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Confidence for intrusion errors during the attentional blink depends on target-defining features

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ABSTRACT

Research surrounding the attentional blink phenomenon – a deficit in responding to the second of two temporally proximal stimuli when presented 150–500 ms after the first – has used a wide variety of target-defining and response features of stimuli. The typical U-shape curve for absolute performance is robust, surviving across most stimulus features, and therefore changes in performance are discussed as dynamics in an attentional system that are nonspecific a stimulus type. However, the patterns of errors participants make might not show the same robustness, and participants' confidences in these errors might differ – potentially suggesting the involvement of different attentional or perceptual mechanisms. The present research is a comparison of error patterns and confidence in those errors when letter target stimuli are defined by either the color of the letter, the presence of a surrounding annulus, or the color of the annulus. Across three experiments, we show that participants erroneously report stimuli that are further away from T2 and they are similarly confident in specifically their post-target errors as their correct responses when annuli define targets, but not when color of the letter defines targets. Experiment 3 provides some evidence to suggest that this error pattern and associated confidence is time-dependent when the color of the annulus defines the target, but not when the color of the letter defines the target. These results raise questions concerning the nature of the errors and possibly the mechanisms of the attentional blink phenomenon itself.

1. Introduction

Investigations of the necessary and sufficient conditions in which the attentional blink (AB; Raymond et al., 1992) occurs – the observation that participants often respond incorrectly to a second target stimulus (T2) when it follows a correctly responded to first stimulus (T1) by approximately 150–500 ms (Broadbent & Broadbent, 1987; Weichselgartner & Sperling, 1987) – have resulted in numerous verbal and computational models of sub-second visual processing (for reviews: Dux & Marois, 2009; Martens & Wyble, 2010). Interestingly, when no nontarget stimulus intervenes T1 and T2, T2 responding is relatively unimpaired (termed lag 1 sparing; Potter et al., 1998). This sparing effect extends to three targets (Di Lollo et al., 2005) or four targets (Olivers et al., 2007; Reeves & Sperling, 1986), suggesting that the AB is not due to limitations in a later-stage memory system. In addition, because participants tend to correctly respond to a “second” target with instructions to ignore a preceding salient perceptual manipulation (Raymond et al., 1992), the AB is also not considered to be due to limitations in an early perceptual system, but rather is the result of an information-processing bottleneck at a later-stage attentional system (Chun & Potter, 1995; Shapiro et al., 1994). That is, the typical U-shape curve

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for T2 responding is thought to reflect the limitations of an attentional system which selects from incoming sensory information for further processing.

However, despite agreements about this mechanistic explanation, little agreement exists concerning even the necessary conditions for eliciting the AB. For example, although most researchers agree that some nontarget stimulus must intervene T1 and T2, the requirements of this T1 + 1 stimulus have been debated (e.g., Brehaut et al., 1999; Chun & Potter, 1995; Grandison et al., 1997; Kawahara et al., 2003; Nieuwenstein et al., 2009; Seiffert & Di Lollo, 1997; Visser, 2007). Furthermore, research on whether T1 and T2 must be processed in the same or different sensory modalities – e.g., auditory vs visual – has also revealed conflicting results (Arnell & Jolicœur, 1999; Chun & Potter, 2001; Potter et al., 1998). One possibility is that the disagreement stems from the variety of specific stimulus characteristics used without direct experimental comparisons within a single study. Nevertheless, research in the expansive literature generally observes an AB effect despite targets and nontargets being defined by many different features or categories (e.g., letters, numbers, symbols, whole words, line orientations, spatially displaced cues, and even pictures), and regardless of whether T1 and T2 are the same or different tasks (Dale & Arnell, 2013).

This generalizability of the AB curve itself does not necessarily indicate that dynamics in the same attentional processes give rise to the conditions which modulate the AB curve. Caution must be taken when relating conclusions concerning the conditions which modulate the magnitude of the AB with those of the AB itself (also see MacLean & Arnell, 2012, for an important measurement concern), as well as when making comparisons of conclusions from the use of different stimuli across lines of research. For example, does the fact that pre-cueing T2 leads to an attenuated AB (Martens & Johnson, 2005; Nieuwenstein et al., 2005; Shih & Reeves, 2007; Vul et al., 2008a) necessarily indicate that attention was delayed to T2 as suggested? Indeed, Tang et al. (2013) suggest that their observation of no AB after creating top-down temporal expectations for when T2 will occur does not necessarily indicate that the conditions that give rise to the AB were removed. The confounding of conditions that give rise to or modulate an observed effect with the hypothesized underlying mechanisms is an important theoretical concern (Lamy, 2021; in the context of the attentional capture debate).

A potential limitation of much research on the AB is that absolute performance – whether participants correctly respond to T2 – is the most typical dependent measure, whereas more insight into the mechanisms of the phenomenon might be gained by measuring *how* participants respond when they respond incorrectly. Interestingly, when target letter stimuli are defined by their color or their outline color, participants frequently report stimuli appearing near T2 as T2 with a moderate post-target pattern when T2 appears after lag 2 (Botella et al., 2011; Chun, 1997; Popple & Levi, 2007). Similar observations have been made when target letters were defined by the presence of a spatially displaced cue (Recht et al., 2019; Vul et al., 2008a, 2008b); however, the proposed mechanism of these errors differs among accounts. In line with feature-integration theory (Treisman & Gelade, 1980), errors are discussed as a failure of a binding mechanism when the target-defining feature is a feature of the to-be-reported stimulus (e.g., stimulus color), whereas errors are discussed as delayed attention when the target-defining feature is a spatially displaced cue (e.g., a surrounding ring). The pre-target pattern at very short T1-T2 lags have been suggested instead to be due to a separate process – e.g., a processing buffer (Ludowici & Holcombe, 2021), an artifact of the grouping of T1 and T2 responses into a single attentional episode (Goodbourne et al., 2016; and consistent with eSTST: Wyble et al., 2009), or sophisticated guessing (Botella et al., 2011). Regardless of the proposed mechanisms, the general switch from pre- to post-target patterns of errors has been observed across a variety of stimulus characteristics.

Research on two-target RSVP tasks should, with some parsimony, also account for data on the conditions giving rise to lag 1 sparing and the frequent observations that participants reverse the order of T1 and T2. To explain lag 1 sparing, some researchers propose that functional limitations in the slow temporal dynamics of attention allow T2 to be processed with T1 (Chun & Potter, 1995; Nieuwenstein, 2006; Raymond et al., 1992), and others emphasize continued and enhanced attention to the stimulus stream resulting from detection of T1 (Di Lollo et al., 2005; Olivers et al., 2007; Olivers & Meeter, 2008; Shih, 2008). Interestingly, although instructions typically specify reporting T1 and T2 in the correct order, participants frequently report targets in the reverse order. This reversal is interpreted as either both targets being integrated into one percept due to both appearing within the same attentional “episode” (Akyürek & Wolff, 2016; Akyürek et al., 2012; Bowman & Wyble, 2007; Goodbourn et al., 2016; Wyble et al., 2009) or, following from “prior entry” (Shore et al., 2001; Spence & Parise, 2010), as T2 being processed *prior to* T1 due to T2 benefiting from the attentional boost from T1 (Hilkenmeier et al., 2012; Olivers et al., 2011; and consistent with data from Olivers & Meeter, 2008, Potter et al., 2002, and Reeves & Sperling, 1986).

Insight into whether intrusion errors are due to a failed binding mechanism or a delayed response selection process might be gained by simply asking participants how confident they are in their responses. Indeed, Recht et al. (2019) found that participants were similarly confident in their post-target responses as their correct responses, consistent with the proposal that attention is delayed during the AB. Additionally, despite observing the typical lag 1 sparing, participants were less confident in their correct responses to T2s appearing at lag 1 than at lags occurring outside the attentional blink, perhaps consistent with the postulation that the mechanisms contributing to lag 1 sparing are different from those underlying the AB (Livesey & Harris, 2011). On the other hand, Botella et al. (2011) noted that participants instead chose to indicate that they did not know what the second target was rather than to provide a guess, possibly indicating that some of the incorrect T2 responses in other studies were guesses. A noteworthy distinction between these studies is that the presence of rings surrounding letters defined targets in the former, but the color of letters defined targets in the latter. Defining a target by the presence of a spatially displaced cue rather than a feature of a compound stimulus potentially introduces several confounding task requirements. Despite the typical U-shape curve being observed with both stimulus features, the exact patterns of errors may differ, and this may correspond to differences in confidence in responses. These differences might also be explained by different cognitive mechanisms.

The present series of experiments compares error patterns and confidence in those errors during a two target RSVP task when targets are defined by spatially displaced cues or by a unique color. The original motivation for the present experiments was to test

whether the finding that participants are confident in their errors is also observed when letter color defines targets. As such, a priori hypotheses are narrowly scoped: because target definitions differ among experimental conditions, different patterns of errors and confidence in those errors may be observed. Results will be discussed post hoc as they fit with prior discussions concerning the mechanisms underlying the attentional blink.

