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Visual Masking During the Attentional Blink: Tests of the Object Substitution Hypothesis

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When 2 masked targets are presented in a rapid sequence, correct identification of the 1st hinders identification of the 2nd. Visual masking of the 2nd target plays a critical role during this 2nd-target deficit, or "attentional blink" (AB). The object substitution hypothesis (B. Giesbrecht & V. Di Lollo, 1998) predicts that late-stage visual processes involved in object substitution mediate masking of the 2nd target during AB, whereby stronger masking should produce a more severe deficit. Six experiments are presented, together testing this hypothesis. Although masking by object substitution was observed, it did not interact with the AB. An alternative hypothesis is proposed stating that mostly early-stage visual processes mediate the masking effects that are critical to the AB.

The visual world is in a continual state of flux, changing over time and space. Despite this constant change, the human observer's typical perceptual experience is one of a constant stream of visual information, with no apparent gaps in awareness, suggesting that all visual information is processed to the same extent. However, there is a large body of literature demonstrating that we are aware only of the stimuli that we are currently attending (e.g., Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992; Rensink, O'Regan, & Clark, 1997). For example, when two objects are presented in rapid succession and each is masked by a backward-pattern mask, attending to the first object interferes with attending to the second object for about 500 ms. This cost of attending to one object is revealed by the reduced likelihood of reporting (i.e., being aware of) the second object. Termed the *attentional blink* (AB; Raymond et al., 1992), this cost of selective attention is, in general terms, considered to reflect the temporal distribution of attention (e.g., Duncan, Ward, & Shapiro, 1994; Ward, Duncan, & Shapiro, 1996). In more specific terms, however, the AB reflects not only the time course of visual attention, but it also reveals the dynamic interplay between attention and early-stage visual processes.

Perhaps the clearest evidence of this interaction between attention and early-stage visual processing comes from recent work demonstrating that visual masking of the second target plays an important role during the AB. For example, Giesbrecht and Di Lollo (1998) systematically manipulated the type of mask used for the second target. In their experiments, the second target was either masked by a backward-pattern (interruption) mask (e.g., a trailing nontarget item, as in typical AB experiments), masked by a simultaneous (integration) mask (e.g., an overlapping digit or noise dots), or not masked at all. Not surprisingly, when the typical backward mask was used, a strong AB was observed. In contrast, however, when the second target was not masked or was masked by integration, no AB was observed (similar results have also been reported by Brehaut, Enns, & Di Lollo, 1999; Jolicœur, 1999). Giesbrecht and Di Lollo argued that while left unattended, the representation of the second target is susceptible to interference from subsequent stimuli, a hypothesis that is consistent with previous accounts of the AB (e.g., Chun & Potter, 1995; Shapiro, Raymond, & Arnell, 1994). Going beyond previous accounts of the AB, however, Giesbrecht and Di Lollo characterized the nature of the interference by proposing that the representation of a backward-pattern mask substituted the representation of the unattended second target in the visual system. Although the proposal that substitution-type mechanisms play a critical role in masking of the second target during the AB has been incorporated into several models of the AB besides the account proposed by Giesbrecht and Di Lollo (see also Brehaut et al., 1999; Shapiro, Arnell, & Raymond, 1997; Vogel, Luck, & Shapiro, 1998), the role of these

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mechanisms in the AB has not been characterized. The aim of the present work is to test explicitly whether object substitution is the mechanism that mediates masking of the unattended target during the AB.

The Object Substitution Hypothesis

Giesbrecht and Di Lollo (1998) proposed that the mechanism mediating masking of the second target during the AB was one of object substitution. Their idea was that during conditions of restricted attentional resources (i.e., during the AB), the representation of the second target is substituted by the representation of the backward mask. In the present work, this proposal will be referred to as the *object substitution hypothesis.* Giesbrecht and Di Lollo borrowed the notion of object substitution from a recent discovery in the visual masking literature (Di Lollo, Bischof, & Dixon, 1993; Di Lollo, Enns, & Rensick, 2000; Enns & Di Lollo, 1997, 2000).

Visual masking refers to the reduction in visibility of one stimulus, called the *target*, by another stimulus, called the *mask*, presented within close spatial and temporal proximity of the target (for a comprehensive review, see Breitmeyer, 1984). A variety of stimuli can degrade the visibility of the target and be effective as masks; the stimuli include flashes of light, noise dots, and complex patterns. Recently, Enns and Di Lollo (1997) demonstrated that four small dots that surround but do not overlap the target can also act as an effective mask. Indeed, under certain conditions, the mask does not merely degrade target visibility, but phenomenologically it "appears to be the new focus of object recognition mechanisms" (Enns & Di Lollo, 1997, p. 138). As a consequence, this new form of masking has come to be known as *object substitution* or *four-dot masking.*

Masking by object substitution is thought to arise from interactions between late-stage cortical areas (e.g., prefrontal cortex) and early-stage visual areas (e.g., primary visual cortex) through reentrant feedback loops (Di Lollo et al., 2000). Thus, just as in other forms of masking, early visual processes play an important role in object substitution, but what makes this new form of masking unique is the influence of late-stage mechanisms via reentrant processing. As a result of this influence of late-stage visual processes in masking, object substitution has several distinctive characteristics. For instance, as implied by the fact that a mere four dots can be effective in producing object substitution, the strength of masking is not dependent on contour proximity or similarity, unlike other forms of masking, such as metacontrast masking (Enns & Di Lollo, 1997). Similarly, the strength of masking is not modulated by adapting luminance; masking is observed under both scotopic (dark-adapted) and photopic (light-adapted) viewing conditions (Di Lollo et al., 2000). In contrast, and perhaps most important, the strength of masking is highly sensitive to the distribution of attention in space, such that if an observer does not have advance knowledge of where the target will appear, strong masking is observed (even at fixation); however, if an observer knows, in advance, where the target will appear and therefore has the opportunity to attend to the target location, masking is attenuated greatly if it is observed at all (Di Lollo et al., 2000; Enns & Di Lollo, 1997).

When considered together, the unique characteristics described above demonstrate that unlike other forms of masking (e.g., metacontrast), late visual processes play a major role in mediating masking by object substitution. Therefore, by proposing the object substitution hypothesis, Giesbrecht and Di Lollo (1998) ascribed a major role for late visual processes in the mediation of masking of the second target during the AB. In support of this view, Giesbrecht and Di Lollo argued that during the AB, conditions are favorable to observing object substitution. Specifically, in masking experiments in which object substitution is observed, attention is distributed over space (e.g., Di Lollo et al., 2000; Enns & Di Lollo, 1997). Similarly in AB experiments, attention is also distributed, but distributed over time (Duncan et al., 1994; Ward et al., 1996). Thus, to the extent that the distribution of attention is similar over space and time, conditions in AB experiments are conducive to object substitution. Moreover, also consistent with the notion of substitution, it appears that the trailing mask in AB experiments becomes the new focus of identification processes, such that a common error during the AB is that of reporting the mask's identity (e.g., Chun, 1997; Isaak, Shapiro, & Martin, 1999). In addition, behavioral and electrophysiological data demonstrating that semantic information survives the AB (i.e., Luck, Vogel, & Shapiro, 1996; Maki, Frigen, & Paulson, 1997; Shapiro, Driver, Ward, & Sorensen, 1997; Vogel et al., 1998) are also consonant with the involvement of late visual processes, in that they suggest that whatever disruption is caused by the mask, it likely occurs after the semantic representation has been extracted. On these lines of converging evidence, Giesbrecht and Di Lollo proposed that the representation of an unattended target is vulnerable to masking by object substitution.

The Present Approach

Although the object substitution hypothesis is plausible, the mechanisms underlying the disruption of second target processing during the AB, substitution or otherwise, have not been clearly defined. As a first step towards addressing this issue, the experiments presented here were designed to define the role of object substitution in masking of the second target during the AB. Characterizing the processes that are disrupted during conditions of restricted attentional capacity, as is the case during the AB, is essential for understanding the interactions between visual perception and attention and how a visually presented object emerges into awareness.

The approach adopted for the present experiments is based on the following premise: If masking by object substitution mediates masking of the second target during the AB, then modulating the strength of four-dot masking should modulate the severity of the AB correspondingly. Or, more precisely, the stronger the masking by object substitution, the more severe the AB. This idea embodies the object substitution hypothesis as first proposed by Giesbrecht and Di Lollo (1998; see also Brehaut et al., 1999) and agrees with how the notion of object substitution has been incorporated into other theories of the AB (e.g., Shapiro, Arnell, & Raymond, 1997; Vogel et al., 1998).

Six experiments are reported here. Experiment 1 was designed to validate our paradigm. Because object substitution is not observed if attention is committed to a target location (Enns & Di Lollo, 1997), all experiments involve a spatial manipulation, such that the location of the second target is unpredictable. However, spatial manipulations of this sort have been demonstrated to impact the temporal character of the AB (e.g., Visser, Bischof, &

Di Lollo, 1999; Visser, Zuvic, Bischof, & Di Lollo, 1999) in a manner consistent with the object substitution hypothesis. As a result, Experiment 1 was designed to establish the time course of the AB in our paradigm where the second target location was unpredictable, but under masking conditions typical in AB experiments (i.e., the second target was always backward masked by a pattern).

The critical tests of the object substitution hypothesis are presented in Experiments 2 through 6. In these experiments, which represent the first direct test of the object substitution hypothesis, the second target was always masked with an object substitution mask (i.e., a four-dot mask). Although the mask stimulus was the same in Experiments 2 through 6, the temporal relationship between the onset of the second target and the mask was changed across experiments. In Experiment 2, the mask was presented after the second target. In other words, the four-dot mask was a backward mask. This experiment provides the most direct link between Experiment 1, other studies of the AB, and the seminal studies of object substitution (i.e., Enns & Di Lollo, 1997). In Experiments 3 through 6, the target and the mask had simultaneous onsets, and the duration of the mask was either the same as the target or persisted beyond that of the target. Changing the paradigm from backward-pattern to simultaneous-onset masking not only allows for comparison to more recent studies of object substitution (i.e., Di Lollo et al., 2000) but also allows for assessment of the relative role of the abrupt onset of the mask in the AB. For example, if an AB was observed when the second target was backward masked by the four dots, we would not know whether the masking effect was generated simply by the onset of the mask or by substitution mechanisms. Using the simultaneous-onset paradigm allows us to rule out the possibility that the onset of the mask alone disrupts processing of the second target (Di Lollo et al., 1993, 2000). Although the modification of the temporal relationship between the target and the mask is justifiable, it necessitates using different metrics to quantify the strength of the object substitution effect. In Experiment 2, in which the target preceded the mask, object substitution was evaluated by comparing conditions in which attention was allocated to the target location with conditions in which attention was not allocated to the target location (i.e., when the second target location was unpredictable; cf. Enns & Di Lollo, 1997). In Experiments 3 through 6, in which the target and mask had simultaneous onsets and the duration of the mask was varied, the object substitution effect was defined as a performance decrement in the condition in which the duration of the mask was longer than that of the target (Di Lollo et al., 1993, 2000).

Despite the change from backward masking to simultaneous masking in Experiments 2 through 6, the approach was the same: If one manipulates variables known to modulate the strength of object substitution, such as spatial uncertainty and display set-size, according to the object substitution hypothesis, the AB should also be modulated. In other words, object substitution and the AB should interact. In contrast to this prediction, when a four-dot mask was used to mask the second target, masking by object substitution was observed, but an AB was not. A summary of these results and the conditions under which they were observed is presented in Table 1. Critically, the finding that object substitution masking does not modulate the AB deficit disconfirms the object substitution hypothesis proposed by Giesbrecht and Di Lollo (1998) and constrains many of the current models of the AB.

Experiment 1

In the experiments reported here, we attempted to match Giesbrecht and Di Lollo's (1998) methods as closely as possible while still being able to fulfill our purpose of testing the object substitution hypothesis. This entailed using a conventional rapid serial visual presentation (RSVP) paradigm, similar to that used in other studies of the AB (e.g., Chun & Potter, 1995; Raymond et al., 1992). In this paradigm, each item was displayed for 32 ms and was followed by the next item after a blank interval of 68 ms. Within the RSVP stream, the two targets were uppercase letters, and the distractors were digits of approximately the same size as the letters (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998). The first target was always presented in the center of the screen, in the same location as the rest of the RSVP stream, and was always masked by the next item in the stream (e.g., Raymond et al., 1992). The second target was also masked by the next item in the stream, but the location of the target and the mask was systematically manipulated (see below). To measure the AB, we had conditions in

Table 1
Summary of Mask Stimuli, Key Manipulations, and Key Results for Each Experiment

Experiment	T2 mask	Key variables[a]	AB	Masking	Masking × AB interaction
1	Digit	T2 location	Yes		
2	4 dots; 100-ms SOA	T2 location	No	Yes	No
3	4 dots; 0-ms SOA	T2 location & mask duration	Yes	Yes	No
4	4 dots; 0-ms SOA	T2 location, T2 display size, & mask duration	No	Yes	No
5	4 dots; 0-ms SOA	T2 location, T2 display size, & mask duration	No	Yes	No
6	4 dots; 0-ms SOA	T2 location, T2 display size, & mask duration	No	Yes	No

Note. T2 = second target; AB = attentional blink; SOA = stimulus onset asynchrony.
[a] Includes only those variables that were changed across the experiments (i.e., does not include the lag from the first target to the second or the presence of a first target). T2 location and T2 display size manipulations were different in each experiment; see the text for a complete description of each manipulation.

which the first target was either present or absent, and the temporal separation between the first and second targets systematically varied among 100, 300, or 700 ms (referred to as Lags 1, 3, or 7, respectively; e.g., Vogel et al., 1998).

