, the warning signal enables participants to achieve a heightened state of preparation (i.e., it increases alertness), resulting in faster reaction times to the forthcoming stimulus. In this so-called *foreperiod effect*, alertness is at its height approximately 150–200 msec after warning signal presentation and then rapidly decays.

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More recently, Nobre and colleagues (e.g., Coull & Nobre, 1998; Nobre, 2001a, 2001b) have suggested that information about the time interval within which a stimulus might be expected to appear can be used dynamically to direct visual attention. For example, in one condition of the Coull and Nobre study, targets were preceded by an informative cue regarding the temporal interval between cue and target (300 or 1,500 msec). A cuing effect was found such that reaction times (RTs) were generally faster when the cue predicted when the target would occur than when no cue or an invalid cue was provided. Although the cuing effect was much more robust for the short cue–target interval, Coull and Nobre argued that the increase in alertness associated with a temporal cue is not necessarily linked to the moment of its presentation, as is suggested by the time course of the foreperiod effect (e.g., Bertelson, 1967), but that deployment of anticipatory resources is at least partially under flexible cognitive control. Such an interpretation suggests that attention can be directed to points in time in an analogous fashion to regions of space. Interestingly, the temporal cuing task of Coull and Nobre engaged activity in frontoparietal networks, which overlapped extensively with brain areas engaged by spatial cuing tasks. However, compared with brain activity during spatial cuing tasks, a different pattern of hemispheric lateralization was found, with temporal cuing being relatively left instead of right lateralized.

The tasks used by Nobre (2001a, 2001b) required speeded motor responses emphasizing response aspects of temporal cuing. What is lacking at present are studies that investigate whether temporal cuing can also be applied when unspeeded responses are required and when identification accuracy of masked targets is measured instead of RT. In other words, it is currently unknown whether the temporal cuing effects for the above-threshold stimuli presented by Nobre and colleagues can also be found for stimuli that are sometimes below threshold. In the present study, the paradigms of temporal cuing and the AB were combined to investigate the extent to which individuals can dynamically direct their attention to specific moments in time, possibly overcoming the restrictions in memory and attention, as reflected by the AB.

EXPERIMENT 1

In the AB paradigm, the time interval or “lag” between two targets is typically varied from trial to trial to measure the time course of interference, and the participant is not informed what the lag of the forthcoming trial will be. In Experiment 1, we contrasted performance in a condition with varying lags with that in a condition in which the lag between the two targets was held constant. A fixed time interval between target stimuli can be considered an implicit temporal cue, enabling participants to predict the moment at which the first target will be followed by the second target. If attention can be oriented toward a particular moment in time, identification accuracy might be enhanced, possibly boosting performance at the difficult short lag, and reducing the AB.

Method

Participants. Thirty-six volunteers (26 females) from the University of Groningen community, ages 14–25 (mean = 20.3), with normal or corrected-to-normal vision, participated in the experiment and received payment of € 5.

Stimuli and Apparatus. The generation of stimuli and the collection of responses were controlled using MEL 2.01 software (Schneider, 1988) running under native DOS on a Pentium III, 1-GHz processor. The participants were tested individually in a dimly lit laboratory room. The stimuli were digits (excluding 1 and 0) and uppercase letters (excluding I, O, Q, and V), subtending $0.3^\circ \times 0.7^\circ$ of visual angle at a viewing distance of approximately 50 cm. The stimuli were presented in black (0.36 cd/m^2) on a gray background (48.2 cd/m^2) on a 15-in. monitor.

Procedure. The participants were instructed to identify two target letters among a stream of digit distractors, presented one after another at the same central location. Prior to each trial, a fixation cross was presented in the middle of the screen, accompanied by a message at the bottom of the screen instructing the participants to press the space bar to initiate the trial. When the space bar was pressed, the message disappeared immediately. The fixation cross remained on the screen for 650 msec. After an additional 100 msec, a sequence of 14 distractor digits and two target letters was presented. Each target and distractor was presented for 90 msec, resulting in a presentation rate of approximately 11 items per second.