2. Experiment 1

The purpose of experiment 1 was to compare T2 responses when targets are defined by a ring (annulus) around the to-be-reported

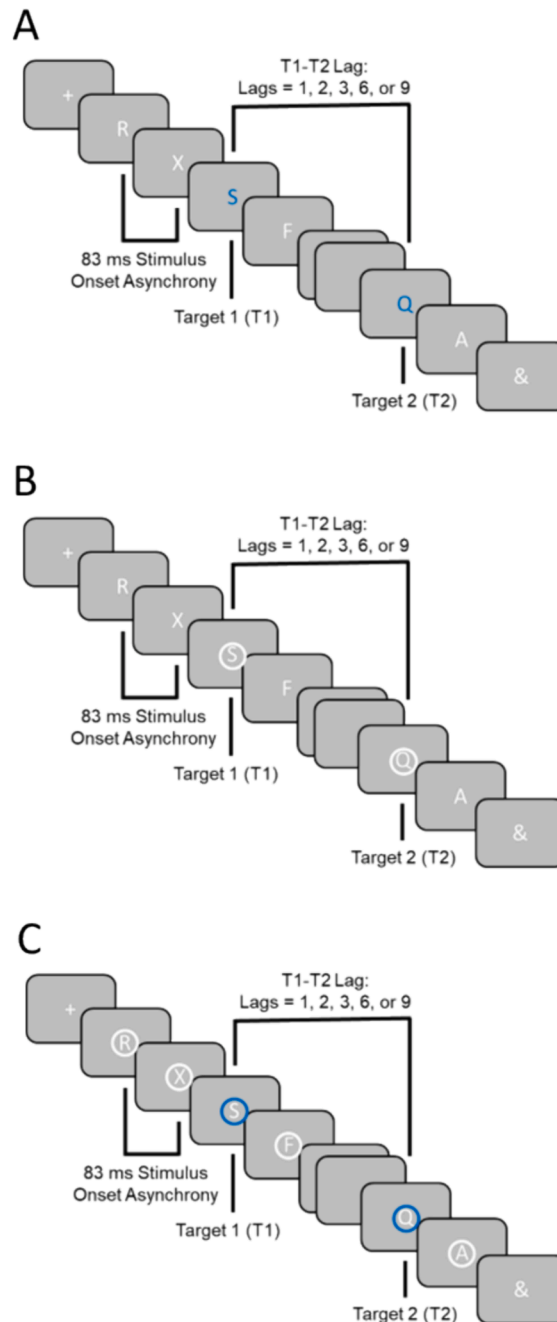


Fig. 1. Procedures for experiment 1 (Panels A and B) and experiment 2 (Panels A, B, and C). Participants searched for target letters defined by either the color of the letter, the presence of an annulus surrounding a letter, or the color of the annulus (experiment 2 only). Stimuli were presented at a rate of approximately 12 per second. The second target appeared either 1, 2, 3, 6, or 9 stimuli after the first.

stimulus (annulus condition) to T2 responses when targets are defined by the color of the stimulus (color condition). Previous studies concluding attention is delayed to the RSVP stream after detection of T1 have used an annulus to define a target (Recht et al., 2019; Vul et al., 2008a; 2008b). Because in traditional AB paradigms targets are defined by a feature of the stimulus rather than a spatially displaced cue, care should be taken when generalizing interpretations of results. Experiment 1 provides some data to justify this criticism of such a generalization. In addition, the present experiment replicates the findings of Recht et al. (2019) that people are confident in their errors when they erroneously report a stimulus after T2 as T2. Gathering confidence data gives insight into the extent that errors made are guesses (e.g., Botella et al., 2011) or true “perceptual” intrusion errors. One possibility is that when an annulus defines a target, the prevalence of post-target errors and associated high confidence comes from additional requirements of the task such as shifting attention from one location to another or perhaps a lasting iconic memory trace (Sperling, 1960). These requirements are not included when the color of a stimulus defines it as a target.

2.1. Methods

2.1.1. Participants

Sixty-six undergraduate students (*Female* = 62.1 %; *Male* = 34.8 %; *Non-binary* = 3 %) ranging in age from 18 to 32 years ($M = 19.15$, $SD = 2.18$) who were enrolled in an Introduction to Psychology course at a medium size university in the Midwest United States participated for partial course credit. Participants identified as White/Caucasian (57.6 %), Black/African American (24.2 %), Hispanic or Latino (16.7 %), and Asian (1.5 %). All participants reported normal or corrected-to-normal vision. Participants read and signed an informed consent form approved by the university’s institutional review board prior to starting the experiment.

2.1.2. Apparatus and stimuli

The experiment was programmed using E-Prime 2.0 software. Stimuli were white and blue uppercase letters of the English language presented in 14-point Arial font on a gray background (default value for “gray” by E-Prime) and subtending approximately 0.5 degrees visual angle vertically and horizontally. For one condition, a white annulus subtending approximately 1 degree (inner) to 1.1 degrees (outer) visual angle surrounded some letters. Stimuli were presented on a 20” Dell monitor with a 60 Hz refresh rate and a resolution of 1600 × 900 pixels. Participants were seated such that the viewing distance was approximately 50 cm; however, no apparatus ensured this distance.

2.1.3. Procedure and design

The general procedure for experiments 1 and 2 can be found in Fig. 1. Participants began each trial by pressing the spacebar. At the beginning of each trial a 300 ms blank was followed by a fixation “+” presented for 300 ms, followed by another 300 ms blank screen. Next, all 26 letters of the English alphabet were randomized and displayed sequentially in the center of the screen followed by an “&” mask at the end of the sequence. Each stimulus was displayed for 33 ms (2 frames) and was followed by a 50 ms (3 frames) inter-stimulus interval (ISI) resulting in a stimulus onset asynchrony (SOA) of 83 ms. Depending on the condition, two of the letters (T1 and T2) were either displayed in blue font or were displayed in white font and surrounded by a white annulus. All nontargets were displayed in white font. After all of the letters were displayed, participants indicated which letters were the targets by pressing the corresponding keys on the keyboard. Participants were instructed to indicate the letters in the order that they appeared. After each response, participants indicated their confidence by pressing the 1, 2, or 3 keys on the keyboard to indicate “Low”, “Moderate”, or “High” confidence, respectively. That is, participants indicated the T1 letter, then provided a confidence rating for that letter prior to indicating the T2 letter. Participants were instructed to input whichever letter they thought was the target even if they were unsure. That is, guessing was encouraged in this experiment and participants should input low confidence in these cases. Participants completed four blocks of 50 trials each.

Participants were randomly assigned to either the color condition or the annulus condition in which targets were either presented in blue font or surrounded by a white ring. T1 appeared randomly as either position 6, 7, 8, 9, or 10 in the letter stream. Relative to T1, T2 was randomly assigned appear in positions +1, +2, +3, +6, or +9 letters (T1-T2 lag) – that is, the number of intervening stimuli is 0, 1, 2, 5, and 8 – with the constraint that each block contained exactly 10 instances of each lag.

2.2. Results

Following previous studies on the AB, primary interest was in how participants responded to T2 provided that they correctly responded to T1 (T2|T1). As such, data from three participants (all in the annulus condition) were removed for correctly identifying T1 on less than 20 % of trials. This cutoff is higher than that of a previous study (10 %; Recht et al., 2019) because the present experiment has fewer trials per participant and therefore fewer remaining observations for analyzing T2 responses. This criterion resulted in 31 participants in the annulus condition and 32 participants in the color condition. For all analyses, Greenhouse-Geisser adjusted degrees of freedom were used when data violated the sphericity assumption. Data for all experiments can be found at Open Science Framework DOI <https://doi.org/10.17605/OSF.IO/ZBAWS>.

2.2.1. T1 responses

Performance Measures. Although the conclusions of this paper emphasize T2 responses, T1 responses should be considered as they serve as a baseline context for interpreting T2 responding. Fig. 2a depicts how participants responded to T1. A 2 (feature condition) × 5 (lag) mixed ANOVA was performed on T1 proportion correct (PC). Participants overall performed better in the color

condition ($M = 0.80$; $SD = 0.16$) than the annulus condition ($M = 0.44$; $SD = 0.17$), $F(1, 61) = 109.46, p < 0.001, \eta_p^2 = 0.642$. In addition, T1 PC increased as the T1-T2 lag increased, $F(3.12, 190.62) = 73.72, p < 0.001, \eta_p^2 = 0.547$. This increase was greater in the color condition than the annulus condition as revealed by a significant interaction, $F(3.12, 190.62) = 19.54, p < 0.001, \eta_p^2 = 0.242$. This interaction was primarily driven by the difference in T1 PC between when T2 appeared at lags 1 and 2 between the two feature conditions and will be discussed in the section on order reversals.

Fig. 2a shows that participants in both feature conditions sometimes reported letters appearing before (pre-target) or after (post-target) T1 as the target. Pre-target vs post-target patterns of these errors were compared between feature conditions with a 2 (feature condition) \times 5 (lag) \times 2 (serial position error [SPE]: pre-target vs post-target) mixed ANOVA. A main effect of SPE $F(1, 244) = 35.83, p < 0.001, \eta_p^2 = 0.37$ revealed participants were more likely to report the post-target letter as the target than the pre-target letter. The magnitude of this pattern was not observed to be different depending on feature condition, $F(1, 244) = 0.02, p = 0.885, \eta_p^2 = 0.000$. However, a two-way interaction between lag and SPE, $F(3.05, 186.04) = 52.08, p < 0.001, \eta_p^2 = 0.461$, demonstrated that the post-target pattern is much stronger when T2 appeared at lag 1 than at the other lags. Finally, the 3-way interaction, $F(3.05, 186.04) = 7.82, p < 0.001, \eta_p^2 = 0.114$, indicated that the greater post-target pattern when T2 appeared at lag 1 compared to other lags was stronger for the color condition than the annulus condition. This interaction appears to be due to there being much fewer errors overall for the color condition, with the exception of when T2 appears at lag 1.

Confidence Ratings (CRs). Analyses of CR revealed a similar trend to those of PC. CRs for correct T1 responses were higher for the color condition than the annulus condition, $F(1, 61) = 6.51, p = 0.013, \eta_p^2 = 0.096$ and increased with lag, $F(3.06, 186.36) = 33.72, p < 0.001, \eta_p^2 = 0.357$. An interaction effect, $F(3.06, 186.36) = 2.95, p = 0.026, \eta_p^2 = 0.044$, was also primarily driven by the difference in T1 CR when T2 appeared at lag 1 compared to lag 2.