The goal of the first experiment was to establish the temporal characteristics of the AB in two conditions: one in which the first and second targets were presented in the same location in the center of the screen (central condition) and one in which the second target was presented in a location different from that of the first target (eccentric condition). Demonstrating the effects of the spatial manipulation prior to testing the object substitution hypothesis is required because spatial manipulations modulate the temporal character of the AB. For example, Visser, Zuvic, et al. (1999) presented the first and second targets either in the same location or in different locations. They found that when the targets were presented in the same location (i.e., the typical case in AB experiments) performance was a U-shaped function across lags. In contrast, when the first and second targets were presented in different locations, performance improved monotonically as lag increased. It is important to note that when these conditions were compared directly, they differed only when the second target was presented immediately after the first (i.e., Lag 1). In this instance, accuracy was higher when the targets were presented in the same location than when they were in different locations. In other words, performance at Lag 1 was "spared" (Potter, Chun, Banks, & Muckenhoupt, 1998). This difference implies that the AB and Lag-1 sparing may be subserved by different mechanisms. In support of this notion, Visser, Bischof, and Di Lollo (1999) demonstrated that across many studies of the AB, the magnitude of Lag-1 sparing is independent of the magnitude of the AB as measured by a performance decrement across the other lags (i.e., after Lag 1). The independence of the AB and Lag-1 sparing indicate that in the present series of experiments, any conclusions drawn about the consequences of restricted attentional capacity during the AB must be measured against performance on Lags 3 and 7.

There were two predictions in Experiment 1. First, an AB would be observed. Second, if the AB and performance at Lag 1 are independent, then the AB across Lags 3 and 7 would be observed regardless of where the second target was presented. Moreover, the only difference between the conditions when the second target was presented centrally compared with when it was presented eccentrically would be in terms of Lag-1 sparing. Note that because Experiments 2 through 6 manipulated spatial uncertainty as a way of modulating masking by object substitution, it was critical that we first confirm the validity of our paradigm by demonstrating that, like Visser, Zuvic, et al. (1999), in our hands, Lag-1 sparing would be sensitive to spatial manipulations whereas the AB at Lags 3 and 7 would not.

Method

Participants. Twenty-four undergraduates (15 female; modal age = 19 years) participated for class credit. Nineteen of the participants were right handed, and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Stimuli. All the stimuli used in this and subsequent experiments were displayed on a Tektronix 608 oscilloscope equipped with P15 phosphor. The viewing distance was 57 cm, set by a headrest. Alphanumeric stimuli subtended approximately 0.8° of visual angle. The distractor items were digits (*0* through *9*), and the target items were letters from the English alphabet. All stimuli had a luminance of 25 cd/m^2, as measured by a Minolta LS-100 luminance meter.[1] The background and surrounding visual field were dark, except for dim illumination of the keyboard.

Procedure. At the beginning of each block, participants were read the instructions appropriate for that block. At the beginning of each trial, a small fixation dot was presented in the center of the screen, indicating where the RSVP items would be presented. Participants initiated each trial by pressing the space bar. After a 500-ms delay, the RSVP stream was presented. Each item was displayed for 32 ms and was separated from the next item by a blank interstimulus interval (ISI) of 68 ms, yielding a presentation rate of 10 items/s. On any given trial, the distractors in the stream were selected randomly with replacement from the set of digits, with the constraint that the selected digit was not one of the two immediately preceding items. The letter targets were selected randomly without replacement from all letters of the English alphabet, excepting *I, O, Q,* and *Z* (these items were omitted because of their visual similarity to *1, 0, 2,* and *7*). The number of distractors preceding the first target was determined randomly on each trial and varied between 7 and 15. The second target and the digit mask were always presented in the same location at the end of the stream. The durations of the second target and the mask were the same as the rest of the RSVP items, as was the ISI between the target and the mask. When the second target and the mask were eccentric, they were displayed so that the center of the letter was offset 1° from the rest of the stream. This ensured that no part of the second target frame (i.e., letter and mask) overlapped with the rest of the stream. In addition, when the second target was presented immediately after the first and was presented in a different spatial location, a digit was presented in the same location as the first target so that it was also masked. A schematic representation of this paradigm is illustrated in Figure 1.

Participants were instructed to type their responses into the keyboard at their leisure. Participants were also instructed to be as accurate as possible but to guess when necessary. In blocks in which both the first and second targets were to be identified, the responses could be entered in any order. After the instructions, participants were given an opportunity to ask questions and then did 15 practice trials to familiarize themselves with the task. After completing the test block of 96 trials, participants were given a rest break and then were given the instructions for the next set of trials.

Design. The experiment consisted of a single 1-hr session. The session was split in half, differing only in the location of the second target and the mask. In one half, the second target and mask were presented in the center of the screen in the same location as the rest of the stream; in the other, the second target and mask were presented together above, below, to the left, or to the right of the rest of the RSVP stream. These conditions will be referred to as the *central* and *eccentric* conditions, respectively. In the eccentric condition, the location of the second target and mask was randomized with the constraint that they were presented an equal number of times (four each) in each of the possible cardinal positions.

Within each second target (T2) location condition, there were two sets of trials, differing only in the number of letters that were present in the stream and that had to be identified. In one set, the first target (T1) was present (present set) and in the other it was absent (absent set). For ease of terminology, we refer to the only target in the absent set as the *second target.* It and the second target in the present set were displayed in corresponding positions within the RSVP streams. That is to say, the

[1] All luminance measurements reported in the present work are based on measurements of a 1.5 cm × 1.5 cm patch of dots (44 dots × 44 dots). Consequently, because of luminance summation over space, the measurements are an overestimate of the actual luminance of the letters. Despite the overestimate, all letters were clearly visible.

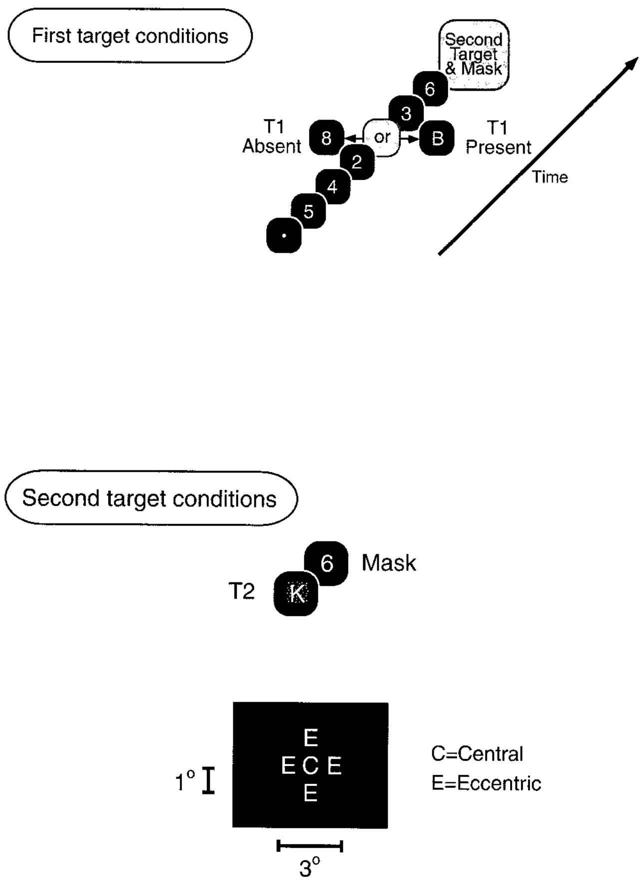

Figure 1. A schematic representation of the display sequences and first (T1) and second target (T2) conditions in Experiment 1. All stimuli were presented sequentially in the center of the screen. The first target was either present or absent, in which case the target letter was replaced with a digit. The second target was always masked by a trailing digit. The second target and the mask were presented either in the same location as the rest of the stream (central) or above, below, to the left, or to the right of the stream (eccentric).

streams in the absent set were the same as those in the present set, except that the first target was replaced by a digit.

The design resulted in four blocks of trials. Within each block of trials, the temporal lag between the first and second targets was varied systematically. The second target was presented either 100, 300, or 700 ms after the first target. These lags will be referred to as *Lag 1, Lag 3,* or *Lag 7,* respectively. In the eccentric condition, when the second letter was presented at Lag 1, a digit was presented in the center of the screen to mask the first target. The second target was presented 32 times at each of the three lags, resulting in four blocks of 96 trials.

Conditions were counterbalanced as follows. Half of the participants received the eccentric condition first and half the central condition first. In each case, half received the present set first and half received the absent set first. This resulted in eight possible orders of first target present or absent (P/A) and second target location (central and eccentric). Three participants were run in each of the eight orders. The order of presentation of the mask duration and T1 to T2 lag conditions was randomized within a block of trials.

Noise dots. Pilot studies using a four-dot mask for the second target but otherwise the same as the paradigm used in Experiments 2 through 4 revealed that although there was evidence of masking, it appeared that the second target task was prone to ceiling effects, in which accuracy was around 90% in all conditions. To prevent the possibility of ceiling effects compromising the results, we lowered second target accuracy by presenting noise dots that overlapped the second target. We used this method to lower second target performance because previous work has suggested that noise dots presented simultaneously with the second target should lower overall performance but should not change the temporal character of the AB (i.e., the masking effect is additive with the AB; Giesbrecht & Di Lollo, 1998). Similar results have also been obtained by varying the stimulus onset asynchrony between the second target and its mask (McLaughlin, Shore, & Klein, 2001), suggesting that data-limiting manipulations (such as adding noise dots) should bring performance off of the ceiling while not affecting the AB.

The number of dots was controlled so that overall accuracy of identification of the second target fell within a 20% range, centered in the middle of the response scale. In this task, ceiling was 100% and chance was 5%; thus the middle of the response scale was approximately 52%. Consequently, the range for accuracy was between 42% and 62%. The noise dots were smaller (0.25 arc min) than the dots of the four-dot mask used in Experiments 2 through 6 and had a luminance of 25 cd/m^2. The dots were placed in random positions within the 0.8° notional frame within which the second target was presented. The number of dots was adjusted after every 24 trials within each experimental block. If accuracy of identification of the second target was below 42%, 10 dots were removed; if accuracy was above 62%, 10 dots were added. This method of titrating the level of second target identification accuracy was used in all experiments. It must be noted that this method will tend to equate experimental blocks for overall level of performance (e.g., first target present and absent blocks as well as central and eccentric blocks in all experiments). As a result, emphasis should be put on the presence of interactions between blocks. Within experimental blocks, both main effects and interactions are relevant. The resulting median number of dots for each experiment and block within the experiments are listed in Appendix A.

Results

Prior to the exposition of the empirical data, several details regarding the analysis must be noted. In this and subsequent experiments, estimates of second target identification accuracy are based on those trials in which the response to the first target was correct (e.g., Giesbrecht & Di Lollo, 1998). In addition, for the sake of comparing the absent and present conditions, notional lags can be devised for the absent condition on the basis of the way in which the RSVP streams were constructed. To wit, the present and absent streams differed in a single detail: In the latter, the first target letter was replaced with a digit. Therefore, notional intertarget lags can be specified for the absent condition in terms of the temporal interval that elapsed from the presentation of the digit that replaced the first target and the presentation of the second target on any given trial. Constructing the streams in this manner controlled for the number of stream items presented before the second target.

As mentioned earlier, because of the apparent independence between Lag-1 performance and the AB, the present analyses are focused on the results from Lags 3 and 7. To justify this approach, however, we designed Experiment 1 to demonstrate the independence of performance at Lag 1 and performance at Lags 3 and 7 using our paradigm. To assess independence, we divided the results into two sections: The first is the analysis of second target identification accuracy including Lags 3 and 7 only; the second is the analysis of second target identification accuracy including all lag conditions. Within each of the sections, the results for the central and eccentric conditions are analyzed separately, comparing first target present and absent conditions. Then the present sets of the central and eccentric conditions are compared directly. In the context of this experiment, if the AB is independent of Lag 1 performance, then an AB should be observed both when Lags 1 and 3 and Lags 3 and 7 are included.

Lags 3 and 7. In the central condition, mean percentage of correct identifications of the first target collapsed across lags was 88.7. Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 2A. There were two main results. First, overall accuracy of identification of the second target was higher in the absent condition than in the present condition. Second, there was a clear interaction between first target P/A and lag. In the absent condition, performance did not change as a function of lag (across lags, $M = 54\%$). In the present condition, however, accuracy changed as function of lag; accuracy was near 34.8% at Lag 3 but was near 56.4% at Lag 7.

