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Both exogenous and endogenous target salience manipulations support resource depletion accounts of the attentional blink: A reply to Olivers et al

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Abstract

Input-control theories of the attentional blink (AB) suggest that this deficit results from impaired attentional selection caused by the post-Target 1 (T1) distractor (Di Lollo et al., 2005; Olivers et al., 2007). Accordingly, there should be no AB when there are no intervening distractors between the targets. Contrary to these hypotheses, Dux et al. (2008) observed an AB (T3 deficit) when three targets, from the same attentional set, were presented successively in a rapid stream of distractors if subjects increased the resources devoted to T1 processing, a result consistent with resource depletion accounts of the AB. However, Olivers et al. (this issue) argue that Dux et al.'s results can be better explained by the relationship between T1 and T2 rather than between T1 and T3, and by target discriminability effects. Here, we find that manipulating the resources subjects devote to T1, either exogenously (target perceptual salience) or endogenously (target task-relevance), affects T3 performance even when controlling for T2 and target discriminability differences. These results support Dux et al.'s conclusion that T1 resource depletion underlies the AB.

The attentional blink (AB; Raymond, Shapiro & Arnell, 1992) refers to subjects' reduced ability to report the second (T2) of two targets in a rapid serial visual presentation stream (RSVP) of distractors, if it appears within 200–600 ms of the first target (T1). Recently, the mechanisms responsible for this deficit have been under debate: We (Dux, Asplund & Marois, 2008) have suggested that the AB reflects T1 resource depletion; however, Olivers, Spalek, Kawahara and Di Lollo (this issue) state we have "no basis for such a claim" (p. 1) and present alternative explanations for our results. Below we present new data and arguments that refute Olivers et al.'s (this issue) hypotheses and provide further support for a T1 resource depletion account of the AB.

As previously discussed (Dux et al., 2008), a classic theory of the AB postulates that the deficit arises due to limited-capacity resources being devoted to T1 processing at the expense of T2 (e.g., Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998). According to this theory, at short T1–T2 lags T2 performance suffers because T1 is the subject of limited-capacity attentional processing when the second target appears, whereas at longer lags T2 performance is unimpaired because T1 processing is complete before the presentation of T2. Recently, such "resource depletion" (RD) accounts have been challenged by the finding that in RSVP streams in which three targets, drawn from the same attentional set, are presented sequentially (Uniform condition), performance for the third target does not differ from that for the first target. However, if the second target is replaced with a distractor from a different attentional set

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(Varied condition), T3 performance is significantly impaired relative to that of T1 (e.g., Di Lollo, Kawahara, Ghorashi & Enns, 2005). According to the RD account, an AB (T1 performance > T3 performance) should be observed in both the Uniform and Varied conditions because T1 will undergo the same limited capacity processing in both conditions. The finding that an AB only occurs in the Varied condition therefore appears inconsistent with RD theories.

To account for these three-target results, Di Lollo et al. (2005) and Olivers, Van der Stigchel and Hulleman (2007) propose that it is not T1 processing that gives rise to the AB, but rather processing of the distractor that directly follows T1 (T1+1 distractor). The precise mechanisms hypothesized to be responsible for causing the AB in these input control (IC) accounts differ, with Di Lollo et al. (2005) suggesting that the T1+1 distractor disrupts an input filter while Olivers et al. (2007) postulate that this stimulus instead triggers a suppressive response. However, both models suggest that the AB does not represent T1 resource depletion, but rather imprecise attentional control upon presentation of the T1+1 distractor.

We (Dux et al., 2008) have recently challenged these IC accounts by demonstrating that an AB can be observed not only in Varied trials, but also under Uniform conditions if subjects increase the resources they devote to T1 processing. Firstly, we replicated Di Lollo et al. (2005) by demonstrating that no AB was observed when three white letter targets were presented sequentially amongst a stream of white digit distractors (Uniform condition), but that a T3 deficit was present when T2 was replaced with a white digit target (Varied condition). To increase attentional resources devoted to T1, we colored the target stimuli red, thus causing T1 to capture attention because of its abrupt color onset (Maki & Mebane, 2006) relative to the preceding distractors. Compared to the Uniform condition with all white stimuli, this target color manipulation increased T1 accuracy and lowered T3 accuracy, thereby creating a blink, as predicted by the RD account of the AB. Finally, we confirmed that the T3 deficit was indeed an AB, and not a working-memory maintenance limitation, by manipulating the lag (the standard AB manipulation) between T1 and T3 under Red Target Uniform conditions, with T3 appearing either directly after T2 (Short Lag) or five distractor items after T2 (Long Lag). We observed a much greater T3 deficit at the Short relative to the Long Lag, indicating that the T1–T3 performance difference was most likely caused by an encoding bottleneck. From these results, we concluded that an AB can be observed under Uniform conditions if sufficient resources are devoted to T1 processing. This finding fits remarkably well with RD theories but poses a serious challenge to IC accounts because this latter group of theories predicts that an AB should not be observed unless a T1+1 distractor impairs attentional control (Di Lollo et al., 2005; Olivers et al., 2007).

