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Does failure to mask T1 cause lag-1 sparing in the attentional blink?

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The attentional blink (AB) effect demonstrates that when participants are instructed to report two targets presented in a rapid visual stimuli stream, the second target (T2) is often unable to be reported correctly if presented 200–500 msec after the onset of the first target (T1). However, if T2 is presented immediately after T1, in the conventional lag-1 position (100-msec stimulus onset asynchrony; SOA), little or no performance deficit occurs. The present experiments add to the growing literature relating the "lag-1 sparing" effect to T1 masking. Using a canonical AB paradigm, our results demonstrate that T2 performance at lag 1 is significantly reduced in the presence of T1 masking. The implications of this outcome are discussed in relation to theories of the AB.

The human information processing system is limited in its capacity to process multiple units of rapid sequential information. One method of studying this limitation is the *attentional blink* (AB). This attentional phenomenon demonstrates that, when participants are instructed to detect or identify two masked targets—commonly presented within a rapid serial visual presentation (RSVP) stream—the *second target* (T2) frequently cannot be reported correctly when presented 200–500 msec postonset of the *first target* (T1; Raymond, Shapiro, & Arnell, 1992). At present, three different accounts of the AB have been proposed, though there is overlap among them (cf. Shapiro, Arnell, & Raymond, 1997). Resource-depletion accounts, such as the interference model proposed by Shapiro, Raymond, and Arnell (1994), suggest that ongoing processing of T1 leaves insufficient resources available for individuating T2 from other items entering a short-term memory buffer. On the other hand, bottleneck accounts, such as Chun and Potter's (1995) two-stage model as well as Jolicœur and Dell'Acqua's (1998) PRP model, propose that T2 is unable to proceed to later stages of processing until an earlier stage is released from processing T1. Both accounts suggest that the dual-task bottleneck of the AB occurs at the point of transferring a momentarily active target into a more durable representation. More recently, it has been proposed that the AB is due to a temporary loss of control over top-down processes related to the monitoring of incoming stimuli to match a target template (Di Lollo, Kawahara, Ghorashi, & Enns, 2005).

A particular outcome known as "lag-1 sparing" has been the focus of considerable empirical investigation due to its relevance to hypothesized accounts of the AB. Lag-1 sparing refers to an absence of processing deficit when T2 is presented approximately 100 msec after T1 onset (i.e., the typical lag-1 position; Raymond et al., 1992). Lag-1 sparing was initially explained in terms of the *attentional gate hypothesis* (Chun & Potter, 1995; Shapiro et al., 1994), which postulates that a "gate-like" ballistic processing mechanism opens upon presentation of T1 and remains open for 150–200 msec. During this brief temporal window, T2 gains access to the same resources used to process T1 by integrating both targets into a single perceptual "episode." Since initially proposed, the conception of this integration mechanism has evolved to include additional parameters such as a "gate filter," which requires T1 and T2 to appear in the same spatial location and have similar task requirements (Juola, Botella, & Palacios, 2004; Visser, Bischof, & Di Lollo, 1999), and recently has been applied to computational accounts of the AB (Bowman & Wyble, 2007). The present report suggests gating accounts of lag-1 sparing neglect to recognize the important role that T1 masking plays in the AB. We will return to this issue later.

In a recent line of research considering what traditionally have been viewed as opposing theories of lag-1 sparing, Hommel and Akyürek (2005) sought evidence to support either the attentional gate hypothesis as described above, which advocates integration of T1 and T2, or an alternative hypothesis suggesting that, when in the lag-1 position, T2 competes with T1 for attentional resources (Potter, Staub, & O'Connor, 2002). As the idea of resource competition implies, the latter hypothesis argues that lag-1 sparing is the product of increased T2 processing at the expense of T1. Hommel and Akyürek concluded that integration and competition accounts of lag-1 sparing should not be viewed as opposing interpretations of the same cognitive mechanism; rather both—either of which can occur, depending upon perceptual factors—are possible outcomes.

Specifically, these authors suggest that whether T1 and T2 are integrated into the same episode or compete for

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resources while being processed in discrete episodes depends on their visual "discriminability." On trials where T1 and T2 were equally discriminable, evidence was found for target integration. Although targets were identified with a high degree of accuracy, information regarding the order of target presentation appeared to have been lost. Such confusion of temporal order has previously been reported to accompany lag-1 sparing, and has been attributed to the overlapping processing of targets integrated into a single perceptual episode (Chun & Potter, 1995; Shapiro et al., 1994). This processing "overlap" has been corroborated neurophysiologically in an AB task by the presence of merged M300 T1/T2 waveforms at the junction of the left temporo-parietal-frontal lobes (Kessler et al., 2005).

When T1 and T2 differed in discriminability, on the other hand, Hommel and Akyürek (2005) found that the more discriminable target was identified with a higher degree of accuracy. On this basis, these authors concluded that greater discriminability was responsible for one target "winning out" in a competition for resources. Perhaps even more importantly than the conditional support for both integration and competition accounts, Hommel and Akyürek's findings, among others, demonstrate that the lag-1 sparing phenomenon can be a "window" into understanding the consequences of (T1) target processing in the AB paradigm. Given that the observation of lag-1 sparing has been a cornerstone of various theoretical accounts of the AB, a more thorough understanding of the cause of the lag-1 sparing phenomenon is warranted.