Due to there being few errors, conventional inferential tests on CR that include SPE as a predictor were impossible. Fig. 2b illustrates aggregate confidence ratings. The aggregate data are similar to those of Recht et al. (2019) in which there were approximately symmetrical CRs for pre-target and post-target errors. For the color condition, but not the annulus condition, the data tended towards higher CRs for post-target errors compared to pre-target errors when T2 appears at lag 1 – that is, when participants incorrectly report T2 as T1. This anecdotal difference must be interpreted cautiously, although it is noteworthy that the patterns for both conditions were similar in experiment 2.

2.2.2. T2|T1 responses

Performance Measures. Only trials in which T1 was correctly responded to were included in the following analyses (T2|T1).

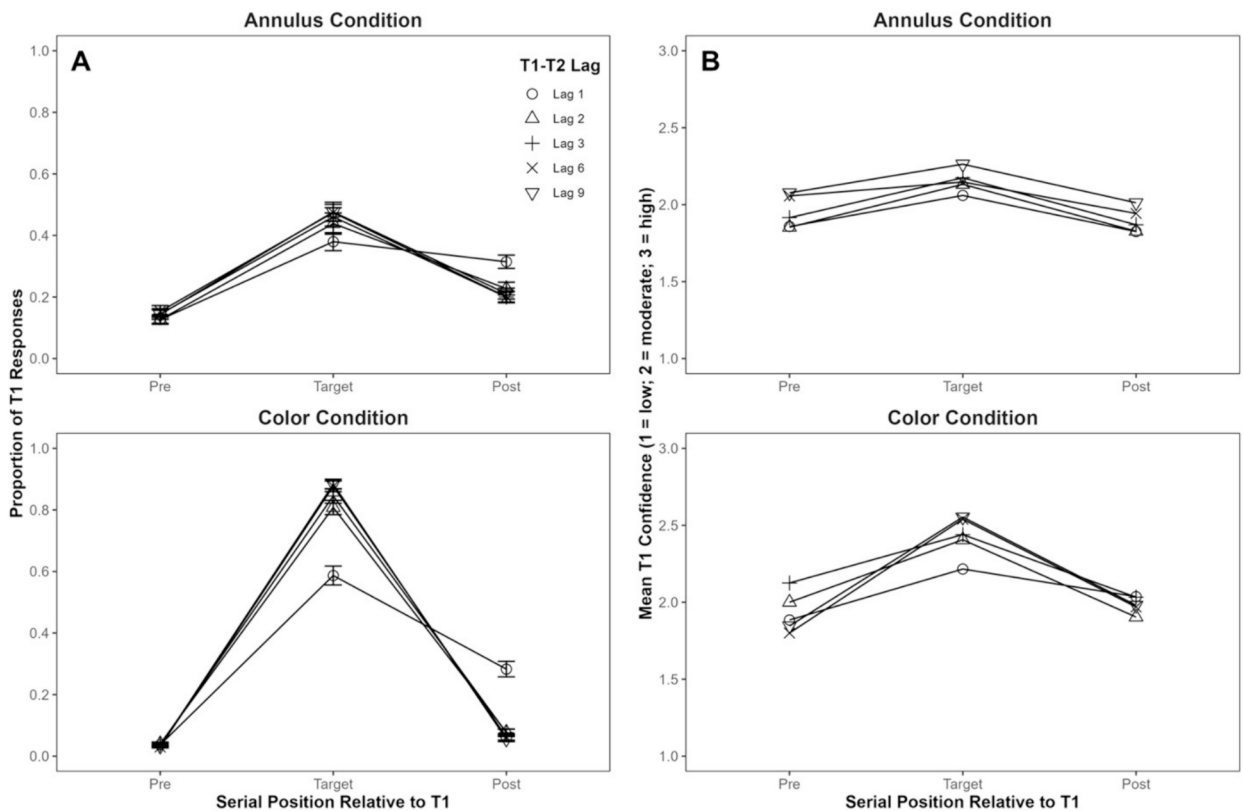


Fig. 2. Responses for T1 in experiment 1. Panel a depicts the proportion of T1 responses plotted by their serial position error relative to T1. Panel b depicts average confidence ratings in those responses. Error bars represent ± 1 SEM.

Correct T2|T1 responses are plotted in Fig. 3a. First, a 2 (feature condition) × 5 (lag) mixed ANOVA revealed the typical AB effect as evidenced by a main effect of lag, $F(2.92, 178.47) = 100.67, p < 0.001, \eta_p^2 = 0.623$. Planned comparisons revealed this effect represents a decrease in T2|T1 PC from lag 1 to lag 2 and increases in T2|T1 PC from lag 3 to lag 6 and from lag 6 to lag 9 (all $ps < 0.001$), but no difference between lags 2 and 3. In addition, a main effect of feature condition, $F(1, 61) = 241.52, p < 0.001, \eta_p^2 = 0.798$, revealed that T2|T1 PC was overall lower for the annulus condition than the color condition. Although an interaction was observed, $F(2.92, 178.47) = 4.98, p = 0.003, \eta_p^2 = 0.076$, such that the effect of lag on T2|T1 PC was smaller for the annulus condition than the color condition, this was likely due to a floor effect in which many participants never correctly reported T2 at lags 2 and 3 in the annulus condition.

Participants frequently reported stimuli appearing near T2 as T2, as depicted in Fig. 3b. Patterns of errors were analyzed by calculating the mean serial position of the reported item for T2 in a 7-stimulus window surrounding and including T2 (mean SPE; following the “C Value” calculations of Vul et al., 2008a; Recht et al., 2019). The result of the formula is a number in which each integer value corresponds to a stimulus position relative to the target. For example, if mean SPE were equal to -1, that would indicate that participants reported on average one stimulus prior to the target as the target. These values are plotted in Fig. 3c. Mean SPE was computed for each participant and separately for each lag. A main effect of lag, $F(2.88, 175.89) = 44.62, p < 0.001, \eta_p^2 = 0.412$, was

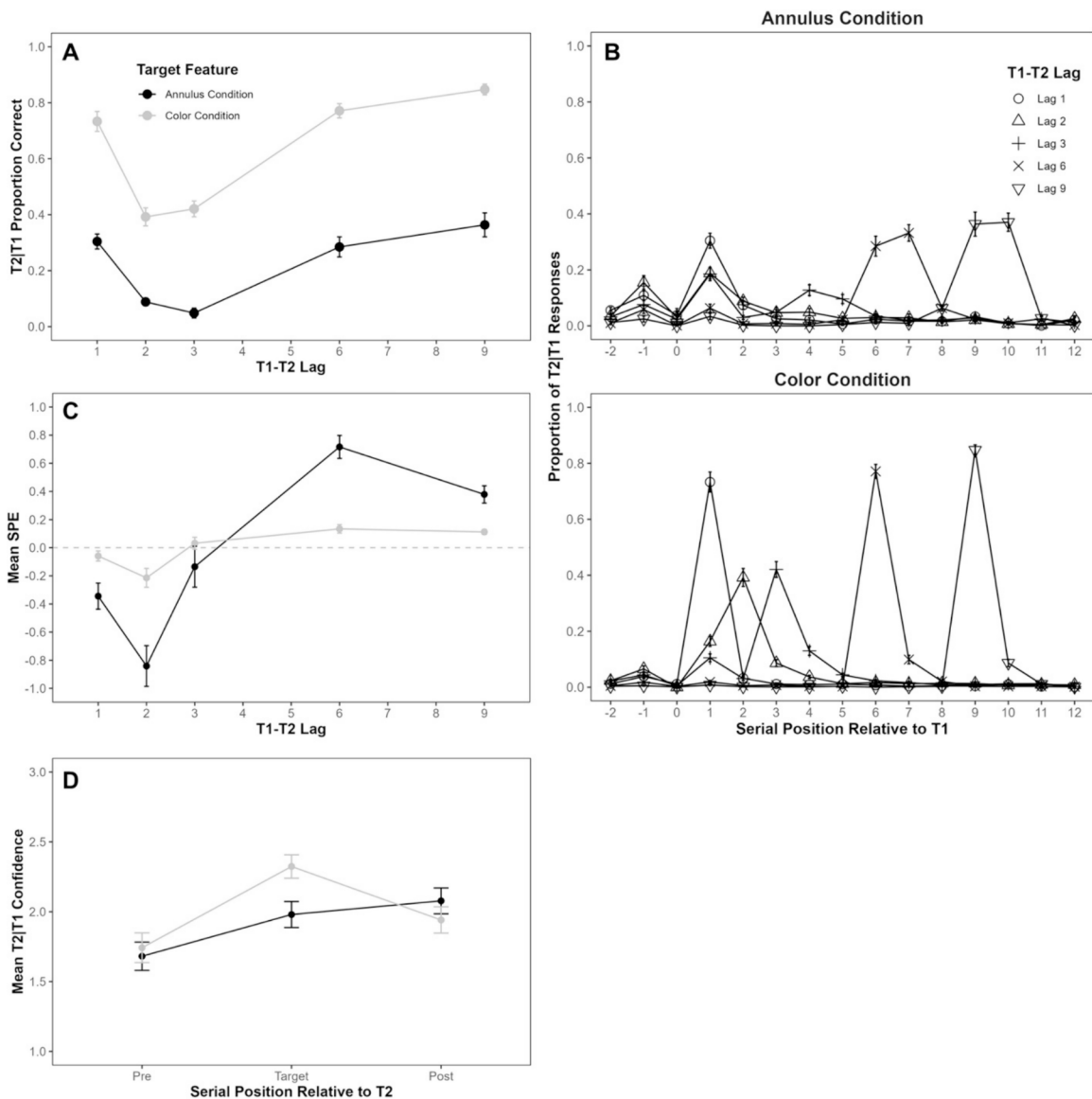


Fig. 3. Responses for T2|T1 responses in experiment 1. Panel a depicts the proportion of correctly reported T2s as a function of lag. Panel b depicts all responses plotted with respect to their serial position relative to the serial position of T1 (0 on the abscissa). This figure shows how errors are distributed around the targets. Panel c depicts the mean SPE as a function of lag. Panel d depicts confidence ratings for T1 responses. Error bars represent ± 1 SEM.

observed such that participants tended towards a pre-target pattern at short lags and a post-target pattern at longer lags. This effect of lag on mean SPE was stronger for the annulus condition than the color condition as evidenced by an interaction, $F(2.88, 175.89) = 17.96, p < 0.001, \eta_p^2 = 0.228$.