Olivers et al. (this issue) agree with us that IC theories cannot account for ABs observed under Uniform conditions, but they dispute whether the T3 deficits observed in our study (Dux et al., 2008) were indeed ABs. They have two main points of criticism: 1) T1 and T3 performance are not directly related and instead reflect separate relationships between T1 and T2, and T2 and T3. Consequently, in their view we have misinterpreted a correlation; 2) The enhanced T3 performance at the Long Lag relative to the Short Lag observed by Dux et al. (2008) reflects increased discriminability for T3 in the former condition rather than recovery from resource depletion. Below, we present arguments and new data that refute the claims made by Olivers and colleagues (this issue). Furthermore, we not only replicate our previous finding that increasing T1 perceptual salience can trigger an AB under Uniform conditions, we also show that manipulations that affect T1 task-relevance can also trigger an AB. Taken together, these new findings provide strong support for resource depletion accounts of the AB.

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Do subjects trade-off T1 and T3 performance?

Olivers et al. (this issue) suggest that differences in T1 and T3 performance between Uniform and Varied trials, where all stimuli are the same color, do not reflect subjects trading-off T1 and T3 performance, but is instead due to the influence of T2 on the two other targets. Put differently, Olivers et al. (this issue) propose that T1 and T3 performance are not related and that the differences between Uniform and Varied performance instead reflect T2 being drawn from a different category in the two conditions. In support of their hypothesis, Olivers et al.'s (this issue) reanalysis of previous data (from Olivers et al., 2007) showed that T1 performance was not affected when a third target was added to either two-target Uniform or Varied trials (as might be expected if targets compete for limited attentional resources), but it was significantly decreased whenever a second target was inserted between T1 and T3. This finding provides evidence that T2 may indeed contribute to T1 performance differences between the Uniform and Varied conditions. However, this result is also somewhat consistent with RD accounts, as it could reflect a trade-off in performance between the first and second targets due to the temporal position of T2. More importantly, Olivers et al.'s (this issue) criticism is not applicable to Dux et al.'s (2008) findings, as their conclusion that T1 and T3 performance are related was not based on the comparison of Uniform and Varied trials, but rather on the comparison of the Red Target Group and White Target Group. Crucially, in both groups, T2 was drawn from the same category as the other targets and T3 was equally discriminable, as it was masked by stimuli of the same color. Thus, Dux et al.'s finding of enhanced T1 and reduced T3 performance in the Red Target Uniform condition relative to the White Target Uniform condition (with a trend in the same condition in the Varied trials) cannot be due to the influence of T2 because there were no differences in T2 stimulus characteristics relative to its surrounding targets between the conditions. Therefore subjects do directly trade-off T1 and T3 performance under three-target RSVP conditions.

Experiment 1: Further evidence of a T1–T3 tradeoff

Our previous study (Dux et al., 2008) provided evidence for a T1–T3 performance tradeoff when the exogenous salience of T1 was manipulated. However, if RD accounts of the AB are correct, other T1 attentional manipulations should also affect T3 performance. Specifically, endogenous manipulations of target relevance should yield the same results. Moreover, if subjects trade-off T1 and T3 performance under RSVP conditions, then just as T1 performance increases and T3 performance decreases when T1 is attentionally emphasized, the reverse pattern of performance (lower T1 performance and higher T3 performance) should be observed when T3 is prioritized.

To test this, we presented subjects with Uniform and Varied trials containing targets and distractors of the same color and manipulated the resources subjects devoted to T1 and T3 by varying each target's task-relevance (see Figure 1A). One group of subjects had to report either all the targets or just T1 (randomized within block; T1-Relevant trials), while the other group had to report either all the targets or just T3 (T3-Relevant trials). Thus, for one group of subjects T1 was relevant in 100% of the trials and T2 and T3 were relevant in only 50% of the trials, whereas for the second group T3 was always relevant and T1 and T2 were relevant in only half the trials. If T1 resource depletion gives rise to the AB and subjects trade-off performance between T1 and T3, then T3 performance should be reduced relative to T1 in T1-Relevant trials. Conversely, T3-Relevant trials should result in increased T3 performance and reduced T1 performance.