The rationale for the present series of experiments begins with two simple observations: First, masking of T1 (as well as T2) is a requirement for producing the AB, though the nature of the T1 mask is flexible (Raymond et al., 1992; Seiffert & Di Lollo, 1997). Second, in an AB paradigm, T2 has the potential to act as the T1 "mask" when it occurs in the lag-1 position. Thus, when T2 occurs in the lag-1 position, it assumes the role not only of the second target, indexing the occurrence of the AB, but, importantly, that of T1 "mask" as well. The present report seeks to unconfound these two roles by examining how the lag-1 sparing phenomenon responds to the presence of a T1 mask prior to the conventional lag-1 position.

Akyürek and Hommel (2005) propose that lag-1 sparing depends not on the presence or absence of T1 masking but on the observer's estimation, aggregated over trials, of the duration of an attentional "episode," as established by the T1–T2 interval. Importantly, although the authors did investigate the same question as in the present report by presenting a mask (i.e., black letter) between T1 and T2 (i.e., black digits), they did so by inserting the T1 mask in the conventional lag-1 position (i.e., approximately 100 msec after T1 onset), where T2 normally occurs. This does not allow the role of masking to be investigated when T2 occurs in the canonical lag-1 position, as is investigated in the present experiments.

Another attempt to examine the role of T1 masking on lag-1 sparing was accomplished by Nieuwenhuis, Gilzenrat, Holmes, and Cohen (2005). These investigators masked T1 prior to the conventional lag-1 position (as did we), yet still found lag-1 sparing: a result in direct contrast with the present report. However, critical methodological differences between their procedure and our own likely account for the different outcome. Although Nieuwenhuis et al. presented an interruption pattern mask between T1 and the conventional lag-1 position, conventional AB tasks present successive stimuli with an intervening interstimulus interval (ISI). Nieuwenhuis and colleagues presented T1, the T1 mask, and T2 (i.e., lag 1) without an intervening ISI (i.e., all three items were presented within 150 msec, each for a duration of 50 msec). With no perceptual break between stimulus presentations, the extremely close temporal proximity of these three critical items may have caused them to be perceptually "chunked" and thus more easily identified (cf. Kellie & Shapiro, 2004).

Perhaps the most convincing examination of this issue was carried out by McLaughlin, Shore, and Klein (2001). Although these authors' primary goal was to examine the theoretically important issue of the relationship between T1 difficulty and the AB, the paradigm they employed did insert a T1 mask prior to the lag-1 position, as does the present series of experiments. T1 difficulty was manipulated by varying reciprocally the ratio of the duration of the target to its mask. The levels of T1 difficulty were hard (i.e., 15-msec T1–15-msec ISI–75-msec T2); medium (30-msec T1–15-msec ISI–60-msec T2); and easy (45-msec T1–15-msec ISI–45-msec T2). T2 and its respective mask were held constant at 45 msec each. The authors concluded that whereas the varying levels of T1 difficulty were found not to significantly affect T2 performance, lag-1 sparing was obliterated in all three difficulty conditions. At first glance, it may seem that the issue we wish to investigate has been resolved. However, whereas McLaughlin et al. make an important contribution to the understanding of lag-1 sparing and its relationship to T1 masking, their use of a noncanonical—that is, skeletal[1]—RSVP paradigm leaves important questions unanswered.

Recent research using electrophysiological evidence to compare the canonical full-stream versus skeletal paradigms suggests that target stimuli may undergo significantly different processing in each. Using a single-target paradigm, Craston, Wyble, and Bowman (2006) report two such distinct differences between the skeletal and full RSVP paradigms. First, the P300 component occurs with an accelerated onset and latency in the skeletal compared with the full RSVP paradigm. This is interpreted as reflecting the differences with which targets are defined in the two procedures: Targets in the skeletal paradigm are defined simply by their (first item) onset, which bypasses the need to search for a target-defining feature. Second, the amplitude of the N1 and P1 waveforms are significantly reduced in a full paradigm compared with a skeletal one. Craston et al. attribute this finding to the difference in the continuity of visual perception; the full RSVP paradigm presents targets in a more temporally regular pattern.

We do note that McLaughlin et al. (2001, Experiment 3) conclude that the skeletal and full RSVP streams are significantly correlated, which is interpreted by McLaughlin et al. to suggest that the two methods reflect similar underlying mechanisms. Nevertheless, as McLaughlin and colleagues did not assess the skeletal versus full RSVP paradigm in specific relation to lag-1 sparing, we believe it is important to study the role of the mask in the conventional AB paradigm, as we do in the present two experiments. The different pattern of results we found in contrast to McLaughlin et al. further underscores the importance of the present report.

EXPERIMENT 1

Method

Participants. Twenty undergraduate psychology students (8 males; 12 females) from the University of Wales, Bangor, with a mean age of 22 volunteered to participate. All participants reported normal or corrected-to-normal visual acuity and signed a consent form before completing the experiment.

Apparatus. Stimuli were presented on a 1,024 × 768 pixel, 32-bit color quality, 17-in. cathode ray tube monitor, using E-Prime Version 1.1 experimental software (Psychology Software Tools, Inc., Pittsburgh, PA). All stimuli were presented in intervals of the 17-msec refresh rate of the monitor.

Stimuli. An RSVP stream of 25 letters was presented in the center of a gray screen at a rate of 10–11 items per second (i.e., 17 msec "on," 85 msec "off"). During the 85-msec ISI, only the gray background was present. All but two of the items in the stream (T1 and T2) were black. All stimuli were presented in Times New Roman 18-point bold font. T1 and T2 were distinguished as white letters; T1 always preceded T2. Nontarget distractor items were drawn randomly from a subset of the alphabet excluding B, G, S, X, K, and Y. The letters B, G, and S were randomly presented as T1 items; X, K, and Y were randomly presented as T2 items. T1 presentation occurred randomly during the RSVP stream varying between the sixth and twelfth items. The lag position of T2 onset also varied randomly, appearing among lag positions 1, 2, 3, 6, and 7. The numerical representation of lag position represents the varying SOA between targets of 102 msec (lag 1) to 714 msec (lag 7). Note that temporal references to "lag positions" do not include the T1 mask inserted prior to 102-msec post-T1 onset. This was done to prevent confusion between the event of T1 masking and the theoretically significant lag-1 position (see Figure 1).