The results in Figure 2A were analyzed in a 2 (first target P/A) $\times$ 2 (Lag 3 or 7) repeated measures analysis of variance (ANOVA). Both the main effect of P/A and lag were highly significant: first target P/A, $F(1, 23) = 15.12$, $p < .05$, $MSE = 110.76$; lag, $F(1, 23) = 28.58$, $p < .05$, $MSE = 94.64$. The P/A $\times$ Lag interaction was also significant, $F(1, 23) = 28.23$, $p < .05$, $MSE = 103.01$.

In the eccentric condition, mean percentage of correct identifications of the first target collapsed across lags was 89.3. Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 2B. Unlike the results of the central condition, there was no overall difference between accuracy in the present and absent conditions (45.0% and 46.9%, respectively). However, there was the clear interaction between first target P/A and lag. In the absent condition, performance did not change as a function of lag (across lags, $M = 46.8\%$). In the present condition, however, accuracy was lowest at Lag 3 (37.5%) and was highest at Lag 7 (52.5%).

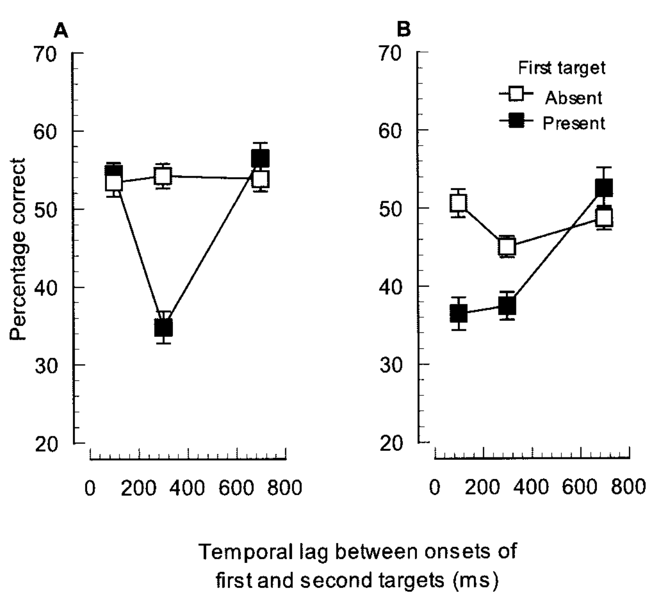

Figure 2. Experiment 1. A: Results of the second target central condition. B: Results of the second target eccentric condition. Scores in the present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the absent conditions are mean percentages of correct responses. Notional lags for the absent condition in this and subsequent experiments were devised on the basis of the way in which the rapid serial visual presentation streams were constructed (see text). Error bars represent standard errors, calculated using the procedure suggested by Loftus and Masson (1994) for repeated measures designs.

The results in Figure 2B were analyzed in a 2 (first target P/A) $\times$ 2 (Lag 3 or 7) repeated measures ANOVA. The main effect of first target P/A was not significant ($F < 1$). However, the main effect of lag was statistically significant, $F(1, 23) = 23.44$, $p < .05$, $MSE = 89.39$; as was the P/A $\times$ Lag interaction, $F(1, 23) = 7.31$, $p < .05$, $MSE = 106.44$.

Visual inspection of the present conditions (Figure 2, filled symbols) suggests that there was no difference in overall level of performance nor in the lag effect in the two conditions.

The central and eccentric conditions were compared directly in a 2 (central or eccentric location) $\times$ 2 (Lag 3 or 7) repeated measures ANOVA. There was a significant main effect of lag, $F(1, 23) = 54.63$, $p < .05$, $MSE = 147.62$. However, the main effect of location was not significant ($F < 1$). Similarly, the Location $\times$ Lag interaction was not significant, $F(1, 23) = 2.27$, $p > .14$, $MSE = 114.25$.

All lags. In the central condition, mean percentage of correct identifications of the first target collapsed across lags was 87.9. The results were reanalyzed including all lags, in a 2 (first target P/A) $\times$ 3 (Lag 1, 3, or 7) repeated measures ANOVA. As with the initial analysis, both the main effect of P/A and lag were statistically significant: first target P/A, $F(1, 23) = 14.90$, $p < .05$, $MSE = 65.57$; lag, $F(2, 46) = 19.18$, $p < .05$, $MSE = 84.77$. Similarly, the P/A $\times$ Lag interaction was also significant, $F(2, 46) = 15.09$, $p < .05$, $MSE = 119.95$.

In the eccentric condition, mean percentage of correct identifications of the first target collapsed across lags was 87.8. The results in Figure 2B were reanalyzed in a 2 (first target P/A) $\times$ 3 (Lag 1, 3, or 7) repeated measures ANOVA. With one exception, the reanalysis of the data paralleled the analysis that included Lags 3 and 7. The exception was that including Lag 1 in the analysis resulted in a significant effect of first target P/A, $F(1, 23) = 9.51$, $p < .05$, $MSE = 135.51$. As before, there was a significant effect of lag, $F(2, 46) = 9.94$, $p < .05$, $MSE = 114.41$; and a significant P/A $\times$ Lag interaction, $F(2, 46) = 10.33$, $p < .05$, $MSE = 96.09$.

When all lags were considered, the graphical evidence shown in Figures 2A and 2B reveals an interaction between the two present conditions (filled squares). Namely, in the central condition, second target accuracy changes nonmonotonically as a function of lag, whereas in the eccentric condition, accuracy changes monotonically as a function of lag. These data were analyzed in a 2 (central or eccentric location) $\times$ 3 (Lag 1, 3, or 7) repeated measures ANOVA. As with the initial analysis, there was a significant effect of lag, $F(2, 46) = 32.69$, $p < .05$, $MSE = 123.37$. However, unlike the analysis that included Lags 3 and 7, the reanalysis revealed a significant main effect of location, $F(1, 23) = 16.94$, $p < .05$, $MSE = 87.47$; and a significant Location $\times$ Lag interaction, $F(2, 46) = 10.17$, $p < .05$, $MSE = 131.31$.

Discussion

There were two notable results of this experiment. First, regardless of the location of the second target relative to the first, an AB was observed. Second, the only difference between the central and eccentric conditions was the magnitude of Lag-1 sparing. In the central condition, the mean percentage of correct responses at Lag 1 was more than 20% better than at Lag 3. In the eccentric condition, on the other hand, the mean percentage of correct responses at Lag 1 was a mere 2% lower than at Lag 3 (not significant). Otherwise, the two performance functions were virtually identical.

The first result serves the purpose of establishing what the AB should look like when the mask is changed to an object substitution mask. The second result replicates the results of Visser, Zuvic, et al. (1999). This replication supports the notion that the mechanisms that mediate the AB and the mechanisms that mediate Lag-1 sparing are independent (Visser, Bischof, & Di Lollo, 1999). More importantly for the present results, this replication justifies basing conclusions about the AB and object substitution only on Lags 3 and 7. Consequently, although all the subsequent experiments contained Lags 1, 3, and 7, we present only the results from Lags 3 and 7 in the text and figures (see Appendix B for a description and analyses of the results including all lags). It must be noted, however, that although the discussion of the experiments is focused on the results from Lags 3 and 7, the conclusions are not contingent on this approach. This is an important point that will be addressed in the General Discussion.

Experiment 2

To briefly review, we reiterate that Enns and Di Lollo (1997) demonstrated that the perceptibility of a target was severely degraded when that stimulus was backward masked by four dots. These authors argued that the mechanism underlying the masking effect was one of object substitution. This form of masking was distinguished from early masking effects, in part, because it was sensitive to attentional manipulations but not contour manipulations (i.e., amount of contour and contour proximity). Giesbrecht and Di Lollo (1998) argued that the form of masking described by Enns and Di Lollo (1997) and the masking observed during the AB were subserved by the same mechanisms (see also Shapiro, Arnell, & Raymond, 1997; Vogel et al., 1998). However, these arguments were based on experiments in which the second target was masked by a trailing digit, such as that used in Experiment 1.

Experiment 2 provides the first test of the object substitution hypothesis through the use of a four-dot stimulus to backward mask the second target. The stimulus onset asynchrony (SOA) between the second target and the mask was the same as that between successive RSVP items: 100 ms. To modulate the strength of object substitution, we varied the location of the second target, as in Experiment 1. Namely, in different blocks of trials, the second target and the mask were always presented in the same location as the rest of the stream (i.e., centrally) or they were presented at one of four locations just above, below, to the left, or to the right of the rest of the stream (i.e., eccentrically). Otherwise, Experiment 2 was exactly the same as Experiment 1. Thus, this study allowed for evaluation of the AB, masking by object substitution, and their interaction.

Method

Participants. Twenty-four undergraduate and graduate students (15 female; modal age = 25 years) participated in this study and were paid $8. Twenty of the participants were right handed, and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Stimuli. The timing of the targets and the distractors was exactly the same as in Experiment 1. The four-dot mask consisted of four small square patches (each 0.2° square). The dots were centered on the corners of a notional square (1° side). This notional square was centered on the same location on which the other RSVP stimuli were presented. This arrangement matched that of Enns and Di Lollo (1997) and ensured the contours of the dots did not overlap with the contours of any other stimuli.

Procedure. The procedure was the same as Experiment 1 with the exception that the second target was masked by a four-dot mask instead of a digit.

Design. The design of this experiment was exactly the same as in Experiment 1.

Results

As with the results of Experiment 1, the results of this experiment are analyzed separately for each location condition, and then the first target present conditions are compared directly to test for the interaction between object substitution masking and the AB.

Central. Mean percentage of correct identifications of the first target collapsed across lags was 91.7. Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 3A. There were two main results. First, overall accuracy of identification of the second target was slightly higher in the absent condition (56.2%) than in the

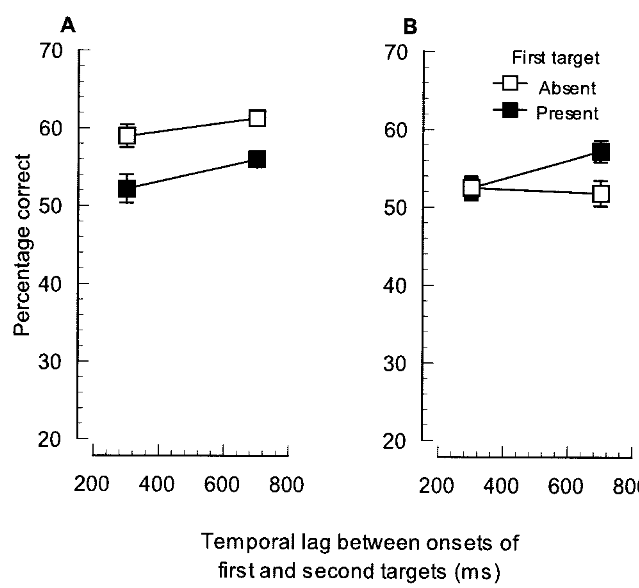

Figure 3. Experiment 2. A: Results of the second target central condition. B: Results of the second target eccentric condition. Scores in the present conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the absent conditions are mean percentages of correct responses. Error bars represent standard errors, calculated using the procedure suggested by Loftus and Masson (1994) for repeated measures designs.

present condition (54.5%). Second, there was no interaction between first target P/A and lag: In both the present and absent conditions, there was a very slight improvement in accuracy from Lags 3 to 7.

The results in Figure 3A were analyzed in a 2 (first target P/A) $\times$ 2 (Lag 3 or 7) repeated measures ANOVA. Only the main effect of P/A was significant, $F(1, 23) = 13.19$, $p < .05$, $MSE = 66.59$. The main effect of lag was not significant, $F(1, 23) = 3.25$, $p > .08$, $MSE = 70.99$; nor was the P/A $\times$ Lag interaction, $F < 1$.

Eccentric. Mean percentage of correct identifications of the first target collapsed across lags was 92.8. Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 3B. There were two main results. First, accuracy of identification of the second target did not depend on whether the first target was present or absent (present = 54.8%; absent = 52.2%). Second, there was no interaction between first target P/A and lag.

The results in Figure 3B were analyzed in a 2 (first target P/A) $\times$ 2 (Lag 3 or 7) repeated measures ANOVA. None of the effects proved to be statistically reliable: first target P/A, $F(1, 23) = 1.68$, $p > .21$, $MSE = 103.32$; lag, $F(1, 23) = 1.56$, $p > .22$, $MSE = 65.9$; P/A $\times$ Lag interaction, $F(1, 23) = 2.05$, $p > .16$, $MSE = 86.76$.

Central and eccentric combined. When the present–central and present–eccentric conditions (filled symbols in Figures 3A and 3B) are compared, there are three notable results. First, overall accuracy was the same in the two location conditions (central = 54.1%; eccentric = 54.8%). Second, in both conditions there was an effect of lag, with accuracy slightly lower at Lag 3 than at Lag 7 (52.3% and 56.6%, respectively). Finally, the lag effect was very similar in both location conditions.