Method

Subjects: Forty-eight members (19 females, mean age = 19 years) of the Vanderbilt University community participated. Subjects were allocated to either the T1-Relevant Group or the T3-

Relevant Group (twenty-four subjects each). All had normal or corrected-to-normal vision. Three additional subjects were excluded for not following the task instructions.

Design: Two independent variables were manipulated: Target Relevance (T1-Relevant Group vs. T3-Relevant Group) and Trial Type (Uniform vs. Varied). Target Relevance was manipulated between groups while Trial Type was manipulated within groups across blocks of trials. T1, T2 and T3 accuracy were the measured variables.

Stimuli & Apparatus: Stimuli were white and appeared centrally on a grey background in Courier New font subtending 1° of visual angle at a viewing distance of approximately 57 cm. Targets were three letters drawn from the alphabet excluding I, L, O, Q, U and V in the Uniform trials and were two letters and a digit (2–9) in the Varied trials. Distractors were also selected from the digits 2–9. No stimulus was repeated in the RSVP stream and each trial contained three targets, seven distractors and an “& ” mask that appeared at the end of the stream. Stimuli were presented for 93.3 ms each with no inter-stimulus interval. T1 appeared equally often at serial positions 3–7, and was immediately followed by T2 and T3. The experiment was programmed using MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

Procedure: The experiment was self-paced. Trials began with a white fixation square for 493 ms, followed by the RSVP stream. For all trials, subjects entered the identity of the target(s), without time pressure, via a keyboard at the end of each stream when visually prompted (e.g., “Target 1?”). To manipulate the resources subjects devoted to the targets, the task-relevance of T1 and T3 was manipulated across groups of subjects. For the T1-Relevant Group, all trials involved reporting T1, while half the trials also required report of T2 and T3. Similarly, for the T3-Relevant Group, all trials involved reporting T3, whereas only half required the report of all three targets. Importantly, subjects were only aware of whether they were to report one or three targets at the end of each trial. The presence of trials where only one target required report was expected to lead subjects to emphasize processing of ether T1 or T3 over the other targets (T1 for the T1-Relevant Group and T3 for the T3-Relevant Group).

Each of the two test blocks contained 120 trials, the first 20 of which were practice and therefore not analyzed. Within groups, the Trial Type of the first block was counterbalanced across subjects.

Results & Discussion—Figure 2 displays mean target accuracy for Uniform and Varied trials plotted separately for the T1-Relevant and T3-Relevant Groups (data from single-target trials were excluded from the analysis). The data were submitted to a 2 (Target Relevance) × (Trial Type) ×3 (Target Number) mixed-factorial ANOVA, which yielded a significant interaction between Target Relevance and Group, $F(2, 92) = 11.9$, $p<.001$, indicating a different pattern of performance, in both Uniform and Varied trials, across the three targets in the two groups.

Unsurprisingly, a T3 deficit (relative to T1) was found in the Varied condition of the T1-Relevant group, $t(23)=10.6$, $p<.001$. More importantly, a T3 deficit was also observed in the Uniform condition of that group, $t(23)=2.9$, $p<.008$. Thus, by endogenously increasing the resources subjects devoted to T1 processing, we observed a T3 deficit under Uniform conditions.

Strikingly, a reversed pattern of results was found in the T3-Relevant group. Specifically, in the Uniform condition, T3 accuracy was superior to that for T1, $t(23)=-.009$. Moreover, although a complete pattern reversal was not observed in the Varied condition, the accuracy difference between T1 and T3 was nevertheless smaller here than that observed in the Varied condition of the T1-Relevant Group, due to a decrease in T1 accuracy and an increase in T3 performance, $t(46)=2.5$, $p<.02$.

Taken together, these results show that subjects do trade-off T1–T3 performance under Uniform conditions, as we found that simply varying the relevance of the targets -without manipulating their physical appearance - influenced the pattern of T1 and T3 accuracy. Importantly, these results were obtained without manipulating T2 category and there was no influence of Target Relevance on T2 (*ps*>.5). Thus, T1 and T3 performance do appear to be directly related, contrary to Olivers et al.'s (this issue) proposal.