Procedure and Design. Two experimental conditions and one control condition, completed in separate trial blocks, were tested in a within-subjects design. In both experimental conditions, on every trial T1 was masked prior to the conventional lag-1 position (i.e., before 102 msec post-T1-onset). The two experimental conditions differed in that the SOA of the T1 mask was either 34 msec or 68 msec after T1 onset (see Figure 1). In the lag-1 sparing control—that is, "typical" AB condition—no T1 mask appeared prior to the lag-1 stimulus presentation. All conditions were dual-task, requiring participants to identify both T1 and T2 at the end of each trial. The order of conditions was counterbalanced across all participants.

With one exception, the number of trials was held constant across conditions (30 trials per lag position). In the 34-msec SOA experimental T1 mask condition, 40 trials were given per lag position. This alteration to the number of trials was implemented on the basis of pilot data which, in accord with previous research (Brehaut, Enns, & Di Lollo, 1999), indicated that the short interval between T1 and its mask (i.e., 34-msec SOA) resulted in a reduction of T1 accuracy. The addition of 10 extra trials per lag position allowed for scoring of all conditions to be based on a sufficient number of trials (15) for which T1 was identified correctly. Figure 1 illustrates the temporal format of stimulus presentation for experimental and control conditions. To begin each trial, participants pressed the keyboard space bar. Prior to the first item of the RSVP stream, a black fixation cross appeared for 500 msec, followed by a 500-msec blank interval. Participants were prompted for a three-alternative forced-choice response to the identity of T1 and T2 at the end of each trial. It should also be noted that the instructions that participants were given clearly stated that T1 presentation would always precede that of T2. Furthermore, participants were also prompted for their T1 response first.

Operationally defining lag-1 sparing. The distinction between the presence and absence of lag-1 sparing was first delineated by Visser et al. (1999), who proposed that to eliminate lag-1 sparing, second target performance at lag-1 must not exceed the lowest point of the AB by more than 5%; in other words, the typical U-shaped function must become more linear than quadratic, with lag-1 performance being within 5% of lag-3, which is typically the deepest point of the blink, occurring at approximately 300-msec post T1.

Although the Visser et al. (1999) definition is useful insofar as it establishes a highly conservative criterion for lag-1 sparing, we propose to relax this criterion for the present experiments, because it prevents us from examining theoretically important differences

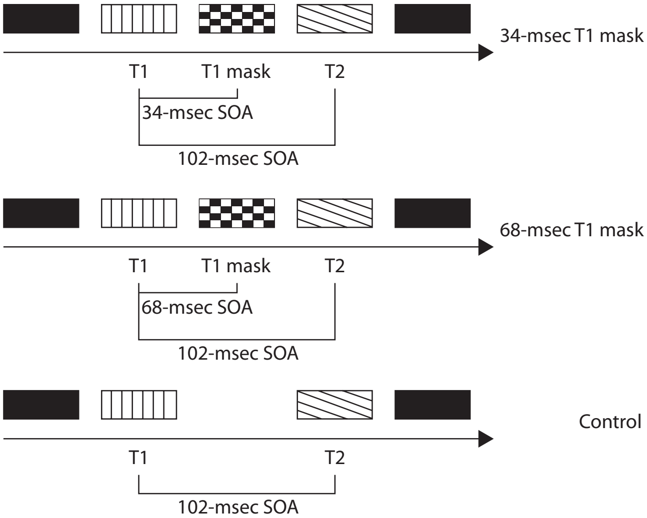

Figure 1. The top two panels show the 34-msec and 68-msec experimental conditions, respectively, indicating when the new T1 mask was inserted. The bottom panel represents the canonical (control) AB task.

arising from our experimental manipulations. Therefore, rather than attempt to classify lag-1 sparing as present or absent by such a stringent criterion, we focus on the degree of attenuation at lag 1 between masked and unmasked T1 conditions. We also evaluate the difference between lag-1 performance and a T2 "baseline" as established by T2 performance at lag 7, where the SOA between targets is sufficient to enable an estimate of T2 unaffected by T1.

Data analysis. Performance was indexed by the percentage of correct T2 detections on trials when T1 was identified correctly. As is common in AB experiments, this procedure was adopted on the grounds that when the first target is identified incorrectly, the source of error for any incorrect T2 responses cannot be accounted for. For the dependent measures of T1 and T2 (conditional; i.e., T2 given T1 correct), separate $3 \times 5 \times 4$ three-way mixed ANOVAs were conducted with the within-subjects factors of condition (i.e., 34-msec T1 mask, 68-msec T1 mask, and lag-1 sparing control) and lag (i.e., 102 msec, 204 msec, 306 msec, 612 msec, and 714 msec), along with the between-subjects factor of order[2] (i.e., the order in which participants completed the three conditions). The third variable, order, was analyzed for possible interactions with other variables, not only to determine whether there were order effects per se, but also to determine whether strategic factors may have affected T2 accuracy, as previously suggested by Akyürek and Hommel (2005). For all statistical tests, the criterion for significance was set at an alpha level of .05. To examine the pattern of reported main effects, pairwise comparisons were calculated using the Bonferroni correction for multiple comparisons.