These data were analyzed in a 2 (central or eccentric location) $\times$ 2 (Lag 3 or 7) repeated measures ANOVA. As suggested by the descriptive analysis, the only statistically significant effect was that of lag, $F(1, 23) = 6.13$, $p < .05$, $MSE = 73.19$. Both the effect of second target location and the Location $\times$ Lag interaction had Fs < 1.

Discussion

The rationale for this experiment was simple: replicate Experiment 1 using a four-dot mask. The object substitution hypothesis predicts that an AB should have been observed. However, in contrast to the prediction, no reliable AB was observed. This was true whether the second target was presented centrally or eccentrically. The lack of an AB when using a four-dot mask is underscored when one compares the results of the present experiment with those of Experiment 1, in which a digit mask was used. Clearly, when the second target was masked by a digit mask, identification accuracy changed dramatically as a function of lag (Figure 2, filled squares), whereas when a four-dot mask was used in what was otherwise exactly the same paradigm, little interference was observed (Figure 3, filled squares). Thus, these results suggest that object substitution may not be crucial to the AB.

But did object substitution occur in the present study? It did indeed. Evidence for the presence of object substitution masking is revealed by a lower mean second target accuracy in the eccentric condition compared with the central condition. And yet, although performance was reliably lower when the second target was eccentric than when it was central, the magnitude of the difference was less than 10%. In other words, although there is evidence of object substitution, one might argue that the effect was relatively small. Experiments 3 and 4 were designed to increase the strength of the four-dot object substitution effect.

Experiment 3

The goal of Experiment 3 was to increase the object substitution effect. To strengthen the effect, we presented the four-dot mask simultaneously with the second target, with the duration of the mask persisting beyond the duration of the target. Earlier we stated that in the instance of simultaneous onsets, the masking effect is marked by decreased performance as the duration of the mask is increased (Di Lollo et al., 1993, 2000). The change to using the simultaneous onset paradigm has the added benefit of being able to evaluate the object substitution effect by comparison of conditions that are presented within the same block, rather than across blocks as in Experiment 2, thereby controlling more tightly for attentional state.

In all other respects, Experiment 3 was the same as Experiment 2: The second target and mask were presented either centrally or eccentrically, and the first target was either present or absent. The only difference was that in Experiment 3, the second target and mask had simultaneous onsets with the duration of the mask being either the same duration as the target (32 ms) or lasting for 600 ms. Comparison of the duration conditions tests whether object substitution occurred (i.e., a deficit in the 600-ms condition compared with the 32-ms condition). The prediction was the same as in Experiment 2: To the extent that object substitution mechanisms mediate masking of the second target, an AB should be observed and should be most severe in conditions in which object substitution is the strongest (i.e., in the 600-ms duration condition).

Method

Participants. Twenty-four undergraduates (22 female; modal age = 19 years) participated for class credit. Nineteen of the participants were right handed, and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure. The procedure for Experiment 3 was the same as Experiment 2 with the exceptions that (a) the target and mask were always presented simultaneously and (b) the duration of the mask was systematically varied so that within each block the duration of the four-dot mask was either 32 ms or 600 ms. Counterbalancing was carried out as in Experiment 2.

Participants did 15 practice trials at the beginning of each of the four blocks of trials. Each test block consisted of 16 trials in each lag and mask duration condition, resulting in four blocks of 96 trials.

Results

Central. Mean percentages of correct identifications of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 89.6; 600-ms duration = 91.8. Mean percentage of correct identifications of the second target collapsed across all conditions (shown in Figure 4A) was 58.2. Overall, there appeared to be no difference between the present and absent conditions (filled vs. open symbols, respectively) nor was there a difference between Lags 3 and

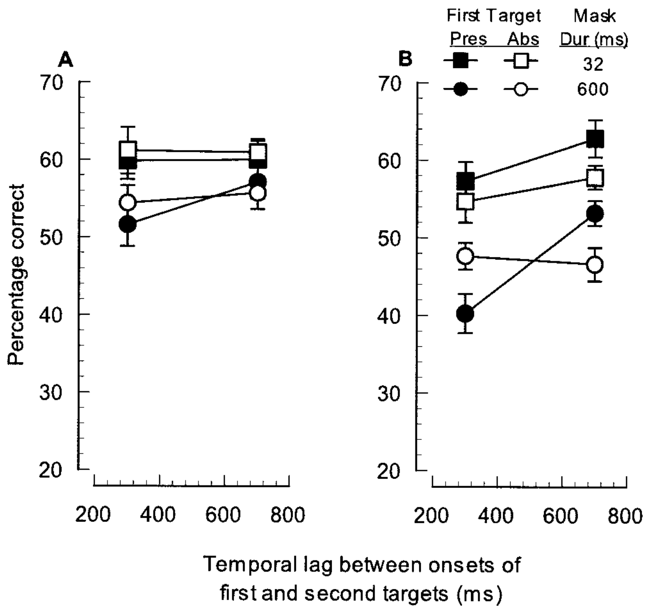

Figure 4. Experiment 3. A: Results of the second target central condition. B: Results of the second target eccentric condition. Scores in the present (Pres) conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the absent (Abs) conditions are mean percentages of correct responses. Error bars represent standard errors, calculated using the procedure suggested by Loftus and Masson (1994) for repeated measures designs. Dur = duration.

7. Mask duration had an effect on performance such that overall, accuracy was lower in the 600-ms condition (54.7%) than in the 32-ms condition (60.5%). This difference did not appear to change as a function of lag, nor as a function of first target P/A.

The results in Figure 4A were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms mask duration) × 2 (Lag 3 or 7) repeated measures ANOVA. The only statistically significant effect was the main effect of duration, $F(1, 23) = 10.25$, $p < .05$, $MSE = 156.12$. All other main effects and interactions were not significant (all Fs < 1.07, ps $> .05$).

Eccentric. Mean percentages of correct identifications of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 93.8; 600-ms duration = 93.9. Mean percentage of correct identifications of the second target collapsed across all conditions (shown in Figure 4B) was 50.1. Overall accuracy was better in the absent than in the present condition (53.3% vs. 48.9%), but this advantage for the absent condition appeared only at Lag 1. Mask duration had an effect on performance, such that in both the present and absent conditions, accuracy was lower in the 600-ms condition (46.9%) than in the 32-ms condition (58.2%). Within the present or absent conditions, the effect of duration did not change as a function of lag.

The results in Figure 4B were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms mask duration) × 2 (Lag 3 or 7) repeated measures ANOVA. As with the analysis of the central condition, the main effect of duration was significant, $F(1, 23) = 41.69$, $p < .05$, $MSE = 145.08$. In addition, there was also a main effect of lag, $F(1, 23) = 11.35$, $p < .05$, $MSE = 111.31$; and a significant P/A × Lag interaction, $F(1, 23) = 6.49$, $p < .05$, $MSE = 123.56$. The remaining effects were not statistically significant: first target P/A, $F < 1$; P/A × Duration, $F(1, 23) = 1.62$, $p > .21$, $MSE = 131.72$; Duration × Lag, $F < 1$; P/A × Duration × Lag, $F(1, 23) = 3.53$, $p > .07$, $MSE = 114.24$.

Central and eccentric combined. When the present–central and present–eccentric conditions (filled symbols in Figures 4A and 4B, respectively) were compared, there were two notable results. First, overall accuracy was roughly similar in the two location conditions (central = 57.2%; eccentric = 53.4%). Second, in both conditions there was an effect of mask duration, with lower accuracy in the long-duration mask condition, but the masking effect was larger in the eccentric condition.

These data were analyzed in a 2 (central or eccentric location) × 2 (32-ms or 600-ms duration) × 2 (Lag 3 or 7) repeated measures ANOVA. There was a significant main effect of duration, $F(1, 23) = 22.77$, $p < .05$, $MSE = 188.17$; and of lag, $F(1, 23) = 10.26$, $p < .05$, $MSE = 169.79$; but, as is suggested by visual inspection of the data shown in Figure 4, there was not a significant main effect of location, $F(1, 23) = 2.48$, $p > .13$, $MSE = 274.38$. In addition, there were two interactions that were significant: Location × Duration, $F(1, 23) = 5.92$, $p < .05$, $MSE = 122.59$; Location × Lag, $F(1, 23) = 4.78$, $p < .05$, $MSE = 102.57$. Finally, the Duration × Lag interaction was not significant, $F(1, 23) = 3.60$, $p > .07$, $MSE = 13.24$; nor was the 3-way Location × Duration × Lag interaction, $F < 1$.

Discussion

There were two notable results emerging from Experiment 3. First, in the central condition, there was an effect of mask duration, but no difference between the first target present and absent conditions. Second, in the eccentric condition, there was also an effect of mask duration; in addition, although there was no overall difference between the present and absent conditions, the effect of temporal lag differed in the two conditions. These results are germane to the present purpose and deserve further consideration.

The object substitution hypothesis states that while attention is devoted to the first target, the representation of the second target remains vulnerable to object substitution by a temporally trailing, spatially superimposed stimulus. The central condition provides the most direct test of this hypothesis because the second target and mask were presented in the same location as the rest of the RSVP stream. There was an effect of mask duration, despite the target location being known in advance. However, second target performance did not change as a function of lag or attentional load (i.e., first target P/A). In other words, masking by object substitution was observed, but there was no AB. Thus, it appears that the object substitution account of the AB is disconfirmed. However, as with the results of Experiment 2, the strength of masking was relatively small (< 10%), perhaps too small to produce the AB.

In contrast to the small effect of mask duration in the central condition, there was a large effect of mask duration in the eccentric condition. In addition, there was also an effect of lag. This was most apparent in the 600-ms duration condition (see Figure 4, circles), whereas in the 32-ms condition there was no difference between the effect of lag in the present and absent conditions. On the basis of these results, it is clear that object substitution was observed, thereby replicating the results of Di Lollo et al. (2000).

There also appears to be an AB, especially when considering the 600-ms condition, as evidenced by the significant P/A × Lag interaction, thereby providing support for the object substitution hypothesis. However, if the object substitution hypothesis were true, then the AB should be more severe when there is strong masking; in other words, there should also be an interaction between the AB and mask duration (i.e., a P/A × Lag × Mask Duration interaction). In contrast with this prediction, there was no interaction between the AB and mask duration. Thus, there is weak evidence that when strong object substitution masking is observed, an AB is observed. Crucially, the support for the object substitution hypothesis is equivocal because of the additivity of mask duration with the AB. So the results of Experiment 3 are, at best, suggestive of support for the object substitution account of masking during the AB.

Experiment 4

Thus far, there has been strong evidence of a robust object substitution effect but weak evidence of an AB (the eccentric condition of Experiment 3 was the exception, but the object substitution effect did not interact with lag). However, one might still wish to argue that the object substitution effect was not as pronounced as it could be. Enns and Di Lollo (1997) demonstrated that masking by object substitution is observed only when attention is distributed over space. In Experiment 3, this was achieved by presenting the second target and mask together in random positions on the screen (i.e., eccentric condition). However, when the combined stimulus of the target and the mask was presented, it was the only abrupt onset in the visual field. It has been well demonstrated that onsets of this sort may automatically capture spatial attention (Jonides & Yantis, 1988; Yantis & Jonides, 1990). Thus, it is possible that on a proportion of trials, presenting the second target alone in the periphery may have automatically captured attention, thereby attenuating the overall object substitution effect. If attention was automatically captured by the second target on some trials, the resulting attenuation of the masking effect may have reduced the likelihood of observing the predicted interaction between object substitution and the AB.

One approach to preventing the automatic capture of attention by an abrupt onset is to present distracting stimuli simultaneously with the target stimulus. With simultaneous presentation of a target with distractors, there is nothing unique to the target–mask onset, and therefore attention cannot be drawn to it alone. This way, attention is distributed over space. Moreover, increasing the number of stimuli presented on the screen with the target amounts to a set-size manipulation, typically used to increase attentional demand in visual search experiments (e.g., Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, 1994). Thus, adding distractors both eliminates the possibility that the target–mask will attract attention as a single abrupt onset, and it also increases the distribution of attention by increasing display set size. Moreover, in their original report of the four-dot masking effect, Enns and Di Lollo (1997) reported larger masking effects when the set size was increased from one to three (for the effects of larger changes in set size, see Di Lollo et al., 2000). Thus, this manipulation should increase the attentional demand of the task and, within the present context, increase the strength of masking by object substitution (Di Lollo et al., 2000; Enns & Di Lollo, 1997).

Experiment 4 is an exact replication of Experiment 3 with one exception: When the second target and mask were presented, eight digits were also presented. The display of the second target and distractors was arranged in an imaginary 3 × 3 grid (i.e., no grid lines were visible). The RSVP stream was presented in the center position of the grid. In the central condition, the second target and mask were also presented in the center location, and digits filled the remaining eight grid locations. In the eccentric condition, the second target and mask were presented in the grid locations that were above, below, to the left, or to the right of the center location, and digits filled the other eight locations. A schematic representation of the second target display is shown in Figure 5. Otherwise the design of the experiment was exactly the same as in Experiment 3. To the extent that increasing the set size of the second target display increases the distribution of spatial attention, the expectation was that masking by object substitution would be observed, and consequently an AB would also be observed.