Does target discriminability, rather than resource depletion, account for the AB?

Experiment 2: Dux et al.'s (2008) lag effect reflects resource depletion

To test if the T3 deficit they observed under Uniform conditions was indeed and AB and did not reflect a working-memory storage limitation (because of the requirement to maintain three targets), Dux et al. (2008) varied the temporal lag (the standard AB manipulation) between T1 and T3 under Red Target Uniform conditions. Their logic was that if T1 resource depletion was responsible for the AB, then T3 performance should recover with increasing lag as more attentional resources were released from T1 processing. A T3 deficit was observed at both the Short (targets presented successively) and Long (T2 and T3 separated by 5 distractors) Lags, but it was much larger in the former condition. Thus, Dux et al. (2008) concluded that their Uniform T3 deficit was an AB most likely caused by an encoding bottleneck.

Olivers et al. (this issue) challenge this conclusion and instead argue that the lag effect observed by Dux et al. (2008) was simply due to T3 being more discriminable at the Long Lag compared to the Short Lag, because only in the former condition was T3 an abrupt color onset. After replicating Dux et al.'s (2008) lag effect when the targets and distractors differed in color, Olivers et al. found no T3 performance difference between the Short and Long Lags when the post-target distractors were the same color as the targets. At first glance, Olivers et al.'s results suggest that Dux et al.'s (2008) lag effect was indeed simply due to differences in T3 discriminability at the Short and Long Lags. However, while Olivers et al. replicated Dux et al.'s (2008) original result, they did not replicate their methodology: In addition to equating T3 discriminability, they randomly varied both Lag and T1 stream position within blocks of trials, whereas Dux et al. (2008) did not. This is important because manipulations that increase the uncertainty of the temporal position of the targets in RSVP have been shown to increase AB magnitude (Chun & Potter, 1995; Martens & Johnson, 2005). Thus, Olivers et al.'s (this issue) results could be due to equating T3 discriminability across the Short and Long Lags, or the interaction of this manipulation and the other experimental characteristics that they altered. To test whether discriminability alone was the important factor, we therefore equated T3 discriminability between Short and Long Lag trials using Dux et al.'s original design (Experiment 2a). In addition we also tested whether increasing the Lag further reduced the T3 deficit, as a more complete recovery from the AB may be observed at very Long Lags (Experiment 2b). Finally, as subjects had to remember T3 for a longer period of time in the Short Lag condition, we also tested whether having an equal number of post-T3 distractors in the Short and the Long Lags yielded the same results (Experiment 2c).

Method—Experiment 2 was identical to Dux et al.'s (2008) second experiment except where specified.

Subjects: Forty-two members (17 females, mean age = 19 years) of the Vanderbilt University community participated. Subjects were excluded if they had low T1 accuracy (n=5, ≤ 69%), but this criterion did not change the pattern of results. Each experiment had 14 subjects.

Design: In all the experiments Lag (Short Lag and Long Lag) was manipulated across blocks of trials. Short Lag trials contained three targets presented successively, whereas in Long Lag trials five (Experiment 2a) or nine (Experiment 2b and 2c) distractors separated T2 and T3.

Stimuli & Apparatus: In both blocks of trials three red letter targets appeared in an RSVP stream of digit distractors (see Figure 1B). Distractors prior to T1 were white and those post-T1 were red. Eight distractors were present in Experiment 2a, twelve in Experiment 2b, three in the Short Lag condition of Experiment 2c and twelve in the Long Lag condition of Experiment 2c. For Short Lag trials, targets appeared at serial positions 3, 4 and 5. In the Long Lag trials of Experiment 2a, targets appeared at serial positions 3, 4 and 10, whereas in Experiments 2b and 2c they appeared at positions 3, 4, and 14. Repeated presentations of distractors (necessitated by the length of the RSVP streams in Experiments 2b and 2c) occurred at least 650ms apart.

Procedure: All targets required report in each trial. One block of each trial type was completed (120 trials each, the first 20 trials were practice). Presentation order was counterbalanced across subjects.

Results & Discussion—Figure 3 shows mean target performance at the Short and Long Lags plotted separately for Experiments 2a, 2b and 2c. The data from the experiments were submitted to separate 2 (Lag) × 3 (Target Number) repeated-measures ANOVAs, each of which yielded a significant 2-way interaction (*F*s>4.9, *ps*<0.02), demonstrating that in all the experiments performance across the three targets was different in the two Lag conditions.