Distractor digits were randomly selected with the constraint that no single digit was presented twice in succession within a trial. The two targets were always different letters. The first target (T1) always appeared as the sixth item in the stream. The second target (T2) followed at a target onset asynchrony (TOA) of either 270 or 720 msec, depending on the group to which the participant was assigned. These specific TOAs, also referred to as lag 3 and lag 8, were chosen on the basis of the literature and previous work in our laboratory. At lag 3, in which T2 followed T1 after two digits, T2 is likely to be “blinked” (i.e., not identified), whereas at lag 8, in which T2 followed T1 after seven digits, T2 is expected to be outside the interval within which an AB might occur. The participants were randomly assigned to one of three groups: lag 3, lag 8, or varying. For the lag 3 group, the TOA was always 270 msec. For the lag 8 group, the TOA was always 720 msec. In the varying group, the lag (3 or 8) varied randomly from trial to trial.

Following the presentation of the RSVP sequence, the participants were asked to type the letters they had seen by using the corresponding keys on the computer keyboard. The participants were instructed to take sufficient time in making their responses to ensure that typing errors were not made. If a letter was not seen, the space bar was to be pressed instead.

The experiment consisted of a practice block of 20 trials and an experimental block of 200 trials, with a short break halfway through the block. Ten additional warm-up trials were given at the start of the experimental block and immediately following the break. The experiment was conducted in one session lasting approximately 30 min.

Results and Discussion

The percentage correct for each target was computed for each lag. Responses were counted as correct regardless of the order in which they were made. Because performance in the constant time interval (lag 3 and lag 8 groups) condition was measured between subjects (in order to keep conditions constant for a given participant), whereas performance in the varying time interval condition was measured within subjects, it was not possible to analyze the data with one analysis of variance (ANOVA). Instead, *t* tests were conducted to test for differences between and within the two constant lag groups

and the varying group for each lag. Table 1 shows performance for T1. Independent samples *t* tests showed no significant differences in T1 performance between constant and varying conditions at lag 3 [$t(22) = .01, SE = 3.98, p = .99$] or lag 8 [$t(22) = .83, SE = 4.67, p = .42$]. Comparisons of lag 3 and lag 8 within the constant condition [$t(22) = .20, SE = 4.13, p = .83$] and within the varying condition [$t(11) = 1.97, SE = 1.57, p = .08$] also revealed no significant differences.

Because the AB is defined as a deficit in reporting a second target after a first, T2 identification was investigated only for those trials on which T1 was correctly reported. Table 2 shows performance for T2, given that T1 was reported correctly. *t* tests showed that performance at lag 3 was significantly worse than performance at lag 8, both when compared between the two constant lag groups [$t(22) = 4.33, SE = 8.09, p = .000$] and within the varying group [$t(11) = 12.06, SE = 2.66, p = .000$]. Thus, both the groups with a constant lag as well as the varying lag group showed an AB. In fact, no significant differences at either lag [lag 3, $t(22) = .17, SE = 8.74, p = .87$; lag 8, $t(22) = .89, SE = 4.92, p = .38$] were found between the constant lag groups and the varying lag group.

The results suggest that when the time interval remains constant, the task of identifying the two targets is just as difficult as it is when the interval varies from trial to trial. In principle, a constant time interval gives participants the chance to anticipate and direct their attention to the precise moment when T2 will be presented. If temporal cuing can improve accuracy in a difficult identification task, an implicit temporal cue such as the constant time interval should have led to better performance in our task. As it turned out, regardless of the lag at which the targets were presented, participants simply did not or could not use the temporal constancy to improve performance.

Table 1
Mean Percentage Correct Report of T1 in Experiment 1 in the Constant and Varying Time Interval Conditions, as a Function of Lag

Lag	Interval			
	Constant		Varying	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
3	79.8	2.69	79.8	2.93
8	80.6	3.14	76.8	3.46

Table 2
Mean Percentage Correct Report of T2 (Given Correct Report of T1) in Experiment 1 in the Constant and Varying Time Interval Conditions, as a Function of Lag

Lag	Interval			
	Constant		Varying	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
3	39.8	7.45	38.3	4.56
8	74.8	3.16	70.4	3.77

EXPERIMENT 2

In Experiment 1, we failed to find a beneficial effect on target identification of keeping constant the time interval between two targets. This finding is consistent with the suggestion that restrictions in attention and memory revealed by the AB are more or less hard wired and cannot be overcome by using strategic information. However, it may simply be that participants did not effectively use the information that was provided. In the spatial cuing literature, it has also been shown that participants do not always use cue information when trials of a certain type are blocked. For example, Posner, Snyder, and Davidson (1980) compared the effects of blocked cuing and trial-by-trial cuing in a task in which a target stimulus appearing at one of four possible locations was to be detected. In one condition, a spatial cue was provided at the start of each trial, indicating the most probable target location (79% likely) for that trial. Compared with performance in conditions in which no spatial cue was given and target locations were equally probable, RT decreased significantly. However, no improvement in performance over the uncued condition was found when one location was most likely for a complete block of trials (instead of participants being cued on each trial). That is, no reduction in RT occurred when 79% of the targets were presented in the same location (out of four possible locations) throughout a block of trials, compared with blocks in which the likelihood of a target was equal for each location (25%). Thus, participants seemed not to attend to the expected position when they were not cued to do so on each trial.