Of particular interest in the present research are cases in which participants reversed the order of T1 and T2 when T2 appears at lag 1 (order reversals were virtually nonexistent at longer lags, occurring on less than 1 % of trials). Out of all experimental trials, order reversals occurred more frequently in the color condition ($M = 14.69\%$, $SD = 9.66\%$) than in the annulus condition ($M = 7.74\%$, $SD = 5.13\%$), $t(47.53) = 3.57, p < 0.001$, *Cohen's d* = 0.893. This difference is especially interesting considering participants were also more likely to correctly identify T1 when T2 appeared at lag 1 in the color condition (58.67 %) than the annulus condition (37.98 %), leaving fewer opportunities for order reversals. That is, of the times participants did not correctly identify T1, 35.54 % constituted order reversals in the color condition, compared to 12.47 % in the annulus condition.

Confidence Ratings. Because many participants (especially those in the annulus condition) never correctly reported T2 at certain lags, and similarly never reported letters at certain serial positions relative to T2, they were unable to provide CRs for those cases. Thus, to preserve the use of inferential statistics and to retain all participants, data were aggregated across all lags and responses from only three serial positions were analyzed (T2 and the stimuli immediately preceding and following T2).

A 2 (feature condition) \times 3 (SPE: pre-target, target, post-target) mixed ANOVA revealed a main effect of SPE, $F(1.63, 99.94) = 50.85, p < 0.001, \eta_p^2 = 0.455$, such that CRs were higher for the target ($M = 2.15$) than pre-target errors ($M = 1.71; p_{\text{adj}} < 0.001$) and post-target errors ($M = 2.00; p_{\text{adj}} < 0.001$) and higher for post-target errors than pre-target errors ($p_{\text{adj}} < 0.001$). Importantly, there was an interaction (depicted in Fig. 3d) between feature condition and SPE, $F(1.63, 99.94) = 14.70, p < 0.001, \eta_p^2 = 0.194$. Although participants in both feature conditions had lower CRs for pre-target errors than other reports, participants in the annulus condition were as confident in their post-target errors as their correct responses whereas participants in the color condition were less confident in their post-target errors than their correct responses. There was not a main effect of feature condition, $F(1, 61) = 0.51, p = 0.476, \eta_p^2 = 0.008$.

CRs for order reversal were also analyzed. A 2 (feature condition) \times 2 (response: first response vs second response) mixed ANOVA revealed a main effect of target, $F(1, 55) = 7.40, p = 0.008, \eta_p^2 = 0.119$, such that participants were more confident in their first response ($M = 1.88$) than their second response ($M = 1.71$). Statistical significance was not found for the main effect of feature condition, $p_s > 0.12$.

2.3. Discussion

Overall, the results of experiment 1 demonstrate that processing of T1 influences how participants respond to T2 differently depending on the target-defining characteristics of the stimuli. Results concerning T1 can be cautiously interpreted as baseline differences in responding when RSVP target stimuli are defined by an annulus surrounding compared to the color of the stimulus. Participants in the annulus condition correctly reported fewer targets than participants in the color condition, consistent with prior work (e.g., Popple & Levi, 2007; Vul et al., 2008a). This lower performance was accompanied by more frequent reports of both post-target and pre-target stimuli with an overall stronger tendency towards reporting post-target items (post-target pattern). Despite the post-target pattern, confidence in the post-target errors was not higher than confidence in pre-target errors except when T2 appeared at lag 1 for participants in the color condition only. This finding will be discussed later with order reversals when T2 appears at lag 1. Because the pattern of responding to T1 was similar between feature conditions, results concerning between-condition differences in responding to T2|T1 can be understood as how processing of T1 interacts with processing of T2, not as the effects of the different stimulus characteristics themselves.

The typical U-shape curve was observed for T2|T1 correct responses for both feature conditions; however, compared to participants in the color condition, participants in the annulus condition reported stimuli further away from T2 as T2. This indicates that although the time course of the standard measure of the AB was not observed to be different depending on feature condition, how participants respond when they incorrectly respond to T2 is differently influenced by feature condition. This difference in responding is important because it potentially suggests that the exact mechanisms underlying the T2 deficit might differ among different stimulus types. Furthermore, because participants in only the annulus condition were similarly confident in their post-target errors for T2 as their correct responses, the nature of "intrusion" errors might also be different depending on stimulus features.

Although Recht et al. (2019) discussed their confidence rating results in terms of metacognition during the AB and how that relates to reduced and delayed attention, the same confidence rating can be interpreted as a self-report measure of the extent that stimulus reports represent feature conjunctions between target-defining and to-be-reported stimulus features. An assumption of this interpretation is that stimulus features, regardless of their spatial displacement, are initially processed in parallel (Botella et al., 1992, 2007; Bowman & Wyble, 2007; Nakayama & Silverman, 1986) prior to an attentional binding mechanism (Treisman & Gelade, 1980). That is, under this account of errors, the binding mechanism frequently fails during the temporal window of the attentional blink. However, why participants are confident in their post-target errors specifically is not directly accounted for by this account. The addition of another guessing mechanism based on which response feature has most recently been detected once a target-defining feature has been detected can possibly salvage the account (Botella et al., 2004; 2011).

Before elaborating on the previous explanations of intrusion errors, two potential confounding variables between the feature conditions of experiment 1 must be ruled out. First, both the target-defining and response features of the stimuli are necessarily masked in the color condition whereas only the response feature is masked in the annulus condition. This difference leads to an obvious explanation for the prevalence of post-target intrusions and higher confidence in those errors in the annulus condition – the iconic memory trace from the annulus is likely to be bound to a post-target stimulus. In addition, the target-defining feature in the color

condition is perhaps processed in a different area of the visual cortex as the response feature (color vs form) whereas the target-defining and response features are of the same type in the annulus condition (both form). Both of these are addressed in experiment 2.

3. Experiment 2

The results of experiment 1 demonstrated, at minimum, that patterns of errors and confidence in those errors for T2 were different when targets were defined by a feature of the stimulus than a spatially displaced cue. In experiment 2 another condition was added in which targets were defined by the presence of a blue annulus among white annuli that are presented around the nontargets. This condition helps to rule out two explanations for the differences between the annulus and color conditions: target-defining features are masked in the color condition but not the annulus condition, and that target-defining features match response features in the annulus condition but not the color condition. The two feature conditions of experiment 1 are also replicated in this experiment.

3.1. Methods

Experiment 2 was exactly the same as experiment 1 with the following exceptions.