In Experiment 2a, significant T3 deficits were present at both the Short, $t(13)=4.7$, $p<.001$, and Long Lag, $t(13)=2.7$, $p<.02$, but this T1–T3 difference was much smaller in the latter condition, $t(13)=2.2$, $p<.05$. Experiment 2b demonstrated that the T3 deficit in the Long Lag condition was abolished when the T1–T3 Lag was increased (from Lag 7 to Lag 11). Here, while there was still a significant T3 deficit at the Short Lag, $t(13)=4.8$, $p<.001$; this deficit was absent at Long Lag ($p=.18$). Finally, Experiment 2c confirmed that T3 performance differences between the Short and Long Lags were not due to a larger number of distractors following T3 in the former condition, for when a single distractor followed T3 at both lags the results mirrored those from Experiment 2b: A T3 deficit at the Short, $t(13)=2.7$, $p<.001$, but not the Long ($p=.34$) Lag.

Taken together, these results replicate those from Dux et al.'s (2008) second experiment and indicate that a Lag effect can be obtained when controlling for T3 discriminability differences between the lags. Evidently, Olivers et al.'s (this issue) failure to find an attenuated T3 deficit at the Long Lag reflects the interaction of their color manipulation with the other methodological differences that they employed relative Dux et al.'s experiment. These results also confirm Dux et al.'s Uniform T3 deficit is not due to a working-memory maintenance limitation, as T3 performance was worse at the Short than at the Long Lag even though both conditions contained the same number of targets.

Conclusions—Olivers et al. (this issue) claimed that Dux et al. (2008) provided no evidence supporting the hypothesis that T1 resource depletion gives rise to they AB. They suggested that subjects do not trade-off performance between T1 and T3 under Uniform conditions and that Dux et al.'s a Lag effect in Red Target Uniform trials was the result of differences in T3

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discriminability at the Short and Long Lags. In short, they postulated that the Uniform T3 deficit found by Dux et al. (2008) was not an AB.

Here, we have not only shown that our Uniform T3 deficit is indeed an AB, but also that it can be produced regardless of whether the attentional resources devoted to T1 are manipulated exogenously or endogenously. In Experiment 1, we demonstrated that three-target RSVP performance could be strongly affected by manipulating the task-relevance of the targets. When T1 required report on 100% of the trials and T2 and T3 only required report on 50% of the trials, T1 accuracy increased and T3 accuracy decreased. When T3 accuracy was emphasised, the opposite pattern of results was observed. In addition, Experiment 2 demonstrates that the larger T3 deficit observed in Uniform trials at the Short relative to the Long Lag was not due T3 discriminability differences between these conditions. This result also demonstrates that a working-memory maintenance limitation cannot explain the AB observed in Uniform trials. Taken together, these findings reinforce those of Dux et al. (2008) and demonstrate that subjects do trade-off target performance in Uniform trials. Our results therefore strongly support RD accounts of the AB because they demonstrate that attentional prioritisation of T1 impairs T3 processing.

It is worth noting, however, that the flexibility of these attentional resources may not be unlimited, as the results from the Varied condition of Experiment 1 demonstrate that while emphasizing T3 influences T1 and T3 performance it does not always lead to performance for the third target being superior to that for T1 (as was the case in the T3-Relevant Uniform trials). In addition, our results do not rule out the possibility that selection limitations may contribute to the AB deficit. However, the findings do place severe constraints on IC accounts (Dux et al., 2008; this issue) because they show that a T1 processing bottleneck plays a vital role in the generation of the AB. Evidently, the T1 resource depletion hypothesis is well and truly back in the saddle.

Acknowledgments

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References

Brainard DH. The psychophysics toolbox. Spatial Vision 1997;10:433–436. [PubMed: 9176952]

Chun MM, Potter MC. A two-stage model for multiple targetdetection in rapid serial visual presentation. Journal of Experimental Psychology: Human Perception and Performance 1995;21:109–127. [PubMed: 7707027]

Di Lollo V, Kawahara J, Ghorashi SMS, Enns JT. Theattentional blink: Resource depletion or temporary loss of control. Psychological Research 2005;69:191–200. [PubMed: 15597184]

Dux PE, Asplund CL, Marois R. An attentional blink for sequentially presented targets: Evidence in favor of resource depletion accounts. Psychonomic Bulletin & Review 2008;15:809–813. [PubMed: 18792508]

Jolicœur P, Dell'Acqua R. The demonstration of short-termconsolidation. Cognitive Psychology 1998;36:138–202. [PubMed: 9721199]

Maki WS, Mebane MW. Attentional capture triggers an attentionalblink. Psychonomic Bulletin & Review 2006;13:125–131. [PubMed: 16724779]

Martens S, Johnson A. Timing attention: Cuing target onset intervalattenuates the attentional blink. Memory & Cognition 2005;33:234–240.