Results

T1 performance. Analysis revealed a significant omnibus effect for condition [$F(2,32) = 29.470$, $MS_e = 1.161$, $p < .001$]. Both the overall effects of lag [$F(4,64) = 0.079$, $MS_e = 8.838$, $p = .988$] and order [$F(3,16) = 0.332$, $MS_e = 1.336$, $p = .802$] were nonsignificant. There were no interactions among variables at the .05 level of significance. Pairwise comparisons revealed the significant main effect of condition on T1 performance to be as follows: 68-msec T1 mask ($M = 81.72\%$, $SD = 11$); 34-msec T1 mask ($M = 73.3\%$, $SD = 18.01$); and lag-1 sparing control ($M = 95.19\%$, $SD = 7.20$). Figure 2 shows the mean percentages of correct T1 responses as a function of lag for each condition. It is no surprise that all three conditions were found to differ significantly in this respect, due to the effect of increased masking interference resulting from the close temporal proximity of T1 and its respective mask in the experimental conditions (Brehaut et al., 1999). Since no interaction occurred between lag and condition, we find no evidence of competition between targets with T2 in the lag-1 position, as suggested by Potter et al. (2002). According to these authors, such competition would be manifest as a reduction in T1 performance as the temporal interval between T1 and its mask decreased.

T2 performance. Analysis revealed no significant omnibus effect of condition [$F(2,32) = 0.601$, $MS_e = 1.486$, $p = .554$], although a significant effect of lag was present [$F(4,64) = 63.190$, $MS_e = 1.447$, $p < .001$]. Importantly, a significant interaction between lag and condition was found [$F(8,128) = 6.16$, $MS_e = 8.23$, $p < .001$]. No significant effect of order was present [$F(3,16) = 1.984$, $MS_e = 0.130$, $p = .157$]. Because neither condition nor lag interacted significantly with the variable of order, we conclude that our experimental design did not facilitate the adoption of any particular response strategy. A detailed treatment of this issue is presented in the discussion of Experiment 1. Figure 3 and Table 1 show the mean percentages of correct T2 responses as a function of nominal lag for each condition.

Lag-1 sparing. That lag-1 sparing occurred in our control condition was confirmed, since T2 performance at lag 1 did not differ significantly from that at lag 7. Lag-1 sparing can also be classified as having occurred according to the conservative criteria set by Visser et al. (1999); that is, lag-1 performance was more than 5% larger than the lowest point of the AB. Examination of the interaction between lag and condition revealed lag-1 performance to be significantly attenuated in the 34-msec and 68-msec T1 masking conditions, compared with the control condition. The 34-msec and 68-msec masking conditions did not differ significantly from each other at lag 1, but both conditions exhibited significantly worse performance than that shown at lag 7.

Lag-2 sparing. Although not statistically significant, an unexpected boost in performance at lag 2 occurred in both the 34-msec and 68-msec T1 mask conditions, relative to the control condition (see Figure 3 and Table 1). Within each experimental condition, performance at lag 2 was not significantly different than that at lag 7. Performance at lag 2 also did not differ between the two experimental masking conditions.

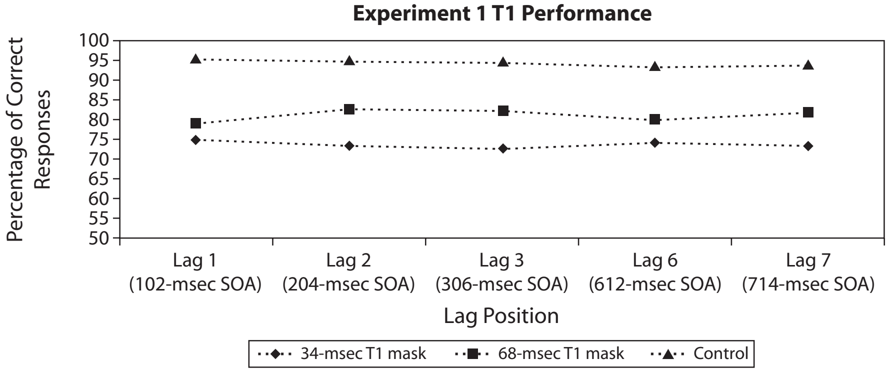

Figure 2. Mean percent correct T1 responses for all T2 lag positions for each of the three conditions of Experiment 1. Standard error bars are not shown in Figure 2, due to the low range of values between .009 and .028.