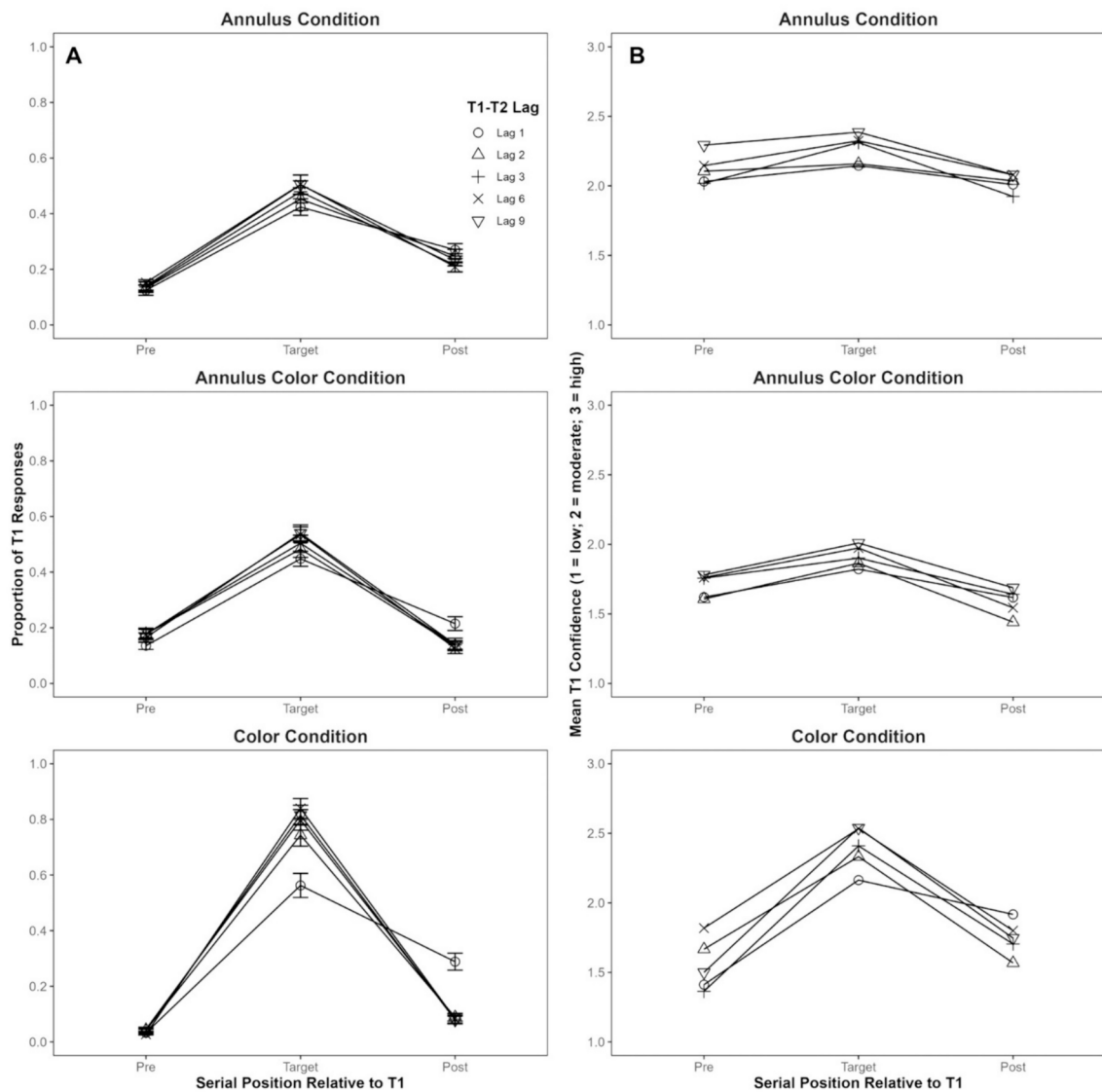


Fig. 4. Responses for T1 in experiment 2. Panel a depicts the proportion of T1 responses plotted by their serial position error relative to T1. Panel b depicts average confidence ratings in those responses. Error bars represent ± 1 SEM.

3.1.1. Participants

Seventy-seven undergraduate students (*Female* = 44.3 %; *Male* = 54.4 %; *Non-binary* = 1.3 %) ranging in age from 18 to 60 years ($M = 19.54, SD = 4.67$) who were enrolled in an introduction to Psychology course at a medium size university in the Midwest United States participated for partial course credit. Participants identified as White/Caucasian (60.8 %), Black/African American (29.1 %), Hispanic or Latino (6.3 %), and Asian (2.5 %).

3.1.2. Stimuli and procedure

The two feature conditions of experiment 1 were directly replicated in experiment 2. The only difference was the inclusion of another between-subjects condition in which every letter was surrounded by white annuli except for the two targets which were surrounded by blue annuli (panel C of Fig. 1).

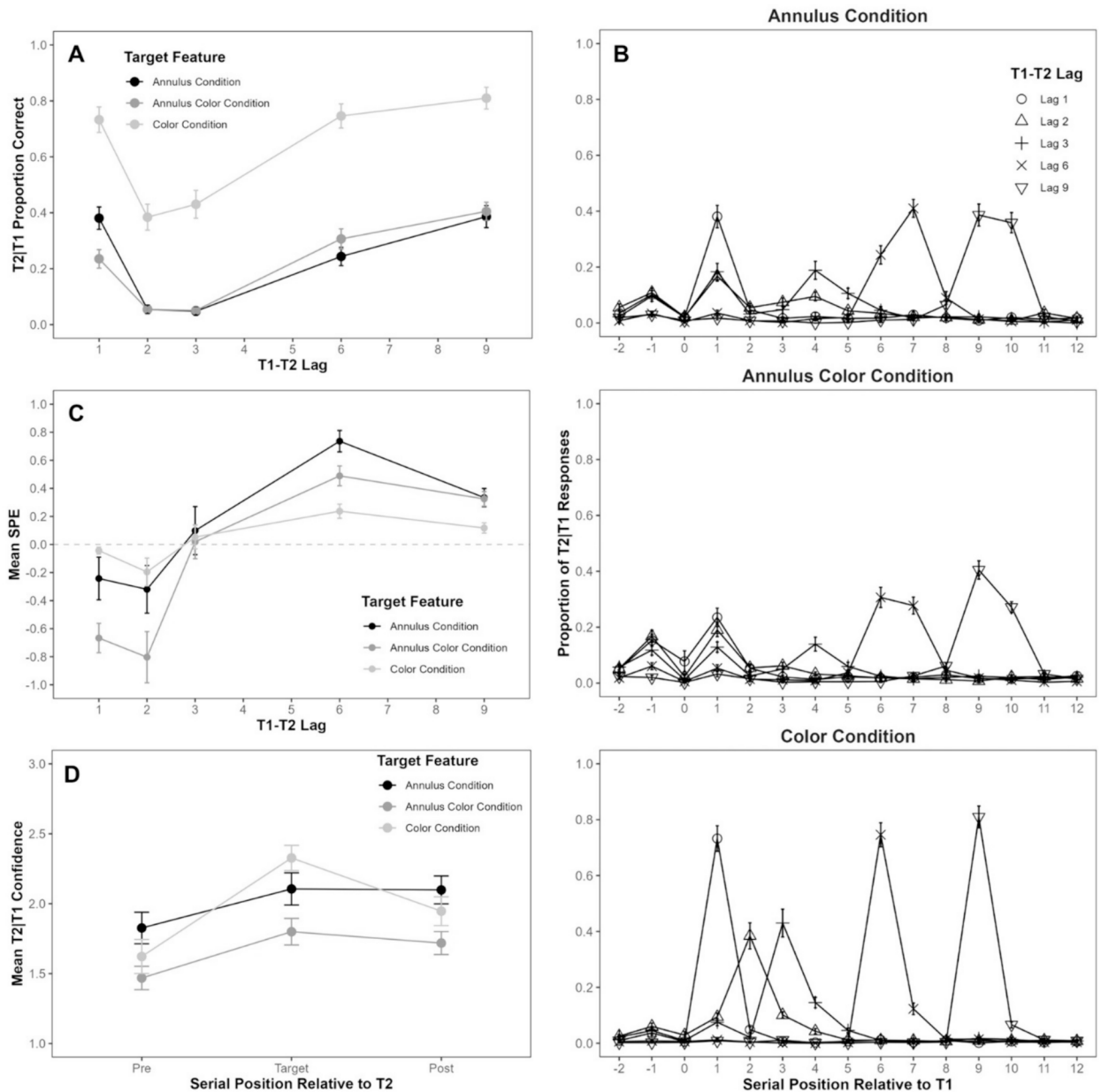


Fig. 5. Responses for T2|T1 responses in experiment 2. Panel a depicts the proportion of correctly reported T2s as a function of lag. Panel b depicts all responses plotted with respect to their serial position relative to the serial position of T1 (0 on the abscissa). Panel c depicts the mean SPE as a function of lag. Panel d depicts confidence ratings for T1 responses. Error bars represent ± 1 SEM.

3.2. Results

As in experiment 1, participants who responded correctly to T1 on less than 20 % of trials were removed from all analyses. Six participants were removed (four in the annulus condition and two in the annulus color condition), resulting in 20 participants in the annulus condition, 25 in the annulus color condition, and 26 in the color condition.

3.2.1. T1 responses

Performance Measures. T1 reports are depicted in Fig. 4a. A 3 (feature condition) \times 5 (lag) mixed ANOVA was performed on T1 PC. There was a main effect of feature condition, $F(2, 68) = 23.48, p < 0.001, \eta_p^2 = 0.409$, such that participants in the color condition ($M = 0.75; SD = 0.22$) performed better than participants in both the annulus condition ($M = 0.47; SD = 0.16; p < 0.001$) and the annulus color condition ($M = 0.50; SD = 0.15; p < 0.001$), with no difference between the two annulus conditions, $p = 1.000$. In addition, T1 PC increased as T1-T2 lag increased, $F(3.50, 238.16) = 46.92, p < 0.001, \eta_p^2 = 0.408$. This increase was greater for the color condition than both of the annulus conditions as demonstrated by an interaction effect, $F(7.00, 238.16) = 9.33, p < 0.001, \eta_p^2 = 0.215$. This interaction appears primarily driven by much poorer performance when T2 appeared at lag 1 compared to other lags in the color condition specifically. This lag 1 specific result will be discussed again in the section on order reversals.

As in experiment 1, participants frequently reported stimuli appearing near T1 as T1 (see Fig. 4a). The nature of these errors was investigated with a 3 (feature condition) \times 5 (lag) \times 2 (SPE) mixed ANOVA. A main effect of SPE, $F(1, 272) = 20.33, p < 0.001, \eta_p^2 = 0.230$ revealed that participants overall tended towards a post-target pattern compared to a pre-target pattern; however, there was an interaction between feature condition and SPE, $F(2, 272) = 10.88, p < 0.001, \eta_p^2 = 0.243$, such that the post-target pattern was observed for both the annulus and the color conditions, but not for the annulus color condition. A 3-way interaction including lag, $F(6.54, 222.60) = 4.19, p < 0.001, \eta_p^2 = 0.110$, revealed that although there was a post-target pattern for the annulus and color conditions, there was a pre-target pattern for the annulus color condition for all lags except lag 1 which followed the normal post-target pattern.

Confidence Ratings. A main effect of feature condition on CRs for correct T1 responses was observed, $F(2, 68) = 6.42, p = 0.003, \eta_p^2 = 0.159$, such that CRs were lower in the annulus color condition than the annulus ($p = 0.036$) and the color ($p = 0.003$) conditions, but not different between the annulus and the color conditions ($p = 1.000$). Additionally, CRs increased with increasing lag as revealed by a main effect of lag, $F(3.47, 236.16) = 33.34, p < 0.001$. Finally, an interaction effect was observed, $F(6.94, 236.16) = 3.09, p = 0.004, \eta_p^2 = 0.083$, such that the increase in CRs with lag was greater in the color condition than the two annulus conditions.