Method

Participants. Twenty-four undergraduates (21 female; modal age = 19 years) participated for class credit. All of the participants were right handed, and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure. The procedure used in Experiment 4 was the same as that in Experiment 3, in which the second target and the mask were presented either centrally or eccentrically. The only difference was that in Experiment 4, when the second target and the mask were presented, eight digits were also presented. The digits were selected randomly with replacement from the digits from *0* through *9.* The second target, the mask, and the eight digits were presented in a 3 × 3 grid centered on the screen, such that the center position of the grid was in the same location as the rest of the RSVP stream. The distance between the center of the middle location and the center of the cardinal positions was 1°. The second target display was approximately 3° × 3° in size. The display configuration is shown in Figure 5.

Design. The design of this experiment was exactly the same as that of Experiment 3.

Results

Central. Mean percentages of correct identifications of the first target collapsed across lags separately for the two mask

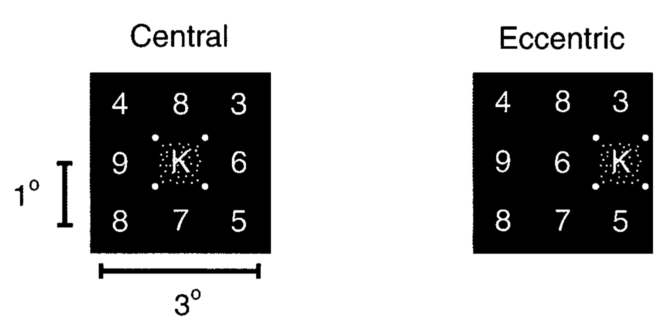

Figure 5. Schematic representation of the second target displays in Experiment 4. The displays consisted of a 3 × 3 matrix of stimuli (eight digits and one letter; i.e., the second target). The second target and the mask either were presented in the same location as the rest of the stream (central condition) or were presented above, below, to the left, or to the right of the stream (eccentric condition).

duration conditions were as follows: 32-ms duration = 92.2; 600-ms duration = 93.4. Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 6A. As in Experiment 2, there appeared to be no difference between the present and absent conditions (filled vs. open symbols, respectively), nor was there a difference between Lags 3 and 7. Mask duration had an effect on performance such that overall, accuracy was lower in the 600-ms condition (57.8%) than in the 32-ms condition (64.4%). The difference between the duration conditions was larger at Lag 3 (10.6%) than at Lag 7 (2.5%).

The results in Figure 6A were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms mask duration) × 2 (Lag 3 or 7) repeated measures ANOVA. There were two statistically significant effects: duration, $F(1, 23) = 13.83$, $p < .05$, $MSE = 149.19$; and Duration × Lag, $F(1, 23) = 4.81$, $p < .05$, $MSE = 162.55$. All other main effects and interactions were not significant (all Fs < 1).

Eccentric. Mean percentages of correct identifications of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 92.4; 600-ms duration = 92.8. Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 6B. As in the central condition, there was no difference between present and absent conditions. Mask duration had an effect on performance, such that in both the present and absent conditions, accuracy was lower in the 600-ms condition (44.0%) than in the 32-ms condition (56.6%). Within the present or absent conditions, the effect of duration did not change as a function of lag.

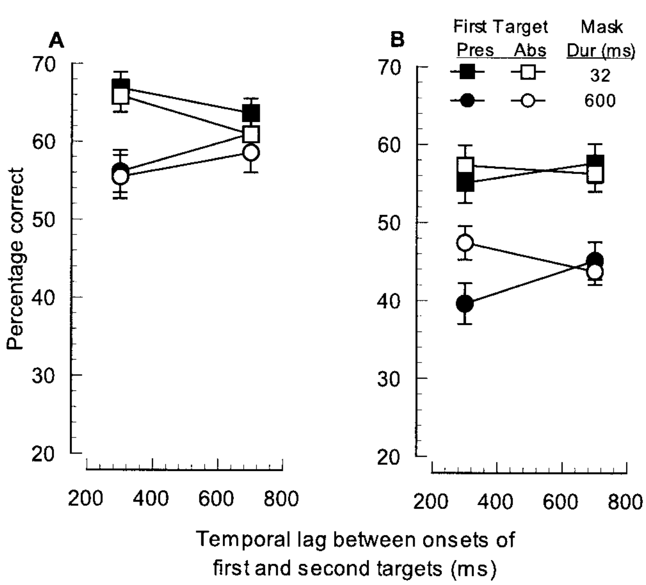

Figure 6. Experiment 4. A: Results of the second target central condition. B: Results of the second target eccentric condition. Scores in the present (Pres) conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the absent (Abs) conditions are mean percentages of correct responses. Error bars represent standard errors, calculated using the procedure suggested by Loftus and Masson (1994) for repeated measures designs. Dur = duration.

The results in Figure 6B were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms mask duration) × 2 (Lag 3 or 7) repeated measures ANOVA. As with the analysis of the central condition, the only statistically significant main effect was that of duration, $F(1, 23) = 39.49$, $p < .05$, $MSE = 192.39$. All remaining effects were not statistically significant: first target P/A, $F(1, 23) = 1.52$, $p > .23$, $MSE = 104.91$; P/A × Lag, $F(1, 23) = 3.04$, $p > .09$, $MSE = 160.01$; all other Fs < 1.

Central and eccentric combined. There were two notable results from the comparison between the present–central and present–eccentric conditions (filled symbols in Figures 6A and 6B, respectively). First, overall accuracy was better in the central than in the eccentric condition (central = 57.2%; eccentric = 53.4%). Second, in both conditions, there was an effect of mask duration in which accuracy was lower in the long-duration mask condition than in the short-duration mask condition, but the masking effect was larger in the eccentric condition.

The central and eccentric conditions were compared directly in a 2 (central or eccentric location) × 2 (32-ms or 600-ms duration) × 2 (Lag 3 or 7) repeated measures ANOVA. There was a significant main effect of location, $F(1, 23) = 29.14$, $p < .05$, $MSE = 260.97$; and of duration, $F(1, 23) = 30.26$, $p < .05$, $MSE = 169.96$; but not of lag, $F(1, 23) = 2.19$, $p > .15$, $MSE = 128.42$. None of the interaction effects was statistically significant beyond the .05 level: Location × Duration, $F(1, 23) = 2.96$, $p > .09$, $MSE = 211.98$; Location × Lag, $F(1, 23) = 1.06$, $p > .32$, $MSE = 116.36$; Duration × Lag, $F(1, 23) = 3.01$, $p > .09$, $MSE = 121.50$; Location × Duration × Lag interaction, $F < 1$.

Discussion

In many ways, the results of Experiment 4 are similar to those observed in Experiment 3. As in Experiment 3, there was an effect of mask duration in the central condition, but there was no difference between the first target P/A conditions in terms of mean level of performance nor was there an interaction between P/A and lag. And, as in Experiment 3, there was an effect of mask duration in the eccentric condition, and again it was larger than that observed in the central condition. However, and most important, unlike Experiment 3, there was no interaction between first target P/A and lag in the eccentric condition. The interpretation of the results of the central condition is the same as that discussed earlier: object substitution was observed, but there was no evidence of an AB. The results of the eccentric condition, however, warrant further consideration.

In Experiment 3, there was evidence of an AB, but the pattern of interference was not consistent with the object substitution hypothesis. Namely, although an AB was observed, it did not interact with the masking effect. One might argue that because there were no distractors presented simultaneously with the second target, the conditions were not optimal for object substitution, despite the fact that masking was observed. Consequently, in Experiment 4, eight distractors were presented with the second target, which would improve the conditions under which object substitution might be observed. Object substitution masking was observed and, as one might predict, it was larger than that observed in Experiment 3. However, under these optimized conditions, and unlike Experiment 3, no AB was observed.

Experiment 5

In the eccentric conditions of Experiment 4, when the second target was presented, eight distractors were also presented within the boundaries of a notional 3 × 3 matrix (see Figure 5). Although the grid formation had nine possible locations, the second target was presented in only four of them. To be sure, the spatial uncertainty induced by choosing between four locations, although effective in producing observable effects of mask duration, was certainly not the most powerful manipulation of spatial uncertainty. Indeed, a more powerful manipulation would have been to present the second target in any one of the nine possible grid locations. Alternatively, because all grid locations were filled on each trial, participants may have become very efficient in detecting the location of the second target and mask within such a limited area. Consequently, simply increasing the number of possible second target locations may also not be the most powerful manipulation of spatial uncertainty.

Experiment 5 was similar to Experiment 4 in most respects except for the degree of spatial uncertainty. In the present experiment, spatial uncertainty was increased by expanding the second target display to a 5 × 5 grid. In addition, the second target appeared in any one of the 25 possible locations, including fixation. Finally, eight digits were also presented simultaneously with the second target in random locations in the new grid formation. Thus, Experiment 5 represents a more powerful manipulation of the spatial distribution of attention by increasing the number of possible locations where the second target could be presented, while maintaining the set size used in Experiment 4. There were two main predictions. First, the expectation was that the effect of mask duration should be larger than in previous experiments. Second, to the extent that masking by object substitution disrupts the processing of the second target while attention is devoted to the first, an AB should be observed under these improved conditions.

Method

Participants. Twenty-four undergraduates (18 female; modal age = 18 years) participated for class credit. Twenty of the participants were right handed, and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure. The procedure for Experiment 5 was the same as that for Experiment 4, in which the second target, the mask, and eight digits were presented simultaneously at the end of the RSVP stream. The main difference between this experiment and Experiment 4 was that the grid formation was enlarged to a 5 × 5 grid, in which horizontal and vertical distance between the center of adjacent locations was 1°. In addition, the second target together with the mask and the eight digits could occur in random positions within the grid formation at the end of the stream, including in the center position. All other aspects of the task remained unchanged from previous experiments. A sample display configuration is shown in Figure 7.

Design. There were two blocks of trials in Experiment 5. In one block of trials, the first target was present, and in the other, the first target was absent. Within each block of trials, the second target and four-dot mask were presented in random locations on the screen, similar to the eccentric conditions in the previous experiments but with no constraint on the number of times the target was presented in each location. As with all the previous experiments, the duration of the four dots was either 32 ms or 600 ms. In each of the duration conditions, the second target was presented 32 times at each of the temporal lags (100, 300, or 700 ms). The order of the dot-duration and temporal lag conditions was randomized within the present and absent blocks. The order of first target P/A blocks was counterbalanced across participants. This design resulted in 384 trials completed in a single 1-hr session.

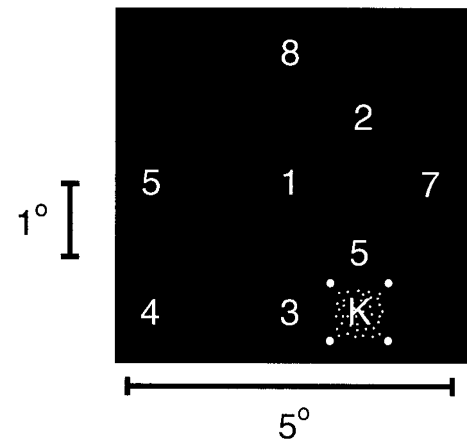

Figure 7. Schematic representation of the second target displays in Experiment 5. The displays consisted of a 5 × 5 matrix of stimuli (eight digits and one letter; i.e., the second target). The second target and the mask were presented together in random locations in the matrix, including fixation. The locations of the digits were also determined randomly with the constraint that a digit could not be shown in the same location as the target.

Results

Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 8. The most notable result shown in Figure 8 is the difference between present and absent conditions. Overall, mean percentage of correct identifications of the second target was slightly higher when the first target was absent than when it was present (absent = 46.9; present = 44.5). There was a large effect of mask duration, such that when the mask was of short duration, accuracy was 53.1%, and it was 38.2% when the mask was of long duration. In addition, when the first target was present, performance improved modestly with lag; however, this improvement was paralleled by a similar change in performance with lag in the first target absent condition.

Mean percentages of correct identifications of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 88.6; 600-ms duration = 90.0. The results in Figure 8 were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms mask duration) × 2 (Lag 3 or 7) repeated measures ANOVA. The only statistically significant effect was that of duration, $F(1, 23) = 109.79$, $p < .05$, $MSE = 110.73$. All remaining effects were not statistically significant: first target P/A, $F < 1$; lag, $F(1, 23) = 1.36$, $p > .25$, $MSE = 84.60$; P/A × Duration, $F(1, 23) = 2.17$, $p > .15$, $MSE = 81.34$; P/A × Lag, $F(1, 23) = 1.25$, $p > .27$, $MSE = 57.34$; Duration × Lag, $F(1, 23) = 3.72$, $p > .06$, $MSE = 84.54$; P/A × Duration × Lag, $F(1, 23) = 1.34$, $p > .26$, $MSE = 50.93$.