Posner et al. (1980) concluded that "Knowledge of where a stimulus will occur produces benefits when it is used actively (cued) but not when it is used to maintain a general set (blocked)" (p. 172). This suggests that knowledge of where to expect a target stimulus must be actively or explicitly maintained in working memory, and the same might be true for temporal information. Participants might simply neglect to use the time interval information that is available to them when the time interval between two targets is held constant within a block of trials. Or, in other words, the task of staying prepared for an entire block of trials may be too taxing. One last possibility is that, in their subjective experience, participants were not fully aware of the constant time interval between the two targets because, of course, the second target was often missed.

Experiment 2 was designed to test whether participants can use foreknowledge about the onset interval between two targets when they are explicitly instructed to do so on each trial. In this experiment, the lag (3 or 8) varied randomly from trial to trial, and participants were informed of the lag of the forthcoming trial on a trial-by-trial basis.

Method

Participants. Twelve new volunteers (8 females) from the University of Groningen community, ages 16–27 (mean = 22.1), with

normal or corrected-to-normal vision, participated in the experiment and received payment of €5. Data from the 12 participants in the varying condition of Experiment 1 were used to form an “uncued” comparison group.

Stimuli and Apparatus. The stimuli and apparatus were the same as in Experiment 1.

Procedure. As in Experiment 1, the participants were instructed to identify two target letters among a stream of distractor digits. The time interval between the two targets (i.e., the TOA) varied from trial to trial and could be either 270 (lag 3) or 720 msec (lag 8). Prior to each trial, a cue was given to indicate the TOA in that trial. The cue was either a single dash (“-”) to indicate a short TOA (lag 3), or a row of three dashes (“---”) indicating a longer TOA (lag 8). The temporal information provided by the cue was always valid. The cue was presented in the middle of the screen and also served as a fixation mark. In addition to the cue, a message was displayed at the bottom of the screen instructing the participants to press the space bar to initiate the trial. When the space bar was pressed, the message disappeared immediately, whereas the cue remained on the screen for 750 msec. After an additional interval of 100 msec, the RSVP stream was presented, as in Experiment 1. The participants were explicitly encouraged to use the cue to prepare for the two targets. The numbers of experimental trials, practice trials, and breaks were the same as in Experiment 1. The experiment was conducted in one session, lasting approximately 40 min.

Results and Discussion

The percentage correct for each target was computed for each lag. Responses were counted as correct regardless of the order in which they were made. Identification accuracy was compared both between lags and with performance of the varying group (hereafter called the *uncued condition*) from Experiment 1. Table 3 shows performance on T1. A repeated measures ANOVA performed on T1 accuracy with lag (3 or 8) as a within-subjects factor and cue (cued or uncued) as a between-subjects factor showed no significant effect of cue or lag [$F(1,22) = .68$, $MS_e = 12.27$, $p = .42$]. However, a significant lag \times cue interaction was found [$F(1,22) = 4.95$, $MS_e = 12.27$, $p =$

Table 3
Mean Percentage Correct Report of T1 in Experiment 2 (Cued) in Comparison With the Varying Time Interval Condition of Experiment 1 (Uncued), as a Function of Lag

Lag	Condition			
	Cued		Uncued	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
3	83.4	3.57	79.8	2.93
8	84.8	2.77	76.8	3.46

Table 4
Mean Percentage Correct Report of T2 (Given Correct Report of T1) in Experiment 2 (Cued) in Comparison With the Varying Time Interval Condition of Experiment 1 (Uncued), as a Function of Lag

Lag	Condition			
	Cued		Uncued	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
3	56.7	6.52	38.3	4.56
8	77.7	4.29	70.4	3.77

.04], such that the difference between cued and uncued conditions was larger at lag 8 than at lag 3.