Olivers CNL, Van der Stigchel S, Hulleman J. Spreading thesparing: against a limited-capacity account of the attentional blink. Psychological Research 2007;71:126–139. [PubMed: 16341546]

Pelli DG. The videotoolbox software for visual psychophysics:transforming numbers into movies. Spatial Vision 1997;10:437–442. [PubMed: 9176953]

Raymond JE, Shapiro KL, Arnell KM. Temporary suppressionof visual processing in an RSVP task: An attentional blink? Journal of Experimental Psychology: Human Perception and Performance 1992;18:849–860. [PubMed: 1500880]

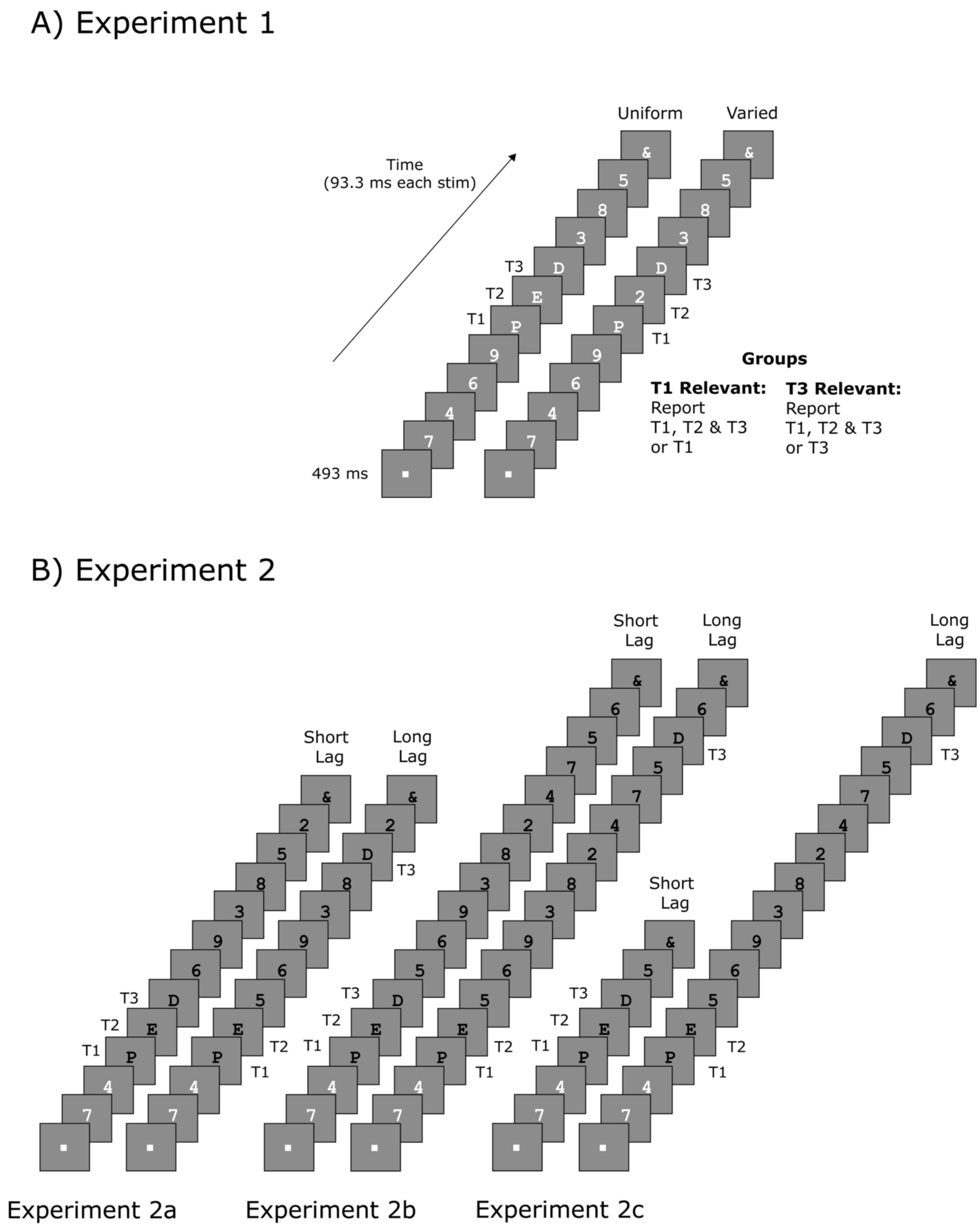

Figure 1.