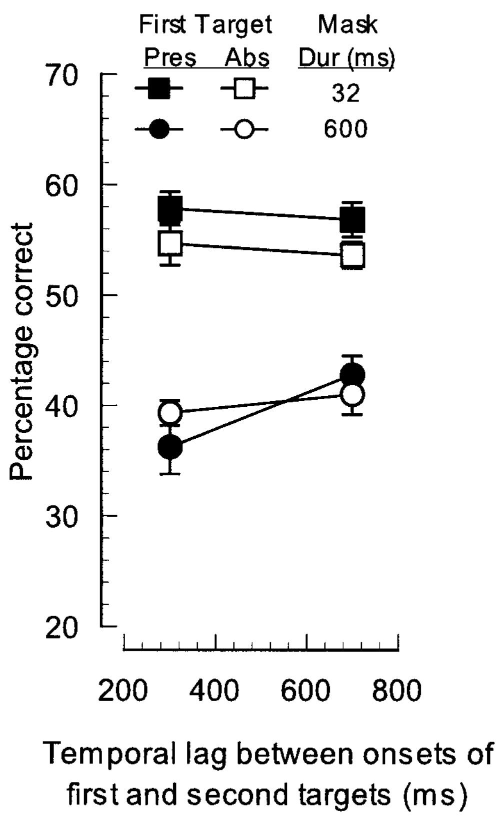

Figure 8. Results of Experiment 5. Scores in the present (Pres) conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the absent (Abs) conditions are mean percentages of correct responses. Error bars represent standard errors, calculated using the procedure suggested by Loftus and Masson (1994) for repeated measures designs. Dur = duration.

Discussion

In Experiment 5, the distribution of spatial attention was increased by increasing the spatial uncertainty about where the second target would be presented. The intention behind increasing the spatial uncertainty was to magnify object substitution masking. Indeed, the masking effect was large, on the order of 20%, but there was no difference in the lag effect in the first target present and absent conditions. That is to say, masking by object substitution was observed, but there was no reliable evidence of an AB. Thus, the result of increasing spatial uncertainty by increasing the number of possible second target locations does not provide support for the object substitution hypothesis.

One might argue, however, that increasing the number of possible second target locations was not the most effective approach to increasing the spatial distribution of attention. Indeed, Enns and Di Lollo (1997) demonstrated that when spatial uncertainty is controlled for, object substitution masking is stronger when there are more possible targets in the display (see also Di Lollo et al., 2000). Thus, with respect to object substitution masking, increasing the display set size appears to be a more effective manipulation of the distribution of spatial attention. Thus, the possibility still remains that the conditions for observing masking by object substitution have not been optimized. Experiment 6 addresses this possibility.

Experiment 6

In Experiment 6, the same number of second target locations was used as in Experiment 5, but the set size was increased to 18 (including the second target). That is to say, not only was there high spatial uncertainty in the display, but there were also a large number of distractor items in the display—larger than what was previously used in four-dot masking experiments (Di Lollo et al., 2000). Thus, if there are any conditions under which an AB was to be produced by object substitution mechanisms, Experiment 6 presents the most likely conditions.

Method

Participants. Twenty-four undergraduates (20 female; modal age = 18 years) participated for class credit. Twenty-two of the participants were right handed, and all reported having normal or corrected-to-normal vision. None of the participants was involved in any of the other experiments reported here.

Procedure. The procedure was the same as that in Experiment 5, except that in this experiment, 17 digits were presented simultaneously with the second target and mask at the end of the stream.

Design. The design of this experiment was exactly the same as that of Experiment 5.

Results

Mean percentages of correct identifications of the second target as a function of lag, averaged over all participants, are shown in Figure 9. The trends in the data are virtually identical to those in Experiment 4. The only exception is that of the effect of first target P/A. As shown in Figure 9, accuracy of identification of the second target was higher in the absent condition than in the present condition (absent = 49.6%; present = 43.5%). Otherwise, the results were identical to those of Experiment 5. There was a large effect of mask duration, such that when the mask was of short duration, accuracy was 55.1%, and it was 37.9% when the mask was of long duration. In addition, performance improved slightly with lag, with no clear visual evidence of any interaction between first target P/A and lag nor between duration and lag.

Mean percentages of correct identifications of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 90.0; 600-ms duration = 88.5. The results in Figure 9 were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms mask duration) × 2 (Lag 3 or 7) repeated measures ANOVA. The effect of removing the first lag from the analysis of the present experiment paralleled that observed in Experiment 5. There was a statistically significant effect of duration, $F(1, 23) = 109.79$, $p < .05$, $MSE = 110.73$; but not of P/A, $F(1, 23) = 3.55$, $p > .07$, $MSE = 196.96$; nor of lag, $F < 1$. None of the interactions was statistically significant: P/A × Lag, $F(1, 23) = 1.31$, $p > .26$, $MSE = 41.85$; all other Fs < 1.

Discussion

Experiment 6 represented the strongest test of the object substitution account of the AB. Spatial uncertainty and set size were

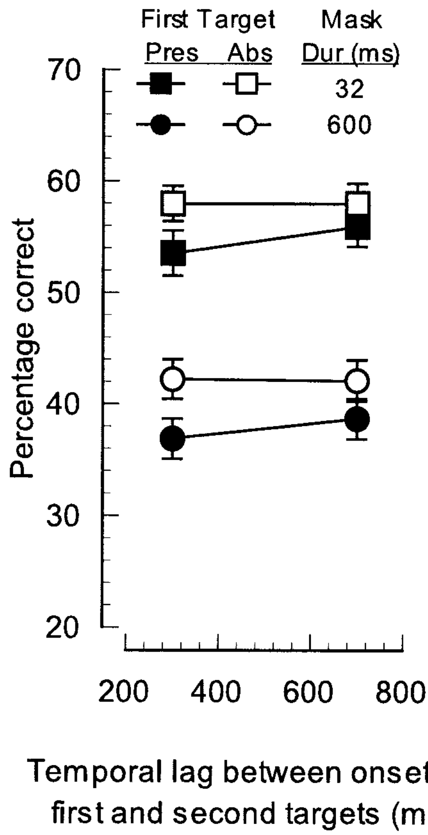

Figure 9. Results of Experiment 6. Scores in the present (Pres) conditions are mean percentages of correct identifications of the second target, given accurate identification of the first target. Scores in the absent (Abs) conditions are mean percentages of correct responses. Error bars represent standard errors, calculated using the procedure suggested by Loftus and Masson (1994) for repeated measures designs. Dur = duration.

increased beyond those used in the previous experiments reported here and those reported in other studies (Di Lollo et al., 2000; Enns & Di Lollo, 1997). Despite these methodological improvements, the results were essentially the same as Experiments 2 through 5. Indeed, the results of Experiment 6 were unequivocal: Masking by object substitution was observed, but there was no AB.

General Discussion

The goal of the present work was to test whether object substitution subserves masking of the second target during the AB. Masking by object substitution has been ascribed an important role in the AB on empirical and theoretical grounds (Brehaut et al., 1999; Giesbrecht & Di Lollo, 1998; Shapiro, Arnell, & Raymond, 1997; Vogel et al., 1998). Indeed, the object substitution hypothesis (Giesbrecht & Di Lollo, 1998) predicted that not only should an AB have been observed in all conditions of Experiments 2 through 6, but the strength of masking should have interacted with the AB. Yet, although the object substitution mask (i.e., four dots) was effective at interfering with performance when attention was distributed over space by manipulations of spatial uncertainty (Experiments 2 and 3) and set size (Experiments 4 through 6), there was no consistent evidence of a reliable AB. This was true both when the mask had a common onset with the second target (Experiments 3 through 6) and when it did not (Experiment 2). In contrast, when the mask was a digit that followed the second target, a robust AB was observed (Experiment 1). Moreover, in the single experiment that used an object substitution mask and an AB was observed (i.e., Experiment 3), there was no interaction between masking and the AB, as predicted by the object substitution hypothesis. Therefore, the results of the present experiments suggest that masking by object substitution does not play a role in the AB. Consequently, the present results constrain current models of the AB, especially the revised two-stage model of the AB (Giesbrecht & Di Lollo, 1998).

The Revised Two-Stage Model

The object substitution hypothesis was proposed within the context of a revised two-stage model of the AB (Giesbrecht & Di Lollo, 1998). In the original version of the model, proposed by Chun and Potter (1995), visual processing is divided into two sequential stages. Potential targets are detected in Stage 1 and then passed on to a limited-capacity second stage (i.e., Stage 2), in which items are processed more completely and encoded into a more durable form for report (e.g., durable storage; Coltheart, 1980). Items gain access to Stage 2 only if it is not already busy processing a target. If Stage 2 is busy, potential targets detected in Stage 1 remain in Stage 1. While delayed in Stage 1, targets remain vulnerable to decay and interference from temporally trailing, spatially superimposed stimuli.

The revised two-stage model proposed by Giesbrecht and Di Lollo (1998) is the same as the original version with the exception of an additional intermediate stage between Stages 1 and 2. This intermediate stage can be conceptualized as a holding buffer where the output of Stage 1 is stored until Stage 2 is free or until the next potential target detected in Stage 1 is passed on to the intermediate stage. In this model, the holding buffer effectively has the capacity of one item, such that any representation that is transferred into the holding buffer replaces the current contents. In other words, if the second target is presented while Stage 2 is busy with the first target, the second target is processed to some extent in Stage 1, and the encoded representation (which may include categorical information and possibly semantic information) gets transferred to the holding buffer. The representation remains in the buffer until Stage 2 is free or until it is replaced by the next input from Stage 1, typically the representation of the mask. Critically, Giesbrecht and Di Lollo argued that the process of replacement in the holding buffer is mediated masking by object substitution, hence, the object substitution hypothesis.

As we have stressed throughout the present article, the object substitution hypothesis predicts that four-dot masking should interact with the AB. This prediction, however, was not obtained, even in the experiment in which an AB was observed (i.e., Experiment 3). Thus, ascribing substitution-type mechanisms as being responsible for replacement in the intermediate stage is not supported by the present results. However, there are two important issues that need to be addressed before the object substitution hypothesis, as currently framed, can be confidently rejected: The first is the approach of focusing the analyses on Lags 3 and 7; the second is the role that visual transients locked to the onset of the mask may have in the discrepancy between the pattern of results predicted by the object substitution hypothesis and the pattern of results actually obtained.

As mentioned in the first section of this article, justification for focusing on the data from Lags 3 and 7 was based on converging meta-analytical and empirical evidence that performance at Lag 1 and the magnitude of the AB are not related (Visser, Bischof, & Di Lollo, 1999; Visser, Zuvic, et al., 1999). The results of Experiment 1 further justified this approach, demonstrating that in our paradigm, performance at Lag 1 was modulated by the spatial relationship between the first and second target, whereas performance at Lags 3 and 7 was not. Using this approach, we have argued that despite observing severe masking deficits in all experiments, there was no interaction between masking and lag; in other words, despite observing strong object substitution, the strength of the masking effect did not interact with the AB. Consequently, the object substitution hypothesis cannot be accepted as a viable account of masking during the AB. Yet, one might argue (reasonably) that inclusion of Lag 1 would alter this conclusion. For instance, in those conditions in which object substitution was observed (i.e., eccentric conditions of Experiments 2 through 6), accuracy at Lag 1 was lower than at Lags 3 and 7 (see Appendix B). This introduces the possibility that perhaps performance at Lag 1 actually represents part of the AB. Crucially, however, inclusion of Lag 1 does not weaken our contention that object substitution does not mediate masking of the second target during the AB; in fact, it strengthens this position. Consider the results of Experiment 6. In both the 32-ms and 600-ms duration conditions, accuracy at Lag 1 (see Appendix B) was low (47.4% and 28.7%, respectively) and improved monotonically as lag increased (32 ms: Lag 3 = 53.5%, Lag 7 = 55.9%; 600 ms: Lag 3 = 36.9%, Lag 7 = 38.6%). The majority of the improvement occurred between Lags 1 and 3, whereas there was no difference in accuracy between Lags 3 and 7. On the basis of this pattern of results, one might argue that an AB was observed, but that it was restricted to Lag 1. Thus, contrary to what has been argued here, one would argue that when Lag 1 is included, the data support the object substitution hypothesis. However, if the alternative explanation was adopted, one would conclude that an AB was observed in both the 32-ms and the 600-ms duration conditions. However, in the 32-ms condition, the target and mask had simultaneous onsets and offsets, a condition under which masking by object substitution masking is not observed (Di Lollo et al., 2000; Enns & Di Lollo, 1997). This is problematic for the alternative explanation that claims there is an AB when one includes Lag 1 data because under conditions in which there is no object substitution, there should be no AB. This alternative account runs afoul further when one considers the additivity between the lag effect (both including and excluding Lag 1) and mask duration (Experiments 4 through 6). This additivity provides further support for the notion that the mechanisms that underlie the lag effect (at Lag 1 and Lags 3 and 7) are independent of those that underlie masking by object substitution. Thus, even if Lag 1 is included in the data, the data demand that the object substitution hypothesis be rejected.