Aggregate CRs are illustrated in Fig. 4b. These data appear similar to those of Recht et al. (2019) and experiment 1 for the annulus condition. In addition, they appear to replicate the findings of experiment 1 for the color condition that participants are more confident in their post-target responses than pre-target responses, especially when T2 appears at lag 1. The pattern for the annulus color condition more closely resembles that of the annulus condition than the color condition.

3.2.2. T2|T1 responses

Performance Measures. Only trials in which T1 was correctly responded to are included in the following analyses (T2|T1). Correct T2|T1 responses are plotted in Fig. 5. First, a 2 (feature condition) \times 5 (lag) mixed ANOVA revealed the typical AB effect as evidenced by a main effect of lag, $F(2.90, 197.70) = 100.67, p < 0.001, \eta_p^2 = 0.660$. Planned comparisons revealed this effect represents a decrease in T2|T1 PC from lag 1 to lag 2 and increases in T2|T1 PC from lag 3 to lag 6 and from lag 6 to lag 9 (all $p_{\text{adj}} < 0.001$), but no difference between lags 2 and 3. In addition, a main effect of feature condition, $F(2, 68) = 72.24, p < 0.001, \eta_p^2 = 0.68$, revealed that T2|T1 PC was overall higher for the color condition than the annulus condition ($p_{\text{adj}} < 0.001$) and the annulus color condition ($p_{\text{adj}} < 0.001$), but not different between the annulus and annulus color conditions ($p_{\text{adj}} = 1.000$). Although an interaction was observed, $F(5.81, 197.70) = 3.73, p = 0.002, \eta_p^2 = 0.099$, such that the effect of lag on T2|T1 PC was smaller for both of the annulus conditions than the color condition, this was likely due to a floor effect for lags 2 and 3 in the annulus and annulus color conditions.

Participants frequently erroneously reported stimuli near T2 as T2, as depicted in Fig. 5b. Mean SPE is plotted separately for each lag in Fig. 5c. A main effect of lag, $F(2.79, 187.31) = 44.79, p < 0.001, \eta_p^2 = 0.401$, was observed such that participants tended towards a pre-target pattern at short lags and a post-target pattern at longer lags. An interaction, $F(5.59, 187.31) = 5.84, p < 0.001, \eta_p^2 = 0.149$, was observed such that compared to those in the other two conditions, participants in the annulus color condition demonstrated a much stronger pre-target pattern for short lags, whereas participants in the color condition overall had a more symmetrical (closer to 0) pattern of errors than the other conditions. Finally, there was an additional effect of target feature such that participants in the annulus condition overall had a greater post- to pre-target error ratio than those in the annulus color condition ($p_{\text{adj}} = 0.011$).

As in experiment 1, the frequency of order reversals was compared across target feature conditions. Results of a one-way ANOVA revealed an effect of target feature on the percentage of order reversals, $F(2, 68) = 7.69, p < 0.001, \eta_p^2 = 0.185$. Planned comparisons showed that order reversals occurred more frequently in the color condition ($M = 12.40\%, SD = 8.47\%, N = 26$) than the annulus condition ($M = 6.75\%, SD = 5.32\%, N = 20; p_{\text{adj}} = 0.016$) and the annulus color condition ($M = 5.60\%, SD = 5.06\%, N = 25; p_{\text{adj}} = 0.001$), but were not different between the two annulus conditions ($p_{\text{adj}} = 1.00$).

Confidence Ratings. A 3 (feature condition) \times 3 (SPE: pre-target, target, post-target) mixed ANOVA revealed a main effect of SPE, $F(2, 130) = 48.52, p < 0.001, \eta_p^2 = 0.427$, such that CR was higher for the target ($M = 2.07$) than pre-target errors ($M = 1.63; p_{\text{adj}} < 0.001$) and post-target errors ($M = 1.91; p_{\text{adj}} < 0.001$) and higher for post-target errors than pre-target errors ($p_{\text{adj}} < 0.001$). In addition, a main effect of feature condition was observed, $F(2, 65) = 4.16, p = 0.020, \eta_p^2 = 0.114$, such that CRs for participants in the annulus color condition ($M = 1.66$) were lower than for participants in the annulus condition ($M = 2.01; p_{\text{adj}} = 0.031$), but not different from those of participants in the color condition ($M = 1.94; p_{\text{adj}} = 0.083$) or between the annulus and the color condition ($p_{\text{adj}} = 1.00$).

Importantly, there was an interaction (depicted in Fig. 5d between feature condition and SPE, $F(4, 130) = 5.26, p < 0.001, \eta_p^2 = 0.140$). Although participants in all three feature conditions had lower CRs for pre-target errors, participants in both of the annulus conditions were as confident in their post-target errors as their correct responses whereas participants in the color condition were less confident in their post-target errors than their correct responses.

To analyze order reversals, a 3 (feature condition) \times 2 (response) mixed ANOVA was conducted. Results did not reveal a reliable difference between responses, $F(1, 58) = 0.25, p = 0.614, \eta_p^2 = 0.004$, feature conditions (2, 58) = 2.47, $p = 0.093, \eta_p^2 = 0.079$, or an interaction, $F(2, 58) = 0.61, p = 0.544, \eta_p^2 = 0.021$. In addition, the main effect of response that was observed in experiment 1 was not replicated in experiment 2 after removing the annulus color condition, $p = 0.254$.

3.3. Discussion

The results of experiment 2 closely resembled those of experiment 1 with respect to the differences between the annulus and the color conditions with two minor exceptions. Participants were not observed to be more confident in their T1 responses in the color condition than the annulus condition, providing additional support for interpreting differences in T2|T1 responses depending on feature condition as the influence of feature condition on T2|T1 specifically. In addition, in experiment 2 participants were similarly confident in their T1 and T2 responses when an order reversal was made. More important was that the responses of participants in the annulus color condition were similar to those of the annulus condition with respect to T2|T1 mean SPE and with respect to the relatively higher confidence in post-target errors. Thus, the prevalence of and confidence in post-target errors in the annulus condition was not due to the target-defining feature being unmasked or the fact that the target-defining feature is of a similar characteristic (form) as the response feature. Although, mean SPE was less positive for the annulus color condition than the annulus condition at lag 6. This difference possibly indicates that a lasting iconic memory trace in the annulus condition was partially responsible for the prevalence of post-target errors.

Two significant differences in responding between the annulus color condition and the annulus condition deserve discussion. First, participants in the annulus color condition were overall less confident in their responses to both T1 and T2 than participants in the annulus condition (and the color condition). An explanation attributing it to “difficulty” of the task is not sufficient as this lower confidence was not accompanied by a decrease in performance. A potential explanation is that although the strong post-target pattern in the annulus condition is not due to a lasting iconic memory trace, that trace allows participants to be more *confident* in any letter they report. Still, confidence in T2|T1 responses were substantially lower in the annulus color condition than either the annulus or the color conditions, possibly indicating the involvement of some other mechanism or due to there being two pairs of stimuli on every frame in the annulus color condition.

A second difference in responding between the two annulus conditions is that participants in the annulus color condition demonstrated a pre-target pattern of errors for T1 for all T1-T2 lags except lag 1. This is the exact opposite pattern to both the annulus and the color conditions. Because responding to T1 is interpreted as “baseline” performance for interpreting T2|T1 performance, and because errors in reports to T2 are traditionally attributed to delays of attention, this opposite pattern should be explained. One potential attentional explanation could be that in the annulus and the color conditions, participants are closely attending to the letter stream and therefore pre-target stimuli are quickly processed and rejected as targets. Then, when a target-defining stimulus is detected, an additional attentional boost is elicited which benefits either the target or the post-target stimulus but cannot benefit a pre-target stimulus as it has already been rejected. However, in the annulus color condition, participants are monitoring the annulus and therefore not attending as much to the letter stream. Drawing from the doctrine of prior entry (Shore et al., 2001), pre-target letter stimuli would be processed slower due to “less attention” whereas the blue annulus would be processed faster, increasing the prevalence of pre-target errors as their response dimension processing encroaches on that of the target-defining feature (see Botella et al., 1992, for an earlier description of how this binding may occur).

The results from experiments 1 and 2 suggest that the spatial displacement of the target-defining feature from the response feature, not iconic memory or separate feature types (color vs form), is principally responsible for the stronger post-target pattern of errors at lags 6 and 9. Following this conclusion, *how* spatially displaced the features are should strongly influence T2|T1 errors. One possibility is that the reason spatial displacement influences errors is that the time required to shift attention from one location to another results in selecting a stimulus occurring after the cue. To test this, in experiments 3a and 3b the distance from the letter to the annuli and the presentation rate were manipulated.

4. Experiment 3

Vul et al. (2008b) demonstrated that increasing presentation rate resulted in a stronger post-target pattern of errors and that presenting the annulus slightly before the target letter reduced the AB. In experiment 3a, the presentation rate is manipulated for the annulus color condition of experiment 2 to see whether the same manipulation similarly results in a stronger post-target pattern. In addition, in experiment 3a the size of the annuli (distance from the letters) is also manipulated. Specifically, in the smallest annulus size condition, the annulus is almost touching the letters. If spatial displacement is principally responsible for the much stronger post-target pattern in the annulus color condition than the color condition, then there should be only a small difference in performance between that and the color condition. The medium annulus size condition was similar to that of experiment 2 and the large annulus size condition increased in diameter by the same difference as between the small and medium conditions. In addition, in experiment 3b, the presentation rate of the color condition is also manipulated to test whether the timing-related delay hypothesized for experiment 3a also applies when target letters are defined by their color. These experiments are discussed together for ease of comparison; however,

separate statistical analyses are conducted on their respective data.