A) Example RSVP streams for Experiments 1. B) Example RSVP streams for Experiments 2a, 2b and 2c. Black stimuli appeared in red in all the experiments.

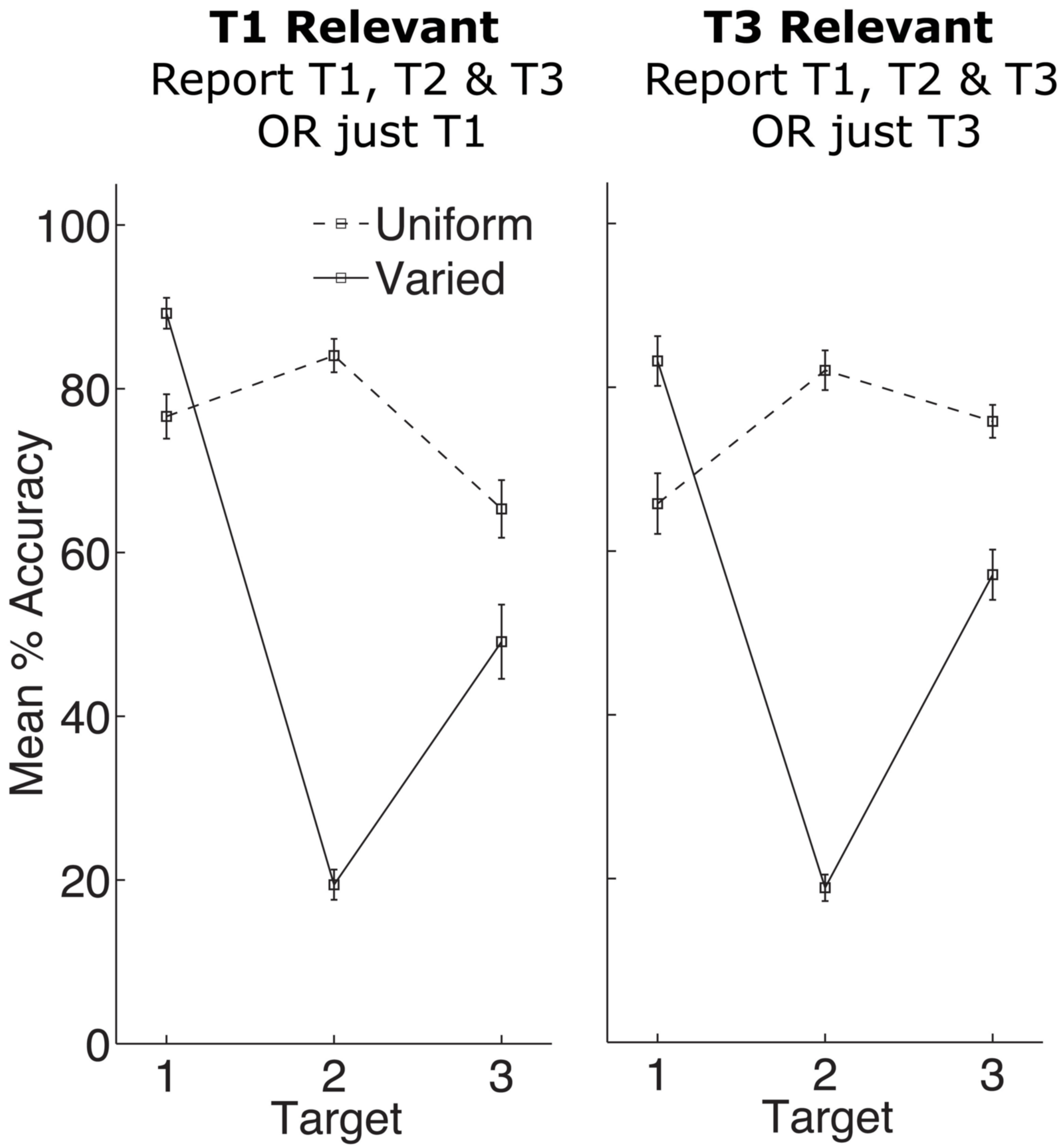

Figure 2.
Mean T1, T2, and T3 accuracy in Experiment 1 as a function of Trial Type (Uniform vs. Varied), plotted separately for the T1-Relevant Group and the T3-Relevant Group.