The second issue, namely, the role of onset transients in masking of the second target during the AB, is more subtle but equally important to consider. In typical studies of the AB using paradigms such as that used in Experiment 1, the second target is followed by the next item in the RSVP stream, and, as such, this trailing distractor acts as a backward pattern mask on the second target. When cast in this light, models of backward masking can be brought to bear on the present experiments, and at least one model provides an alternative interpretation of our results. A common view in the masking literature is that visual onsets evoke two types of neural responses at early levels of the visual system: One is a fast, transient response time-locked to the onset of the stimulus; the other is a slower, sustained response (e.g., Breitmeyer & Ganz, 1976). Masking is brought about by inhibitory interactions between the onset transient associated with the mask and the sustained activity associated with the target (for reviews of this type of model, see Breitmeyer, 1984; Breitmeyer & Ganz, 1976; Breitmeyer & Ogmen, 2000; Di Lollo et al., 2000; Enns & Di Lollo, 2000). This so-called *two-channel theory* provides a parsimonious account of backward masking during the AB, such that transients time-locked to the onset of the mask degrade the unattended second target. More important, if one were to use this model to interpret the present data, it could be argued that little or no AB was observed in the critical experiments (e.g., Experiments 3 through 6) because the mask and the target had simultaneous onsets. In the two-channel theory, no masking is observed in the instance of common onsets because the inhibitory responses of onset transients associated with the target and mask cancel, thereby precluding inhibitory interactions of the transient on sustained activity. However, this model would predict that if the four-dot mask followed the second target, the onset transients from this backward mask would now be effective in degrading the unattended second target, and as a result, the AB should be observed. Recall, however, that in Experiment 2, the four-dot mask was used as a backward mask, and although masking was observed, there was no AB. Therefore, visual transients locked to the onset of the mask cannot account for the discrepancy between the pattern of results predicted by the object substitution hypothesis and the pattern of results actually obtained.

In summary, the object substitution hypothesis made explicit predictions regarding the mechanisms mediating masking of the second target and the AB: Masking the second target with a four-dot mask should produce the AB, and as masking strength increases, so should the severity of the AB. Neither of these predictions was obtained. Thus, the late-stage mechanisms involved in object substitution cannot be responsible for masking unattended information during the AB. Moreover, the hypothesis cannot be considered a viable component in not only the revised two-stage model but also other models that have incorporated the object substitution hypothesis as an account of masking during the AB.

Implications for Other Models of the AB

Besides the revised two-stage model (Giesbrecht & Di Lollo, 1998), there are now at least seven other published accounts of the AB in the literature (e.g., Chun & Potter, 1995; Duncan et al., 1994; Jolicœur, 1998; Raymond et al., 1992; Shapiro, Arnell, & Raymond, 1997; Shapiro et al., 1994; Vogel et al., 1998; Ward et al., 1996). Although the specifics of the models differ, they all generally account for the AB deficit in a similar manner: The impairment in performance is due to the failure to encode the second target representation into a durable form for report because attention has been devoted to the first target. Four of these models, the two-stage model (Chun & Potter, 1995), the short-term consolidation model (Jolicœur, 1998), the unified model (Shapiro, Arnell, & Raymond, 1997), and the hybrid model (Vogel et al., 1998), suggest that the failure to encode the second target representation into a more durable form is due to degradation of the representation while attention has been devoted to the first target. The two-stage and short-term consolidation models do not make explicit claims about how the second target representation is degraded, other than in descriptive terms (e.g., "erasure"). The unified model and the hybrid model, on the other hand, are more specific in that they suggest that object substitution is responsible for the degradation of the second target representation.

Although the present results demonstrating that object substitution does not mediate masking of the second target during the AB may seem problematic for accounts of the AB, particularly those that implicate object substitution, these results do not completely undermine all the tenets of each of the models. For instance, the fact that object substitution does not mediate masking of the second target does not mean that the intermediate stage of the revised two-stage model does not exist; rather it could simply mean that either the replacement of items in the buffer is not mediated by object substitution or that substitution mechanisms play a role in replacement in the buffer, but the masking mechanisms that are important to the AB do not. The present results do, however, allow one to be more precise regarding the nature of the disruption of the representation of the second target during the AB. To wit, although the representation of the second target during the AB is vulnerable to interference, the present results indicate that late-stage mechanisms arising in our paradigm and involved in masking by object substitution processes are not responsible for that interference.

An Alternative Account

The falsification of the object substitution hypothesis raises this question: If late-stage processes involved in object substitution are not involved in masking of the second target during the AB, then what mechanisms are involved? The immediate alternative is that the representation of an unattended target during the AB is degraded by early masking mechanisms. By *early mechanisms,* we mean masking effects that are dependent on physical stimulus characteristics such as contour proximity, contour similarity, and adapting luminance. This is not to say that other mechanisms are not involved. Indeed, decay of the target representation is likely to be involved. However, under typical conditions, passive decay of the visual representation is not sufficient to observe the AB (for conditions in which decay may be sufficient, see Enns, Visser, Kawahara, & Di Lollo, 2001; Giesbrecht & Di Lollo, 1998; Kawahara, Di Lollo, & Enns, 2001). It is important to note that the proposal here is that early visual processes are the main mechanisms that underlie masking of the second target during the AB.

In the corpus of the published AB literature, in every experiment in which an AB was observed, the second target was masked by a temporally trailing, spatially superimposed pattern. Backward masks of this sort have a distinct early component: The target and mask share similar contours. Contour similarity is one of the major variables in early masking effects. The more similar the contour between the target and the mask, the stronger the masking effect (for comprehensive reviews, see Breitmeyer, 1984; Scheerer, 1973).[2] Thus, if early visual processes mediate masking of the second target during the AB, then there should be a relationship between the severity of the AB and the similarity of the second target and the mask. Although there are studies that have manipulated the similarity of the first target and the mask (e.g., Grandison, Ghirardelli, & Egeth, 1997; Seiffert & Di Lollo, 1997), to our knowledge there are no published studies that have tested this possibility by parametric variation of contour similarity between the second target and the mask. There is, however, suggestive evidence reported by Giesbrecht and Di Lollo (1998), who found more severe deficits when the second target was masked by a digit (high contour similarity) compared with when the second target was masked by a patch of noise dots (low contour similarity).

To a first approximation, appealing to early masking effects is inconsistent with many of the findings in the literature on two counts. First, it has been argued that the early visual representation of the second target is destroyed by the mask, yet there are several published observations that an unreported second target is processed to a semantic level (e.g., Luck et al., 1996; Maki et al., 1997; Shapiro, Driver, et al., 1997; Vogel et al., 1998). Beyond a first approximation, however, simply because the early representation is masked does not mean that the item cannot be processed beyond that early stage. Consider that in the present experiments when a delayed mask was used, each item (targets and distractors) was clearly suprathreshold—subjectively, there was a constant stream of stimuli with no "hiccups" as might be expected if some stimuli were not suprathreshold. To be sure, each item enters into the visual system and therefore can be processed to some extent, even if it is masked. For example, the SOA between the target and the mask in this and many other studies of the AB is approximately 100 ms, which is apparently enough time to process the category of an item; otherwise, the first target could not be picked out from the stream (Chun & Potter, 1995). Moreover, it is unlikely that the mask completely obliterates the representation of the target in the visual system, and as a result, there is likely still residual information regarding the target remaining in the visual system after the presentation of the mask. Therefore, although the early representation is masked by early processes, it is still possible that processing can proceed beyond a low level. Formal demonstrations of this possibility come from the literature on masked priming and perception without awareness in which subthreshold stimuli have been shown to influence behavior (Cheesman & Merikle, 1986; Marcel, 1983a, 1983b).

When one relates this proposal to the models discussed previously, it is noteworthy that although the specifics of the models differ, without exception, each explains the AB as a failure of late cognitive processes to encode the second target. This issue is not in dispute. However, Giesbrecht and Di Lollo (1998) illustrated that for this high-level failure to be observed, particular conditions must be met: The second target must be masked by a trailing pattern. The implicit assumption was that because the AB reflects a late cognitive failure, the masking effect must also be mediated by similarly late mechanisms. This assumption had intuitive appeal and was supported by converging lines of evidence showing that

[2] It must be noted that this relationship excludes the extreme possibility of a perfect correspondence between the contours of the target and the mask, in which case masking would not be observed.

an unattended second target was processed to a semantic level (Maki et al., 1997; Shapiro, Driver, et al., 1997; Vogel et al., 1998). Consequently, this assumption was embodied in the object substitution hypothesis incorporated into the revised two-stage model (Giesbrecht & Di Lollo, 1998). The appeal of this assumption was apparently not lost on others who also embraced the same hypothesis (i.e., Shapiro, Arnell, & Raymond, 1997; Vogel et al., 1998). The present experiments, however, demonstrate that the logic that a late-stage phenomenon needs to be disrupted by a late mask is incorrect. Indeed, our results demonstrate that this is not the case: During the AB, processing is not disrupted by a late mask. The simpler and equally plausible alternative is that for this late stage phenomenon to be observed, early visual representations must be disrupted by a low-level mask.

Adopting the early masking hypothesis allows one to use what is known about early visual processes to make distinctive predictions about how early visual processes should interact with the AB. Perhaps the most distinctive prediction that can be made is the effect of adapting luminance on the AB. It is well established that the early visual response is very different under dark-adapted (scotopic) and light-adapted (photopic) viewing conditions (for reviews, see Breitmeyer, 1984; Coltheart, 1980; Di Lollo & Bischof, 1995). According to one model (Sperling & Sondhi, 1968), the retinal response under photopic viewing conditions is faster than the response under scotopic viewing conditions. Moreover, the response under photopic viewing conditions is biphasic: An initial positive phase is followed by a negative phase, the size of which decreases with increases in the spatial frequency of the visual stimulus (Breitmeyer & Ganz, 1977; Watson & Nachmias, 1977). In contrast, under scotopic conditions, the retinal response shows only a positive phase. The positive phase in both conditions is thought to represent excitatory activity triggered by the onset of a stimulus, and the temporal extent of the positive phase is thought to be an index of visible persistence (Di Lollo & Bischof, 1995). The negative phase is thought to represent inhibitory activity triggered by the offset of a stimulus. This inhibitory activity is thought to mediate local contour interactions via the suppression of persistence beyond stimulus offset. The suppression of persistence is thought to occur early in visual processing (i.e., no later than primary visual cortex) and is thought to mediate early masking effects, such as metacontrast masking (Breitmeyer, 1984).

The implication of the impact of adapting luminance on the response of early stages of the visual system is that one can manipulate viewing conditions to decouple the involvement of early- and late-stage processes in viewing visual displays. For example, if a particular form of masking is sensitive to manipulations of adapting luminance such that masking is observed under photopic but not scotopic viewing conditions, then one may conclude that early visual processes are primarily involved in that form of masking. If, on the other hand, the masking effect is insensitive to viewing conditions, then it would suggest that the form of masking is mediated mostly by late visual processes. Using this line of reasoning, Bischof and Di Lollo (1995) found no metacontrast masking when observers viewed displays under scotopic viewing conditions, thereby implicating the involvement of early visual processes. Similarly, Di Lollo et al. (2000) found robust object substitution masking under both photopic and scotopic viewing conditions, thereby implicating a role for late-stage visual processes and little or no role for early-stage visual processes in object substitution. Thus, manipulating adapting luminance allows for the decoupling of early-stage and late-stage processes in visual masking.

According to this analysis, the early masking hypothesis proposed here would predict the AB should be observed under photopic viewing conditions but not under scotopic viewing conditions. Recently, we tested this prediction (Giesbrecht, Bischof, & Kingstone, 1998). In this experiment, observers participated in an experiment very similar to those reported here, in which the task was to identify two letters in an RSVP stream of digits, and the second target was always masked by a single digit. The same observers were tested under photopic and scotopic viewing conditions. Under the typical task parameters (i.e., two targets and a 100-ms SOA between all RSVP items), an AB was observed under photopic conditions. In contrast, there was no AB under scotopic viewing conditions. This result contrasts sharply with the object substitution hypothesis, which predicts that the AB should be observed under both photopic and scotopic viewing conditions. In contrast, this result is exactly what would be predicted if early visual processes mediate masking of the second target during the AB. These preliminary data provide suggestive evidence consistent with the notion that primarily early visual processes mediate masking of the second target during the AB.

Concluding Remarks

The present results underscore the importance of treating the AB as a multifaceted phenomenon (e.g., Isaak et al., 1999; Kawahara et al., 2001). Indeed, not only can the AB be characterized as reflecting the time course of interactions between attention and memory-encoding processes, as all published models of the AB have captured, but the AB also reflects the dynamic interaction between attention and early visual perception. As a consequence, to provide a more complete understanding of the AB and how it relates to perception, attention, and memory more generally, researchers will need to elucidate all aspects of the phenomenon.