4.1. Methods

4.1.1. Participants

For experiment 3a, seventy-one undergraduate students (*Female* = 69 %; *Male* = 31 %) ranging in age from 18 to 21 years ($M = 18.74$, $SD = 0.94$) who were enrolled in an Introduction to Psychology course at a medium size university in the Midwest United States participated for partial course credit. Participants identified as White/Caucasian (49.3 %), Black/African American (33.8 %), Hispanic or Latino (12.7 %), and Asian (4.2 %). All participants reported normal or corrected-to-normal vision. For experiment 3b, participants were thirty-eight undergraduate students (*Female* = 60.5 %; *Male* = 36.8 %; *Non-binary* = 2.6 %) ranging in age from 18 to 23 years ($M = 19.26$, $SD = 1.11$). Participants identified as White/Caucasian (50 %), Black/African American (34.2 %), Hispanic or Latino (7.9 %), and Asian (7.9 %). All participants reported normal or corrected-to-normal vision.

4.1.2. Stimuli and apparatus

The stimuli for experiment 3a were identical to the annulus color condition of experiment 2 with two exceptions. The thickness of the annuli was increased from approximately 0.1 degree to 0.2 degrees of visual angle. That is, for the small annulus size, the inner and outer diameters were approximately 0.5 and 0.7 degrees. For the medium and large annulus sizes, the inner diameters were approximately 1.5 and 3.0 degrees. The stimuli for experiment 3b were identical to the color condition of experiments 1 and 2.

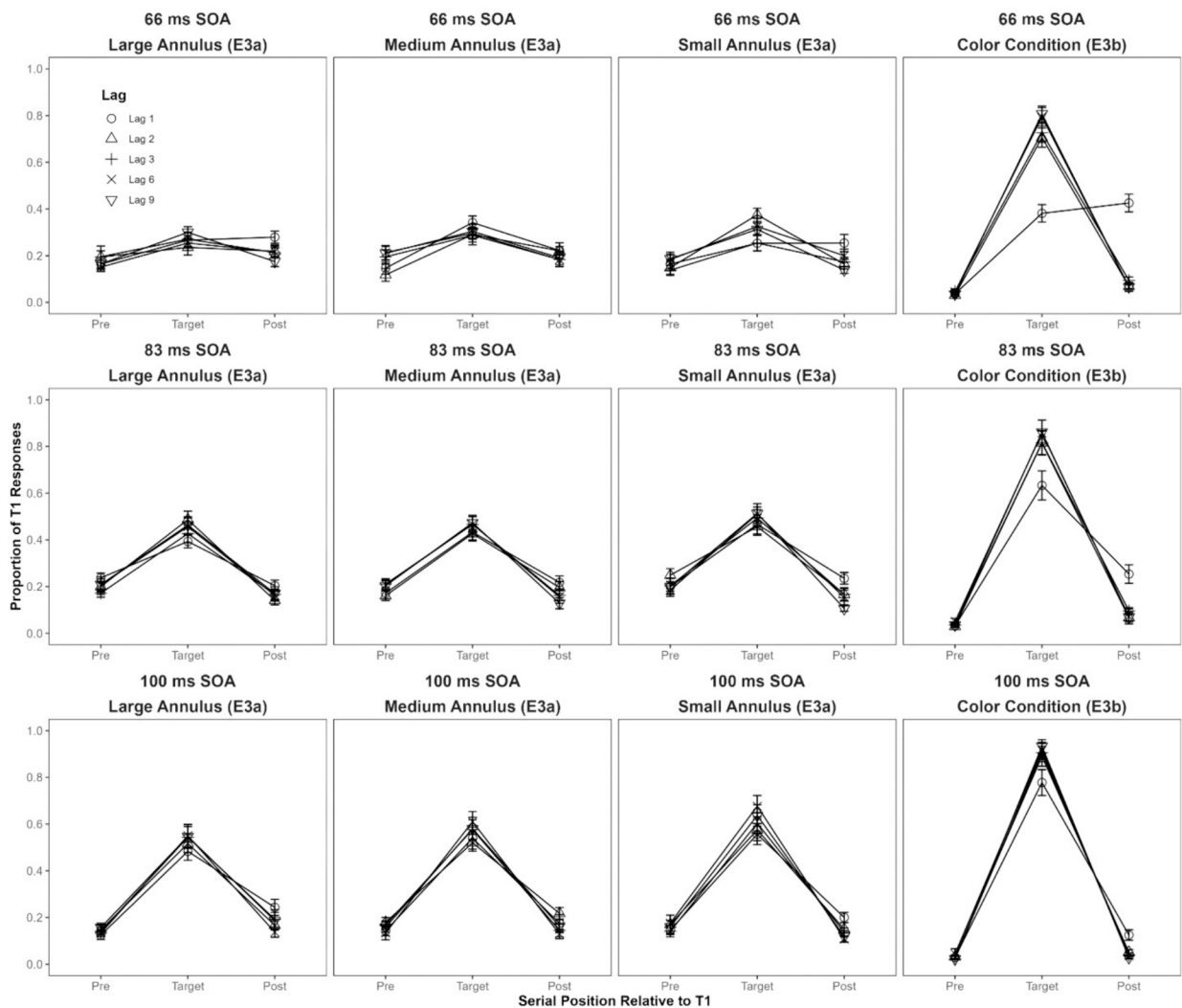


Fig. 6. Responses for T1 in experiment 3. These plots depict the proportion of T1 responses plotted by their serial position error relative to T1 for experiment 3a (left three columns) and experiment 3b (right column), plotted separately for each SOA and annulus size. Error bars represent ± 1 SEM.

4.1.3. Procedure and design

Participants began a trial by pressing the spacebar. A 300 ms blank screen was followed by a fixation cross “+” presented for 500 ms which was followed by another 300 ms blank screen. For experiment 3a, unlike the procedure for experiment 2, the fixation cross was surrounded by a white annulus that was the size of all the other annuli in the trial. The remainder of the trial was the same as the prior annulus color conditions for experiment 3a and for the prior color conditions for experiment 3b.

Participants completed three blocks of 75 trials each. Within each block, for experiment 3a, the five lags and three annulus sizes were randomized with the constraint that there was an equal number of occurrences of each lag and annulus size. For experiment 3b, the five lags were randomized with the same constraint, but without the additional annulus size variable. Each block was the same. Participants in both experiments were randomly assigned to the three presentation rates. Specifically, all stimuli were displayed for 33 ms and the ISI between them varied (33 ms = fast; 50 ms = medium; 67 ms = slow) resulting in SOAs of 66, 83, and 100 ms. To control the resulting varying trial time, the presentation time of the “&” mask at the end of the trial increased with faster presentation rate.

4.2. Results

As in the previous experiments, participants who responded correctly to T1 on less than 20 % of trials were removed from analyses. For experiment 3a, this criterion resulted in the removal of 15 participants, leaving 16 in the 66 ms SOA condition, 20 in the 83 ms SOA condition, and 20 in the 100 ms SOA condition. No participants were removed from analysis for experiment 3b. Because fewer participants remained than in previous experiments and because fewer observations per participant were obtained due to the inclusion of the annulus size within-subject variable as well as the overall poorer performance in the 66 ms SOA condition, some inferential statistics cannot be performed. These analytic deviations will be specified in the upcoming sections.

4.2.1. T1 responses

4.2.1.1. Performance measures. Experiment 3a. For experiment 3a, A 3 (SOA) \times 3 (annulus size) \times 5 (lag) mixed ANOVA was performed on T1 PC. There was a main effect of SOA, $F(2, 53) = 26.04, p < 0.001, \eta_p^2 = 0.496$, such that T1 PC was lower in the 66 ms condition ($M = 0.287$) than both the 83 ms condition ($M = 0.462; p < 0.001$) and the 100 ms condition ($M = 0.566; p < 0.001$) and also lower for the 83 ms condition than the 100 ms condition ($p = 0.020$). In addition, a main effect of annulus size was observed, $F(2, 106) = 12.97, p < 0.001, \eta_p^2 = 0.197$, such that T1 PC was lower when the annulus was large ($M = 0.412$) than when the annulus was medium ($M = 0.438; p = 0.013$) or small ($M = 0.464; p < 0.001$), but was not different between when the annulus was medium or small ($p = .066$). Finally, a main effect of lag was observed $F(4, 212) = 4.20, p = 0.003, \eta_p^2 = 0.074$, such that T1 PC was lower when T2 appeared at lag 1 ($M = 0.413$) than either lag 6 ($M = 0.461; p = 0.016$) or lag 9 ($M = 0.459; p = 0.023$), but not different for any other pairwise comparisons ($ps > 0.13$). No interaction effects were observed, $ps > 0.20$.