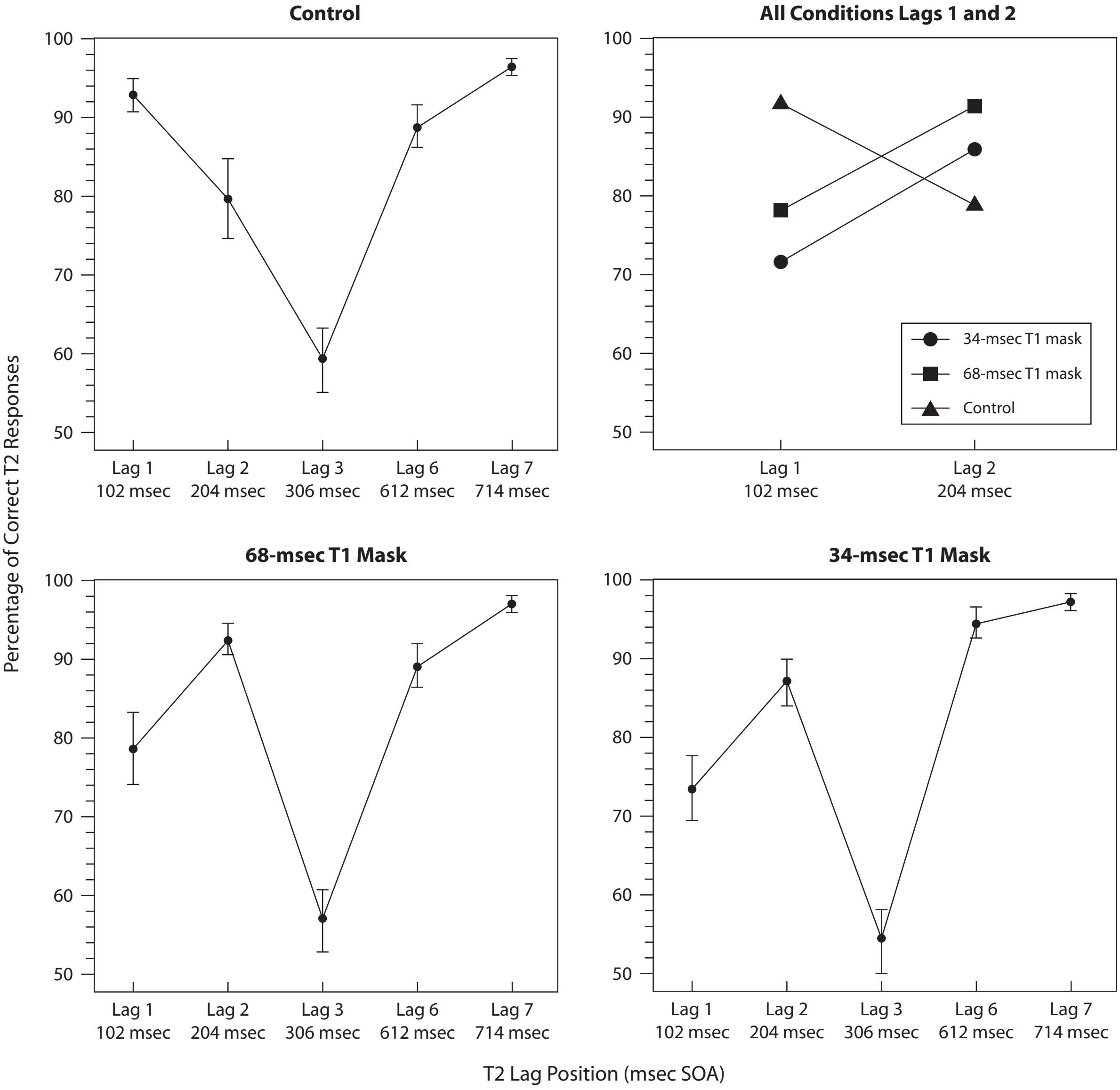

Figure 3. Mean percent correct T2 responses (contingent on correct T1 responses) for all lag positions for each of the three conditions in Experiment 1. Error bars represent standard errors of the means. The upper right panel shows an overlap of performance across all conditions at lag-1 and lag-2 positions.

Discussion

The results of Experiment 1 suggest that, in a canonical AB paradigm, masking T1 with a nontarget prior to the lag-1 position significantly attenuates lag-1 sparing. This finding supports the original notion of Raymond et al. (1992), that adequate masking of T1 is required in order for an AB to be caused. Importantly, our results suggest that processing of T1, by itself, in the canonical AB para-

Table 1
Mean Percentages of Correct T2 Responses (Experiment 1), With Standard Deviations

	Lag 1 102-msec SOA		Lag 2 204-msec SOA		Lag 3 306-msec SOA		Lag 6 612-msec SOA		Lag 7 714-msec SOA	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Lag-1 sparing control	94.05	6.52	79.80	12.38	59.10	15.71	88.42	15.30	96.35	6.46
34-msec T1 mask	73.80	13.25	86.75	13.11	53.60	21.39	94.80	8.24	96.75	4.75
68-msec T1 mask	78.05	12.42	92.15	7.59	56.75	18.30	89.35	15.47	97.25	5.05

digm does not cause a *time*-dependent lapse of attention, as might be presumed on the basis of reports by Akyürek and Hommel (2005) and Nieuwenhuis et al. (2005); instead, it suggests that the cause of the AB is *event*-dependent, that event being the occurrence of at least a nontarget (mask) uninterruptedly following T1.

As previously indicated, the lack of any interaction effects pertaining to the order in which participants completed conditions allows us to discount an alternative account proposed by Akyürek and Hommel (2005), according to whom participants keep the target integration window open for variable intervals of time, depending on the temporal rate at which stimuli are presented. Such a strategy, if present in Experiment 1, would undermine our conclusions regarding the theoretical basis of lag-1 sparing. Such an order effect might have reflected a shortened integration window being adopted each time a respective mask was shifted closer to T1 offset. It should be noted, however, that certain parameters used by Akyürek and Hommel—for instance, long-duration T1 targets—may have inadvertently contributed to the use of such strategies in their experiments.

Although we maintain that such an integration strategy did not take place in our own experiment, recent work by Akyürek, Riddell, Toffanin, and Hommel (2007) reports electrophysiological evidence further supporting the assertion that participants are strategically able to leave integration windows open for variable lengths of time. In their experiment, a "slow" and "fast" RSVP stream was presented to participants. In the fast condition, stimulus durations were held constant at 30 msec, with ISI of 70 msec. The slow condition presented stimuli at durations of 70 msec, with ISI of 30 msec. These authors interpret the presence of distinct ERP modulations isolated to the fast condition as reflecting the creation of a separate "event" for T2 not required in the slow condition; the integration window was maintained long enough to incorporate T2 in the slow condition, but not in the fast. This interpretation of the electrophysiological data, if correct, would, as the authors suggest, imply that global task expectations can guide attention. Whereas Akyürek et al. demonstrate that such a strategy can take place in certain circumstances, we maintain that this strategy was not adopted in our experiment.