Performance for T2, given that T1 was reported correctly, is shown in Table 4. A mixed ANOVA with lag (3 or 8) as a within-subjects factor and cue (cued or uncued) as a between-subjects factor showed a significant effect of lag [$F(1,22) = 126.88$, $MS_e = 66.27$, $p = .000$], a marginally significant effect of cue [$F(1,22) = 3.89$, $MS_e = 509.00$, $p = .06$], and a significant lag \times cue interaction [$F(1,22) = 5.58$, $MS_e = 66.27$, $p = .03$]. As can be seen in Table 4, performance was better at lag 8 than at lag 3 for both the cued and the uncued groups, which is consistent with an AB. However, the difference between performance at lag 3 and lag 8 (i.e., the AB effect) was smaller for the cued than for the uncued group. In order to examine any possible learning effects, a mixed ANOVA with block (1 or 2) and lag (3 or 8) as within-subjects factors and cue (cued or uncued) as a between-subjects factor was conducted. This ANOVA showed no main effect of block [$F(1,22) = .53$, $MS_e = 59.11$, $p = .48$], and no interactions of block with other factors. This indicates that there was no significant change in performance in the second half of the experiment relative to the first half, suggesting that participants quickly learned to make use of the temporal cue and continued using it throughout the experiment.

The major finding from this experiment was that temporal cues can be used to attenuate the AB. Thus, participants can use foreknowledge about target onset interval when explicitly cued to do so on a trial-by-trial basis.

EXPERIMENT 3

The results of Experiment 2 provide evidence that people can use a cue regarding the time interval between the targets to improve identification performance. When participants were cued (with a single dash [“-”] or three dashes [“---”] for a short or long interval, respectively) on a trial-by-trial basis as to whether the time interval between the two targets would be short or long, they showed less of an AB than did individuals who received no cue. The aim of Experiment 3 was to replicate this result within subjects and with a cue that more directly conveys temporal information.

Method

Participants. Thirty new student volunteers (23 females) from the University of Groningen, ages 18–31, (mean = 20.3) with normal or corrected-to-normal vision participated in the experiment and received course credit for their participation.

Stimuli and Apparatus. The generation of stimuli and the collection of responses were controlled using E-Prime 1.0 software (Schneider, Eschman, & Zuccolotto, 2002) running under Windows 98 on a PC with a 1.2-GHz processor. The stimuli were digits (excluding 1 and 0) and uppercase consonants (excluding q and v), subtending $2^\circ \times 3^\circ$ of visual angle at a viewing distance of approximately 75 cm. The stimuli were presented in black (1.5 cd/m^2) on a white background (165 cd/m^2) on a 15-in. TFT monitor at a refresh rate of 75 Hz.

Procedure. As in Experiments 1 and 2, the participants were instructed to identify two target letters among a stream of distractor

digits. The time interval between the two targets varied from trial to trial and could be either 270 msec (lag 3) or 720 msec (lag 8). Two conditions were contrasted, one with cuing and one without. In the cued condition, a cue consisting of two briefly presented dashes, with the interval between them matching the interval between the two targets in the forthcoming trial, was presented prior to each trial. In the uncued condition, the task was the same, but no cue was presented. The experiment was conducted in two sessions, which took place at least 2 weeks apart. Half of the participants completed the cued condition in Session 1 and the uncued condition in Session 2; the other half of the participants completed the conditions in the reverse order.

Prior to each trial, a fixation cross was presented in the middle of the screen, accompanied by a message at the bottom of the screen instructing the participants to press the space bar to initiate the trial. In the uncued condition, the message disappeared immediately when the space bar was pressed, the fixation cross remained on the screen for 750 msec, and after an additional 100 msec, the RSVP stream was presented. In the cued condition, both the message and the fixation cross disappeared from the screen when the space bar was pressed. After 200 msec, a single dash was presented twice in succession in the middle of the screen, for 90 msec each time with a TOA of either 270 msec (corresponding to lag 3) or 720 msec (corresponding to lag 8) between the two presentations. After 1,100 msec, the RSVP stream containing the two targets was presented. The participants were explicitly instructed to use the cue to enhance their identification accuracy.

Both the RSVP stream and the rest of the procedure were identical to those of the conditions of Experiments 1 and 2 in which the lag was varied from trial to trial. Each session lasted approximately 45 min.

Results and Discussion

The percentage correct for each target was computed for each lag. The responses were counted as correct regardless of the order in which they were made. Table 5 shows performance for T1.¹ A repeated measures ANOVA performed on T1 accuracy with lag (3 or 8) and cue (cued or uncued) as within-subjects factors showed no significant effect of lag [$F(1,29) = 1.04, MS_e = 7.68, p = .32$]. However, a significant effect of cue was found [$F(1,29) = 6.06, MS_e = 25.07, p = .02$], as was a lag \times cue interaction

[$F(1,29) = 7.51, MS_e = 6.92, p = .01$]. The difference between the cued and the uncued conditions was larger at lag 3 than at lag 8, although all differences were relatively small.