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(*Appendixes follow*)

Appendix A

Number of Noise Dots

The median number of noise dots that were presented simultaneously with the second target in each experiment are reported here.

Experiment 1

There were four experimental blocks: first target present or absent and second target central or eccentric. The median number of dots in each block was as follows: present–central = 17.5; absent–central = 15.0; present–eccentric = 17.5; absent–eccentric = 15.0.

Experiment 2

There were four experimental blocks: first target present or absent and second target central or eccentric. The median number of dots in each block was as follows: present–central = 22.5; absent–central = 20.0; present–eccentric = 22.5; absent–eccentric = 20.0.

Experiment 3

There were four experimental blocks: first target present or absent and second target central or eccentric. The median number of dots in each block was as follows: present–central = 90; absent–central = 85; present–eccentric = 90; absent–eccentric = 75.

Experiment 4

There were four experimental blocks: first target present or absent, second target central or eccentric. The median number of dots in each block was as follows: present–central = 80; absent–central = 75; present–eccentric = 80; absent–eccentric = 70.

Experiment 5

There were two experimental blocks: first target present or absent. The median number of dots in each block was as follows: present = 10; absent = 10.

Experiment 6

There were two experimental blocks: first target present or absent. The median number of dots in each block was as follows: present = 0; absent = 7.5.

Appendix B

Statistical Analyses

Statistical analyses, including all lags, for Experiments 2 through 6 are reported here. For ease of comparison, the results for each experiment are presented in a fashion that parallels the analyses of Lags 3 and 7 described in the text.

Experiment 2

Central

Mean percentage of correct identifications of the first target collapsed across lags was 90.1. Second target accuracy was slightly lower in the present condition than in the absent condition (54.1% vs. 60.2%, respectively), and although accuracy was the highest at Lag 1 in the present condition (57.3%), there was no statistically reliable change in identification accuracy as a function of lag.

The results were analyzed in a 2 (first target P/A) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. As with the analysis that included only Lags 3 and 7, the main effect of P/A was statistically significant, $F(1, 23) = 12.78$, $p < .05$, $MSE = 58.19$. Similarly, there was no main effect of lag, $F(2, 46) = 1.88$, $p > .16$, $MSE = 69.11$; nor was there a P/A × Lag interaction, $F(2, 46) = 1.35$, $p > .27$, $MSE = 65.86$.

Eccentric

Mean percentage of correct identifications of the first target collapsed across lags was 90.8. Second target accuracy was similar in the present (54.8%) and absent (52.1%) conditions and was lowest at Lag 1 in both conditions (present = 43.6%; absent = 50%).

A 2 (first target P/A) × 3 (Lag 1, 3, or 7) repeated measures ANOVA revealed that both the main effect of lag and the P/A × Lag interaction were statistically reliable: lag, $F(2, 46) = 10.24$, $p < .05$, $MSE = 74.62$; P/A × Lag, $F(2, 46) = 4.36$, $p < .05$, $MSE = 95.52$. The main effect of first target P/A was not significant ($F < 1$).

Central and Eccentric Combined

The combined analysis included the following variables, which were entered into a repeated measures ANOVA: location (central or eccentric) and lag (1, 3, or 7). Unlike the analysis that included only Lags 3 and 7, all effects were significant. There was a significant main effect of location, $F(1, 23) = 5.56$, $p < .05$, $MSE = 107.29$; lag, $F(2, 46) = 7.19$, $p < .05$, $MSE = 66.59$; Location × Lag, $F(2, 46) = 8.27$, $p < .05$, $MSE = 100.98$.

Experiment 3

Central

Mean percentages of correct identification of the first target collapsed across lags separately for each mask duration condition were 88.9 when the mask duration was 32 ms and 92.4 when the duration was 600 ms. Second target identification accuracy was lower in the 600-ms mask duration condition than in the 32-ms duration condition (55.5% vs. 61.0%, respectively), but this difference did not change as a function of lag. Collapsed across first target P/A, accuracy at Lag 1 was 62.2% and 56.9% for the 32-ms and 600-ms duration conditions, respectively.

A 2 (first target P/A) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA revealed that the only reliable effect was that of duration, $F(1, 23) = 14.19$, $p < .05$, $MSE = 158.79$. All other main effects and interactions were not statistically significant: P/A, $F < 1$; lag, $F(2, 46) = 1.13$, $p > .33$, $MSE = 160.02$; P/A × Duration, $F < 1$; P/A × Lag, $F(2, 46) = 2.24$, $p > .12$, $MSE = 159.27$; Duration × Lag, $F < 1$; P/A × Duration × Lag, $F < 1$.

Eccentric

Mean percentages of correct identification of the first target collapsed across lags separately for each mask duration condition were as follows: 32-ms duration = 91.5; 600-ms duration = 91.7. Again, second target identification accuracy was lower in the 600-ms duration condition compared with the 32-ms condition (43.9% vs. 56.3%, respectively). In the first target present condition, second target identification changed as a function of lag, such that accuracy was lowest at Lag 1 (32 ms = 41.6%; 600 ms = 25.9%) and increased monotonically as the interval between the first and second targets increased (32 ms: Lag 3 = 57.3%, Lag 7 = 62.8%; 600 ms: Lag 3 = 40.3%, Lag 7 = 53.2%).

The results were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. This analysis revealed a different pattern of results compared with the central condition. All three main effects were statistically significant: first target P/A, $F(1, 23) = 15.25$, $p < .05$, $MSE = 198.54$; duration, $F(1, 23) = 65.58$, $p < .05$, $MSE = 168.82$; lag, $F(2, 46) = 19.65$, $p < .05$, $MSE = 119.92$. The only statistically significant interaction was the P/A × Lag interaction, $F(2, 46) = 41.01$, $p < .05$, $MSE = 127.64$. All other interactions were not significant: P/A × Duration, $F(1, 23) = 1.30$, $p > .26$, $MSE = 164.93$; Duration × Lag, $F < 1$; P/A × Duration × Lag, $F(2, 46) = 1.52$, $p > .22$, $MSE = 139.33$.

Central and Eccentric Combined

Overall, identification accuracy was lower in the eccentric than in the central condition. This was especially true at Lag 1, where accuracy was almost 30% lower in the eccentric condition than in the central condition (33.8% vs. 62.2%, respectively, collapsed across mask duration). In addition, the long-duration four-dot mask was more effective in the eccentric (32 ms = 60.1%; 600 ms = 46.7%) than in the central condition (32 ms = 59.9%; 600 ms = 54.4%). The repeated measures ANOVA of these data included the following variables: location (central or eccentric), duration (32 or 600 ms), and lag (1, 3, or 7). All three main effects were statistically significant: first target location, $F(1, 23) = 21.39$, $p < .05$, $MSE = 484.44$; duration, $F(1, 23) = 33.37$, $p < .05$, $MSE = 206.97$; lag, $F(2, 46) = 15.67$, $p < .05$, $MSE = 163.75$. In addition, there were two reliable interactions: Location × Duration, $F(1, 23) = 7.69$, $p < .05$, $MSE = 175.36$; Location × Lag, $F(2, 46) = 50.92$, $p < .05$, $MSE = 100.74$. The remaining interactions were not significant: Duration × Lag, $F(2, 46) = 1.52$, $p > .22$, $MSE = 166.01$; Location × Duration × Lag, $F < 1$.

Experiment 4

Central

Mean percentages of correct identification of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 91.1; 600-ms duration = 91.7. As in the previous experiment, second target identification accuracy was lower in the long-duration mask condition than in the short-duration mask condition (58.7% vs. 65.1%, respectively), and this effect did not change as a function of lag. Collapsed across first target P/A, accuracy at Lag 1 was 66.7% and 60.4% for the 32-ms and 600-ms duration conditions, respectively.

The data were entered into a 2 (first target P/A) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. The only effect that was significant beyond the .05 level was the main effect of duration, $F(1, 23) = 21.09$, $p < .05$, $MSE = 142.79$. All other main effects and interactions were not statistically significant: P/A, $F(1, 23) = 2.35$, $p > .13$, $MSE = 111.81$; lag, $F(2, 46) = 1.68$, $p > .19$, $MSE = 113.78$; P/A × Duration, $F < 1$; P/A × Lag, $F < 1$; Duration × Lag, $F(2, 46) = 2.89$, $p > .06$, $MSE = 113.78$; P/A × Duration × Lag, $F < 1$.

Eccentric

Mean percentages of correct identification of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 91.1; 600-ms duration = 91.1. As in the central condition, second target identification accuracy was lower in the long-duration mask condition than in the short-duration mask condition (41.8% vs. 56.2%, respectively) and although accuracy changed monotonically as a function of lag (lowest at Lag 1 in both present and absent conditions, 43.1% and 49.7%, respectively), the size of the masking effect did not change as a function of lag (32 ms = 56.2%; 600 ms = 41.8%).

The results were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. All three main effects were statistically significant: first target P/A, $F(1, 23) = 10.09$, $p < .05$, $MSE = 83.82$; duration, $F(1, 23) = 55.11$, $p < .05$, $MSE = 271.51$; lag, $F(2, 46) = 3.82$, $p < .05$, $MSE = 128.06$. The only statistically significant interaction was the P/A × Lag interaction, $F(2, 46) = 3.26$, $p < .05$, $MSE = 131.74$. All other interactions were not significant: P/A × Duration, $F(1, 23) = 1.60$, $p > .21$, $MSE = 165.35$; Duration × Lag, $F(2, 46) = 1.48$, $p > .23$, $MSE = 163.61$; P/A × Duration × Lag, $F < 1$.

Central and Eccentric Combined

The results of the present conditions were compared directly in a 2 (central or eccentric location) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. As with the corresponding analysis that included only Lags 3 and 7, two main effects were statistically significant: location, $F(1, 23) = 42.43$, $p < .05$, $MSE = 412.08$; and duration, $F(1, 23) = 47.91$, $p < .05$, $MSE = 175.72$. The main effect of lag was not significant, $F(2, 46) = 15.67$, $p < .05$, $MSE = 163.75$. Unlike the initial analysis, two interactions were statistically reliable: Location × Duration, $F(1, 23) = 11.41$, $p < .05$, $MSE = 192.22$; Location × Lag, $F(2, 46) = 132.65$, $p < .05$, $MSE = 132.65$. The remaining interactions were not significant: Duration × Lag, $F(2, 46) = 1.81$, $p > .17$, $MSE = 109.75$; Location × Duration × Lag, $F(2, 46) = 1.49$, $p > .24$, $MSE = 22.99$.

Experiment 5

Mean percentages of correct identification of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 86.8; 600-ms duration = 88.7. As in the previous experiments, there was an effect of mask duration on second target identification accuracy, such that performance was higher in the short-duration mask condition (53.1%) than in the long-duration condition (38.2%). In the present condition, accuracy was lowest at Lag 1 (32 ms = 44.4%; 600 ms = 28.9%) and improved as the interval between the targets increased.

The results were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. Two main effects were statistically significant: duration, $F(1, 23) = 168.59$, $p < .05$, $MSE = 94.94$; lag, $F(2, 46) = 22.55$, $p < .05$, $MSE = 59.04$. There were also two statistically significant interactions: P/A × Lag, $F(2, 46) = 13.24$, $p < .05$, $MSE = 73.99$; P/A × Duration, $F(1, 23) = 5.08$, $p < .05$, $MSE = 65.58$. The main effect of P/A was not significant, $F(1, 23) = 3.02$, $p >$

(*Appendixes continue*)

.09, $MSE = 135.03$; nor were the remaining interactions: Duration × Lag, $F(2, 46) = 2.35$, $p > .10$, $MSE = 97.93$; P/A × Duration × Lag, $F < 1$.

Experiment 6

Mean percentages of correct identification of the first target collapsed across lags separately for the two mask duration conditions were as follows: 32-ms duration = 88.8; 600-ms duration = 87.7. As in Experiment 5, there was a large effect of mask duration on second target identification accuracy (32 ms = 55.1%; 600 ms = 37.9%) and an effect of lag, such that in both mask duration conditions, performance was lowest at Lag 1 (32 ms = 47.4%; 600 ms = 28.7%) and highest at Lags 3 and 7 (Lag 3: 32 ms = 53.5%, 600 ms = 36.9%; Lag 7: 32 ms = 55.9%, 600 ms = 38.6%).

The results were analyzed in a 2 (first target P/A) × 2 (32-ms or 600-ms duration) × 3 (Lag 1, 3, or 7) repeated measures ANOVA. All three main effects were significant beyond the .05 level: P/A, $F(1, 23) = 13.14$, $p < .05$, $MSE = 202.04$; duration, $F(1, 23) = 135.08$, $p < .05$, $MSE = 158.29$; lag, $F(2, 46) = 9.18$, $p < .05$, $MSE = 82.27$. There was a single reliable interaction: P/A × Lag, $F(2, 46) = 5.56$, $p < .05$, $MSE = 70.66$. All other interactions had Fs < 1.

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