Regarding the unexpected occurrence of lag-2 sparing: We attribute this outcome to a potential "capture of attention" resulting from a perceived increase in rate of stimulus presentation (i.e., a short transient event). Put another way, the inclusion of the new T1 mask altered the intervening ISI between stimuli for a brief three-item portion of the stream, relative to the regularity occurring from RSVP stream onset. The otherwise 85-msec ISI became 17 msec between T1 and the 34-msec mask, and 54 msec between T1 and the 68-msec mask. Furthermore, the ISI between the 34-msec mask and the lag-1 item was 51 msec, whereas the same ISI for the 68-msec mask was 17 msec.

A review of the literature reveals considerable debate on whether abrupt stimulus onsets alone are sufficient to guarantee attentional capture (Jonides & Yantis, 1988; Yantis & Jonides, 1984, 1990), or whether, instead of specific stimulus properties, the critical factor is the observer's attentional control setting (ACS), as calibrated by task demands (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992, 1993). Specifically, Folk and colleagues propose that attentional capture depends on whether the features of the capturing stimulus are included in the ACS. If stimulus features are not task-relevant (i.e., not part of the ACS), they will not capture attention.

In our view, the specific point in time at which an observer begins to evaluate each stream item is no doubt related to the temporal regularity of the RSVP stream itself. As this applies to targets and nontargets alike, the expected temporal rhythm (i.e., regularity of stimulus onsets) is likely included in the ACS. Although it is not the goal of the present work to systematically evaluate the relationship between exogenous and endogenous determinants of engaging attention, we believe attentional capture to be a likely mechanism underlying our unanticipated finding of lag-2 sparing.

EXPERIMENT 2

The results of Experiment 1 suggest that the lag-1 sparing phenomenon is not a ballistic process set in motion by the occurrence of T1 alone and is significantly attenuated when a nontarget stimulus occurs between the T1 and the (T2) stimulus, normally appearing in the lag-1 position of the canonical AB paradigm. The question that remains to be addressed, however, is the requirement of this intervening stimulus to produce this outcome. Given that lag-1 sparing is typically revealed by a second target appearing in the lag-1 position, in Experiment 2 we investigated whether the occurrence of T2 in the same temporal position as the T1 mask in the previous experiment would similarly attenuate lag-1 sparing. Moreover, this design enables us to investigate the outcome of changing the temporal regularity of the stream, as was effected in Experiment 1 by the introduction of the new mask, and which revealed lag-2 sparing. Finally, Experiment 2 was designed to enable a replication of the main outcome of Experiment 1.

Method

With the exception of a new sample of participants ($n = 15$), and the addition of 30 trials during which T2 was presented 34 msec post-T1 onset (see Figure 4), all methods were the same as in the 34-msec condition of Experiment 1. Specifically, T2 could occur 34 msec following T1, or in any one of the canonical lag-1 to lag-7 positions. When T2 occurred in the canonical lag positions, a nontarget (mask) was presented 34 msec following T1, as occurred in Experiment 1.

Data analysis. T1 and T2 performance were analyzed separately with a one-way ANOVA for the within-subjects factor of lag position. As in Experiment 1, pairwise comparisons were carried out with the Bonferroni correction, with .05 set as the criterion for significance.

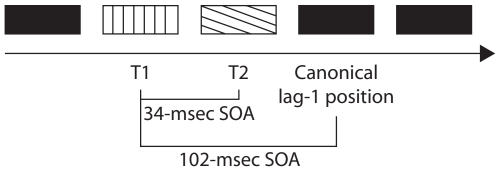

Figure 4. Temporal parameters for the 30 experimental trials presenting T2 at 34 msec post-T1-onset.

Results

T1 performance. No significant effect for the within-subjects factor of lag position was found [$F(5,70) = 1.041$, $MS_e = 4.55$, $p = .401$]. A summary of T1 and T2 performance by lag position can be viewed in Table 2.

T2 performance. One-way ANOVA analysis revealed a significant effect of the within-subjects factor of lag position for T2 performance [$F(5,70) = 18.519$, $MS_e = 3.53$, $p < .001$]. Pairwise comparisons revealed that T2 performance was not impaired (i.e., it was "spared") when presented 34 msec after T1 onset, because T2 performance on these trials was not significantly different than for trials at lag 7. Replicating the results of Experiment 1, T2 performance at the canonical lag-1 position was attenuated as significant differences emerged when compared with lag 7, as well as T2 performance at 34-msec SOA.

Discussion

In Experiment 1, masking T1 with a nontarget during the ~100-msec T1–T2 interval attenuated the lag-1 sparing effect. In Experiment 2, this finding was replicated (see canonical lag-1 position, Figure 5 and Table 2). However, lag-1 sparing remained when T2 was presented 34 msec post-T1 onset, placing it in the same temporal position as a nontarget that occurred in Experiment 1. Experiment 2 thus further supports our assertion that the insertion of a nontarget T1 mask prior to the canonical lag-1 position—not the resulting alteration in temporal parameters—is responsible for the attenuation of lag-1 sparing, revealed in Experiment 1. Finally, despite the exceptionally close temporal proximity between targets, no competition trade-offs between T1 and T2 were observed; T1 performance with T2 at 34 msec post-T1 onset was not significantly lower at the .05 level than with T2 presented at later lags (see Table 2). We return to this issue in the General Discussion.