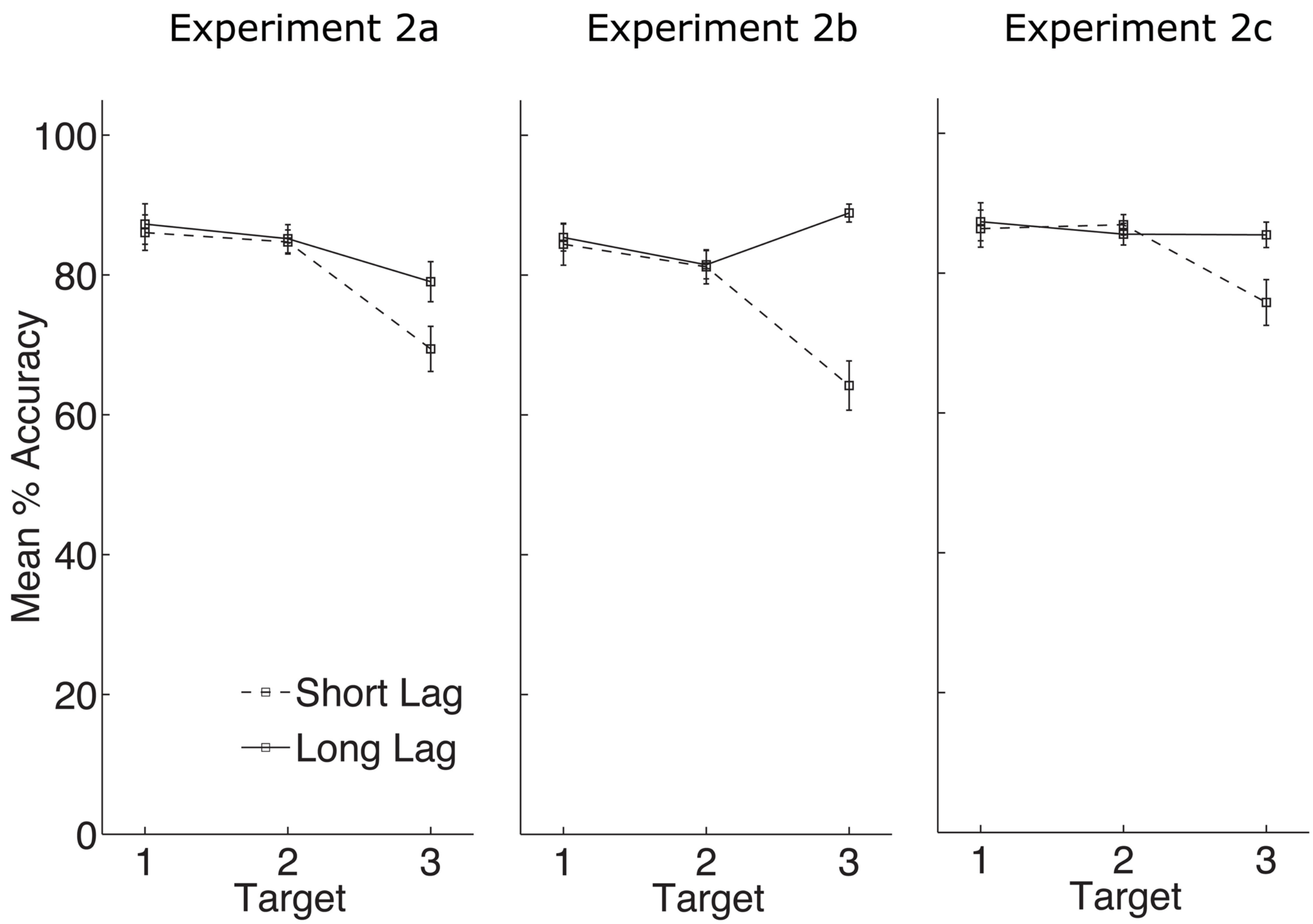

Figure 3.
Mean T1, T2, and T3 accuracy as a function of T1–T3 Lag (Short Lag vs. Long Lag) plotted separately for Experiments 2a, 2b and 2c.