The performance for T2, given that T1 was reported correctly, is shown in Table 6. A repeated measures ANOVA with lag and cue as within-subjects factors showed significant effects of lag [$F(1,29) = 58.36, MS_e = 243.56, p = .000$] and cue [$F(1,29) = 15.11, MS_e = 51.33, p = .001$] and a significant lag \times cue interaction [$F(1,29) = 10.87, MS_e = 29.76, p = .003$]. As can be seen in Table 6, the difference in T2|T1 accuracy at lag 3 versus lag 8 was smaller in the cued than in the uncued condition.

As in Experiment 2, cuing the temporal onset between T1 and T2 reduced the magnitude of the AB. This result allows us to conclude that both symbolic (length of line) and more direct (interval between the first and second presentations of a dash) information about the temporal interval between two targets can help in overcoming the restrictions in working memory and attention revealed by the AB.

GENERAL DISCUSSION

The goal of the present study was to examine whether people can use strategic information to overcome the limitations in attention and memory reflected by the AB. In three experiments, participants were provided with explicit (Experiments 2 and 3) or implicit (Experiment 1) information on when to expect two target letters in an RSVP stream of nontarget digits. In Experiment 1, the accuracy of identifying the targets was found not to depend on whether the time interval (270 or 720 msec) between the two targets varied from trial to trial or was kept constant throughout the experiment.

In contrast, in Experiments 2 and 3, in which the time interval between the two targets varied from trial to trial as in a standard AB paradigm, the AB was attenuated when a cue indicating the temporal separation between the targets in the upcoming trial was given. The results suggest that, despite the strong restrictions in memory and attention that are typically revealed by the AB, some strategic control over the allocation of resources is possible.

The present results show that temporal cues can affect identification accuracy when responses are nonspeeded, extending previous findings from studies on temporal cuing in speeded-response tasks (e.g., Nobre, 2001b). Moreover, the present experiments suggest that temporal cues will only be effective in orienting attention when they are presented on a trial-by-trial basis, which presumably encourages participants to actively maintain the cues in working memory. A similar conclusion was reached by Posner et al. (1980) in the domain of spatial cuing, based on the finding that spatial cues were ineffective when entire blocks, instead of individual trials, were cued.

The finding in Experiment 1 that the AB was equally large in the constant and varying conditions is especially interesting in that it shows that varying the lag from trial

Table 5
Mean Percentage Correct Report of T1 in Experiment 3 in the Cued and Uncued Conditions, as a Function of Lag

Lag	Condition			
	Cued		Uncued	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
3	92.6	1.09	89.0	1.66
8	91.8	1.20	90.9	1.47

Table 6
Mean Percentage Correct Report of T2 (Given Correct Report of T1) in Experiment 3 in the Cued and Uncued Conditions, as a Function of Lag

Lag	Condition			
	Cued		Uncued	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
3	70.8	3.60	62.4	3.69
8	89.3	1.58	87.5	1.88

to trial does not contribute to the AB. In other words, there is no benefit to performance from repeating a given lag from one trial to the next. Repetition effects are commonly found in a range of tasks from speeded-choice reaction tasks (e.g., Pashler & Baylis, 1991) to visual search (e.g., Müller & Found, 1996; Maljkovic & Nakayama, 2000; Olivers & Humphreys, 2003). In the case of an AB task, one might thus expect a benefit of repeating lag even though the particular targets to be identified vary from trial to trial. As mentioned earlier, blocking trial type did not benefit performance. In addition, a comparison of repetition (e.g., a lag 3 trial following a lag 3 trial) and nonrepetition (e.g., a lag 3 trial following a lag 8 trial) trials in the varying condition of Experiment 1 revealed no differences in performance.

The fact that identification performance in Experiment 1 did not depend on whether the lag varied or was kept constant also implies that a single time interval of approximately 300 msec is sufficient to induce an AB. That is, one lag might be sufficient in many AB studies, substantially reducing the number of trials required to investigate the AB in, for instance, patients, elderly people, or children in both behavioral and brain-imaging studies.

Finally, an important finding from Experiments 2 and 3 is that the improved performance for T2 presented at a short interval did not come at a cost to T1. In other words, the temporal cuing effect does not appear to be the outcome of a bias to select T2 over T1 when the two targets occur close together in time.