GENERAL DISCUSSION

Experiments 1 and 2 suggest that lag-1 sparing does not result solely from the close temporal proximity of targets per se in the AB paradigm, but rather that it is to a great extent due to the absence of T1 masking. We are the first to definitively demonstrate the importance of T1 masking for lag-1 sparing while maintaining the canonical AB paradigm and parameters, notably the temporal position of the lag-1 item in a full RSVP stream. Although similar results were reported by McLaughlin et al. (2001) using a skeletal RSVP stream, the considerable interest in the literature on the lag-1 sparing phenomenon necessitates a full evaluation of the phenomenon. As emphasized in our introduction, Craston et al. (2006) suggest that the clear differences in detection and ensuing processing of targets in the skeletal versus full RSVP stream procedures underscores the need for a full evaluation of the lag-1 sparing phenomenon.

We now know that despite these differences, T1 masking plays a important role in lag-1 sparing for both skeletal and full RSVP AB paradigms. As to why masking T1 did not cause lag-1 performance to fall within 5% of the lowest point of the AB—as was the case in McLaughlin et al.'s (2001) skeletal experiment—the most likely answer lies in the fundamental difference between the two methods. In a skeletal RSVP stream, the first item to appear is T1. As reported by Craston et al. (2006), the P300 component for a single target in a single-target AB paradigm occurs with accelerated onset and latency for skeletal relative to full RSVP method. Thus, we argue that the appropriation of attention triggered at T1 onset was greater in McLaughlin et al.'s experiment that in our own.

We cannot fully evaluate whether integration or competition is operating at lag 1 in our experiment, because participants' foreknowledge of target order, along with restrictions placed on T1 versus T2 responses, prevented us from observing order reversals. However, this approach, rather than being a weakness, provides, we believe, an opportunity to obtain a "pure" measure of lag-1 performance unconfounded by T2 report errors resulting from order reversals. We do note, however, that although our approach prevented *report* of order reversals, it does not prevent the perception of order reversals. For most experiments investigating the lag-1 sparing phenomenon, it is impossible to tell what proportion of T2 errors reflect target order reversals or the AB, per se. Assuming, as most research has, that lag-1 sparing is always the product of either integration or competition, our results support integration. To reiterate: In neither experiment did T1 analysis reveal evidence of competition trade-offs between targets, as proposed by Potter et al. (2002).

Turning to the issue of lag-2 sparing, we propose this to be simply a by-product of an unexpected ISI value resulting from our T1 masking manipulation. This midstream alteration of presentation rate likely induces attentional capture (see Experiment 1 discussion), which is capable of temporarily overriding the AB bottleneck. Within the framework of traditional AB models with their emphasis on resource limitations (e.g., Chun & Potter, 1995; Shapiro et al., 1994) such a "capture" of attention could

Table 2
Mean Percentages of Correct T1 and T2 Responses (Experiment 2), With Standard Deviations

	34 msec Post-T1		Lag 1 102-msec SOA		Lag 2 204-msec SOA		Lag 3 306-msec SOA		Lag 6 612-msec SOA		Lag 7 714-msec SOA	
Performance	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
T1	95.13	4.59^{b}	96.87	4.37^{b}	97.40	5.00^{b}	93.00	6.64^{b}	97.20	8.13^{b}	94.67	8.29^{b}
T2	93.70	5.93^{a}	73.00	7.53^{b}	80.08	9.28^{b}	54.54	15.42^{c}	91.04	25.5^{a}	93.82	6.69^{a}

Note—Means in the same row that do not share the same designation "a," "b," or "c" differ at $p < .05$ with the applied Bonferroni correction for multiple comparisons.

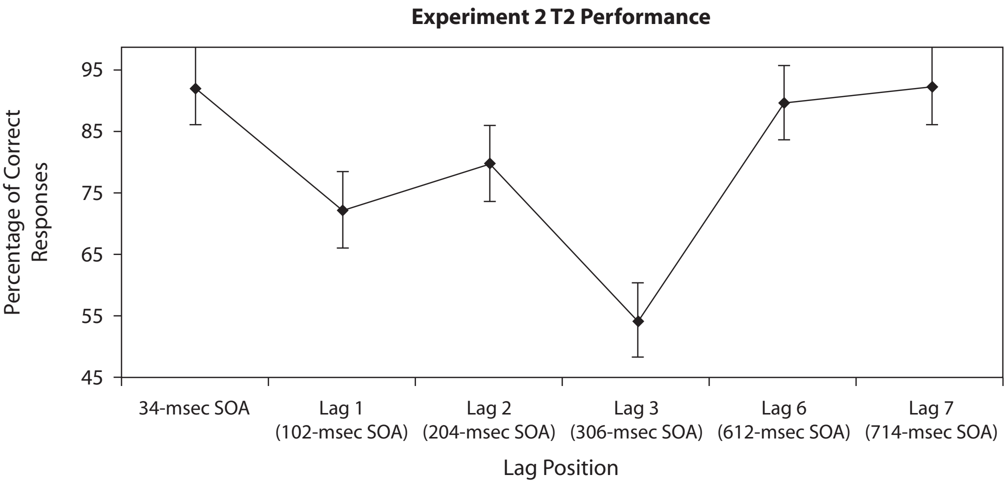

Figure 5. Mean percent correct T2 responses (contingent on correct T1 responses) for all temporal positions of T2 in Experiment 2. Error bars represent standard errors of the means.

easily be said to summon additional attentional resources for target processing. For example, such resources could prevent the representation of T2 from decaying before it gains access to the second stage of Chun and Potter's two-stage model.