The Locus of Temporal Cuing Effects

Early accounts of the AB included the idea of an attentional window or gate that is opened when a target is encountered (cf. Raymond et al., 1992) and then shut to exclude distractors. According to such an account, the AB is the result of a sluggish reopening of an attentional gate for the second target. It could be argued that when observers know that the interval between two targets will be short, they adopt a strategy of keeping the attentional gate open to allow processing of both T1 and T2. However, such a strategy would result in the admittance not only of T2 in the same attentional episode as T1, but of the distractors presented between T1 and T2 as well. According to most models of the AB (e.g., Chun & Potter, 1995; Potter, Staub, & O'Connor, 2002; Raymond, Shapiro, & Arnell, 1995; Shapiro, Raymond, & Arnell, 1994), the entry of the additional items should come at a cost to processing of the targets. Because the improvement in identification of the second target did not come at a cost of identifying T1, such an account of the temporal cuing effect does not seem plausible.

One possible explanation of the temporal cuing effect might be that temporal cues enhance the perceptual description of target items—and target templates. That is, information about the expected time of occurrence of a target might function as a perceptual feature or extra attribute of a target, along with other perceptual features such as form, color, and so forth. Temporal cues might

thus be useful in distinguishing relevant from irrelevant information and in selecting targets from nontargets. The interference model of Shapiro et al. (1994; see also Raymond et al., 1995) provides a possible mechanism by which temporal information could influence identification performance. Temporal cues might play a role in the assignment of weights if they provide additional information that can be used to distinguish targets from nontargets. In this view, both targets might receive a high weight, not at the expense of each other but at the expense of the distractors, whose weights will be diminished. As a result, distractors will be less likely to enter visual short term memory, and the competition for selection in VSTM will also be diminished due to larger differences in target versus nontarget weights. When the interval between T1 and T2 is short, a temporal cue might effectively influence the relative weight of T2, such that identification performance for that target can be significantly enhanced. At a long target-onset interval, the relative weight of T2 is already high, such that no additional cuing benefit would be expected. This pattern of behavioral results was observed in the experiments reported here.

Turning back to the temporal cuing work of Nobre and colleagues (Griffin, Miniussi, & Nobre, 2002; Miniussi, Wilding, Coull, & Nobre, 1999; Nobre, 2001b), these authors found that the P3 component of the event-related potential in response to a target had a reduced latency and an enhanced amplitude when the target was temporally cued. Since the P3 component is associated with the updating of working memory, it could be argued that the findings of Nobre and colleagues suggest a late locus of temporal cuing, at a level of processing that corresponds to Stage 2 rather than to Stage 1. However, the enhanced P3 component could merely reflect the consequence of temporal cuing effects that took place at an earlier processing stage, rather than the direct reflection of the cuing effects themselves. In other words, each item presented in the RSVP stream might induce a P3 component that is as large as the relative strength of its weight. This prediction seems to fit well with the finding that the P3 component is reduced or absent when T2 is “blinked” (e.g., Kranczioch, Debener, & Engel, 2003; Rolke et al., 2001; see also Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2005).

Conclusion

We have demonstrated that strategic information can be used to partially overcome the attentional restrictions reflected by the AB. Presumably, temporal cues can influence the allocation of resources by adding temporal information to the perceptual description of a target. This information can be used to filter relevant targets from irrelevant nontargets, resulting in enhanced accuracy in reporting targets. If attention has a limited capacity, the observed benefit for T2, with T1 performance remaining intact, can most easily be explained by assuming that there was a cost to the processing of the distractors. According to the interference theory of Shapiro et al.

(1994), the relative strength of the target weights in comparison with those of the distractors reduces the chance that the distractors enter working memory, leaving more resources available for the consolidation of the targets, thus increasing the chance of successful T2 report.

The fact that participants profited from temporal information only when it was explicitly presented to them on a trial-by-trial basis provides additional support for the view that the temporal cuing effect observed here has a strategic or top-down origin. Active maintenance of temporal cues in working memory might contribute to the description of target templates (see, e.g., Duncan & Humphreys, 1989), which presumably play a crucial role in the selection of targets from nontargets.

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NOTE

1. Report of both T1 and T2 was higher in Experiment 3 than in Experiments 1 and 2, although the display times were nominally the same. Pilot work indicated that this was most likely due to differences in the fonts and monitors used. Note that the basic hallmark of the data (i.e., the AB) was found in all cases.