The present results are congruent with the conclusion drawn from the first AB study (Raymond et al., 1992), that masking is required to yield an AB. Importantly, along with McLaughlin et al. (2001), we are able to conclude that lag-1 sparing is, at least in part, an epiphenomenon of the failure to adequately mask T1. We consider our work to be congruent with Di Lollo et al. (2005) in regard to distinctly different responses that arise to a "nontarget" versus a "target" mask in the T1+1 position. Di Lollo and colleagues argue that the AB occurs as a result of a temporary loss of control over endogenous search processes. Specifically, when the T1+1 item fails to match an endogenously set target template, processes involving search become disrupted, resulting in a reduced ability to process subsequent targets. Because the nontarget T1 mask we inserted in Experiment 1 would have failed to match any endogenously set target template for T1, our findings are congruent with Di Lollo et al.'s account.

Because reference to the temporary loss of control model has become common in the AB literature, it is important to point out that the theory is not incongruent with more traditional AB models. Such models—for example, Chun and Potter (1995) and Shapiro et al. (1994)—argue that sufficient perceptual aspects of the second target are recognized to determine whether it is a target or a nontarget, but that resource limitations prevent access to conscious awareness. The notion of "temporary loss of control" is arguably another way of describing the process by which information not matching a (T1) target template strains limited resources.

AUTHOR NOTE

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REFERENCES

Akyürek, E. G., & Hommel, B. (2005). Target integration and the attentional blink. *Acta Psychologica*, **119**, 305-314.

Akyürek, E. G., Riddell, P. M., Toffanin, P., & Hommel, B. (2007). Adaptive control of event integration: Evidence from event-related potentials. *Psychophysiology*, **44**, 383-391.

Bowman, H., & Wyble, B. (2007). The simultaneous type, serial token model of temporal attention and working memory. *Psychological Review*, **114**, 38-70.

Brehaut, J. C., Enns, J. T., & Di Lollo, V. (1999). Visual masking plays two roles in the attentional blink. *Perception & Psychophysics*, **61**, 1436-1448.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance*, **21**, 109-127.

Craston, P., Wyble, B., & Bowman, H. (2006). An EEG study of masking effects in RSVP [Abstract]. *Journal of Vision*, **6**(6), 1016a.

Di Lollo, V., Kawahara, J., Ghorashi, S. M. S., & Enns, J. T. (2005). The attentional blink: Resource depletion or temporary loss of control? *Psychological Research*, **69**, 191-200.

Folk, C. L., & Remington, R. [W.] (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception & Performance*, **24**, 847-858.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception & Performance*, **18**, 1030-1044.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1993). Contingent attentional capture: A reply to Yantis (1993). *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 682-685.

Hommel, B., & Akyürek, E. G. (2005). Lag-1 sparing in the attentional blink: Benefits and costs of integrating two events into a single episode. *Quarterly Journal of Experimental Psychology*, **58A**, 1415-1433.

Jolicœur, P., & Dell'Acqua, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology*, **36**, 138-202.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics*, **43**, 346-354.

Juola, J. F., Botella, J., & Palacios, A. (2004). Task- and location-switching effects on visual attention. *Perception & Psychophysics*, **66**, 1303-1317.

Kellie, F. J., & Shapiro, K. L. (2004). Object file continuity predicts attentional blink magnitude. *Perception & Psychophysics*, **66**, 692-712.

KESSLER, K., SCHMITZ, F., GROSS, J., HOMMEL, B., SHAPIRO, K. [L.], & SCHNITZLER, A. (2005). Cortical mechanisms of attention in time: Neural correlates of the Lag-1-sparing phenomenon. *European Journal of Neuroscience*, **21**, 2563-2574.

MCLAUGHLIN, E. N., SHORE, D. I., & KLEIN, R. M. (2001). The attentional blink is immune to masking-induced data limits. *Quarterly Journal of Experimental Psychology*, **54A**, 169-196.

NIEUWENHUIS, S., GILZENRAT, M. S., HOLMES, B. D., & COHEN, J. D. (2005). The role of the locus coeruleus in mediating the attentional blink: A neurocomputational theory. *Journal of Experimental Psychology: General*, **134**, 291-307.

POTTER, M. C., STAUB, A., & O'CONNOR, D. H. (2002). The time course of competition for attention: Attention is initially labile. *Journal of Experimental Psychology: Human Perception & Performance*, **28**, 1149-1162.

RAYMOND, J. E., SHAPIRO, K. L., & ARNELL, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception & Performance*, **18**, 849-860.

SEIFFERT, A. E., & DI LOLLO, V. (1997). Low-level masking in the attentional blink. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 1061-1073.

SHAPIRO, K. L., ARNELL, K. M., & RAYMOND, J. E. (1997). The attentional blink. *Trends in Cognitive Sciences*, **1**, 291-296.

SHAPIRO, K. L., RAYMOND, J. E., & ARNELL, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 357-371.

VISSER, T. A. W., BISCHOF, W. F., & DI LOLLO, V. (1999). Attentional switching in spatial and nonspatial domains: Evidence from the attentional blink. *Psychological Bulletin*, **125**, 458-469.

WARD, R., DUNCAN, J., & SHAPIRO, K. L. (1996). The slow time-course of visual attention. *Cognitive Psychology*, **30**, 79-109.

YANTIS, S., & JONIDES, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception & Performance*, **10**, 601-621.

YANTIS, S., & JONIDES, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 121-134.

NOTES

1. The skeletal paradigm employs only four items: two targets, both masked, separated by a varying SOA (cf. Ward, Duncan, & Shapiro, 1996). Targets and their respective masks can occur in different spatial locations (see Ward et al., 1996) or in the same spatial location.

2. In Experiment 1, although the three conditions could have been completed in six possible orders, only four such orders were implemented during data collection and subsequent analyses.

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