Fig. 6 shows that participants frequently reported letters appearing before (pre-target) or after (post-target) T1. The patterns of pre-target vs post-target errors were compared in a 3 (SOA) \times 3 (annulus size) \times 5 (lag) \times 2 (serial position error [SPE]: pre-target vs post-target) mixed ANOVA. A main effect of SOA was observed, $F(2, 53) = 5.10, p = 0.009, \eta_p^2 = 0.162$, such that overall reports of letters either before or after T1 were greater in the 66 ms condition ($M = 0.171$) than the 100 ms condition ($M = 0.126; p = 0.008$), but not different for other pairwise comparisons $ps > 0.14$. A main effect of annulus size was observed, $F(2, 106) = 5.110, p = 0.008, \eta_p^2 = 0.088$, such that overall reports of letters either before or after T1 were greater when the annulus was large ($M = 0.158$) than when the annulus was small ($M = 0.140; p = 0.012$) but not different for any other pairwise comparisons, ($ps > 0.13$). In addition, a main effect of lag was observed, $F(3.44, 182.64) = 6.35, p < 0.001, \eta_p^2 = 0.107$, such that reports of letters before and after T1 were greater when T2 appeared at lag 1 ($M = 0.171$) than lag 2 ($M = 0.145; p < 0.001$), lag 3 ($M = 0.149; p = 0.010$), lag 6 ($M = 0.144; p = 0.001$), or lag 9 ($M = 0.142; p < 0.001$), but no other pairwise comparisons were significantly different ($ps = 0.100$). An interaction between annulus size and SPE was observed, $F(2, 106) = 5.84, p = 0.004, \eta_p^2 = 0.099$, such that when the annulus was large, post-target errors ($M = 0.173$) were more frequent than pre-target errors ($M = 0.144; p = 0.051$; note that Bonferroni adjustments tend towards type II error), but not different among any other pair-wise comparisons ($ps > 0.39$). Finally, an interaction between lag and SPE was also observed, $F(4, 212) = 12.28, p < 0.001, \eta_p^2 = 0.188$, such that when T2 appeared at lag 1, participants were much more likely to report the post-target ($M = 0.210$) than a pre-target letter ($M = 0.133; p < 0.001$), but no other pairwise comparisons were significant ($ps > 0.09$; all Ms ranged [.128: 0.157]). All other effects did not reach significance ($ps > 0.05$).

Experiment 3b. A 3 (SOA) \times 5 (lag) mixed ANOVA was performed on T1 PC. There was a main effect of lag, $F(2.74, 96.01) = 115.81, p < 0.001, \eta_p^2 = 0.76$, such that T1 PC was lower for lag 1 ($M = 0.597$) than all other lags (all $ps < 0.001$), lower for lag 2 ($M = 0.804$) than lag 6 ($M = 0.857; p = 0.005$) and lag 9 ($M = 0.867; p < 0.001$), and lower for lag 3 ($M = 0.816$) than lag 6 ($p = 0.042$) and lag 9 ($p < 0.001$). A main effect of SOA, $F(2, 35) = 6.02, p = 0.006, \eta_p^2 = 0.256$, indicated that T1 PC was higher for the 100 ms SOA condition ($M = 0.885$) than the 66 ms SOA condition ($M = 0.683; p = 0.004$), but not different for other pairwise comparisons (83 ms SOA $M = 0.797$; all $ps > 0.19$). Finally, the interaction between SOA and lag, $F(5.48, 96.01) = 11.02, p < 0.001, \eta_p^2 = 0.386$, revealed that although T1 PC was generally lower when T2 appeared at lag 1, this relative decrease in T1 PC was greater with decreasing SOA.

Fig. 6 shows that participants sometimes indicated a stimulus appearing in positions adjacent to T1. A 3 (SOA) \times 5 (lag) \times 2 (SPE) mixed ANOVA was conducted. The main effect of lag, $F(2.33, 81.63) = 136.23, p < 0.001, \eta_p^2 = 0.796$, revealed that erroneous reports of nearby stimuli was greater when T2 appeared at lag 1 ($M = 0.144$) than lag 2 ($M = 0.033; p < 0.001$), lag 3 ($M = 0.037; p < 0.001$), lag 6 ($M = 0.027; p < 0.001$), and lag 9 ($M = 0.027; p < 0.001$). A main effect of SPE, $F(1, 35) = 95.93, p < 0.001, \eta_p^2 = 0.733$, indicates that post-target errors ($M = 0.091$) were greater than pre-target errors ($M = 0.017; p < 0.001$) and the lag \times SPE interaction, $F(1.90,$

66.75) = 102.83, $\eta_p^2 = 0.746$, shows that the SPE effect was primarily driven by when T2 appeared at lag 1. In addition, there was a main effect of SOA, $F(2, 35) = 13.85$, $\eta_p^2 = 0.442$, such that fewer errors occurred for the 100 ms SOA condition ($M = 0.024$) than both the 66 ms SOA condition ($M = 0.082$; $p < 0.001$) and the 83 ms SOA condition ($M = 0.055$; $p = 0.027$). The SOA \times SPE interaction, $F(2, 35) = 11.88$, $p < 0.001$, $\eta_p^2 = 0.404$, indicated that the general post-target pattern of errors was greater with faster SOAs. Finally, the three-way interaction between SOA, lag, and SPE, $F(3.81, 66.75) = 12.15$, $p < 0.001$, $\eta_p^2 = 0.410$, suggests that the increase in post-target errors with faster SOAs was primarily driven by cases in which T2 appeared at lag 1, although there was also a small increase in post-target patterns at other lags.

4.3. Confidence measures

Experiment 3a. Fig. 7 depicts confidence ratings for experiments 3a and 3b. Analyses concerning CR revealed a main effect of annulus size, $F(2, 94) = 6.11$, $p = 0.003$, $\eta_p^2 = 0.115$, such that CRs were higher when the annulus was small ($M = 2.019$) than when the annulus was large ($M = 1.947$, $p = 0.019$) or medium ($M = 1.945$, $p = 0.020$), but not different between when the annulus was medium or large ($p = 1.000$). In addition, there was a main effect of lag, $F(2.68, 126.40) = 14.61$, $p < 0.001$, $\eta_p^2 = 0.237$, such that CRs for T1 generally increased with increasing lag. After Greenhouse-Geisser adjustments, no other effects reached significance, $ps > 0.05$. Because there were often instances in which participants never reported a letter before or after T1, inferential statistics concerning CR for T1 errors are impossible and inspection of aggregate ratings do not suggest any reliable or meaningful pattern; therefore, results are not reported.

Experiment 3b. Because many participants never made pre-target and post-target errors, inferential tests concerning CRs are

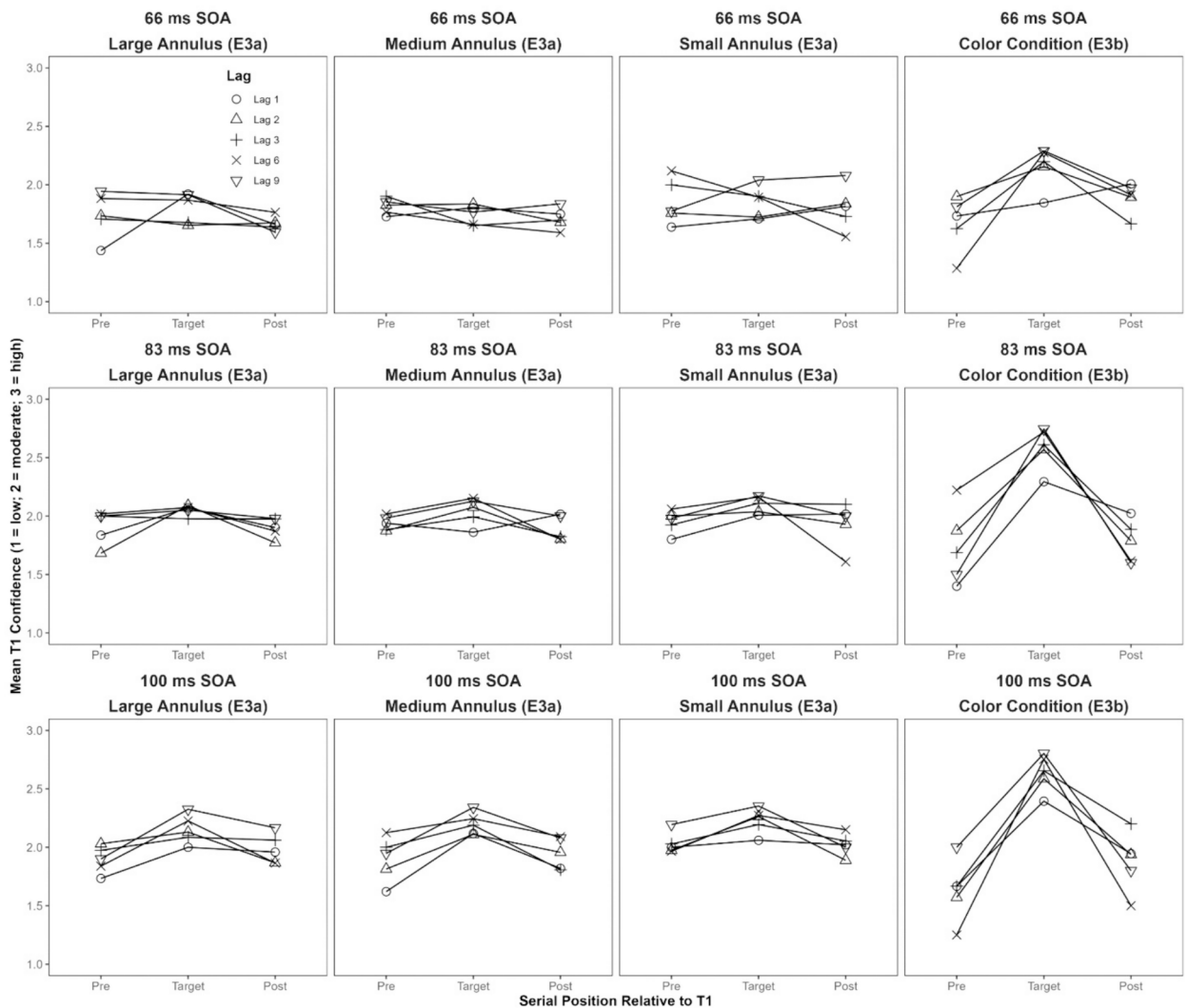


Fig. 7. Confidence ratings for T1 in experiment 3. These plots depict mean confidence ratings for T1 responses plotted by their serial position relative to T1, for experiment 3a (left three columns) and experiment 3b (right column), plotted separately for each SOA and annulus size.

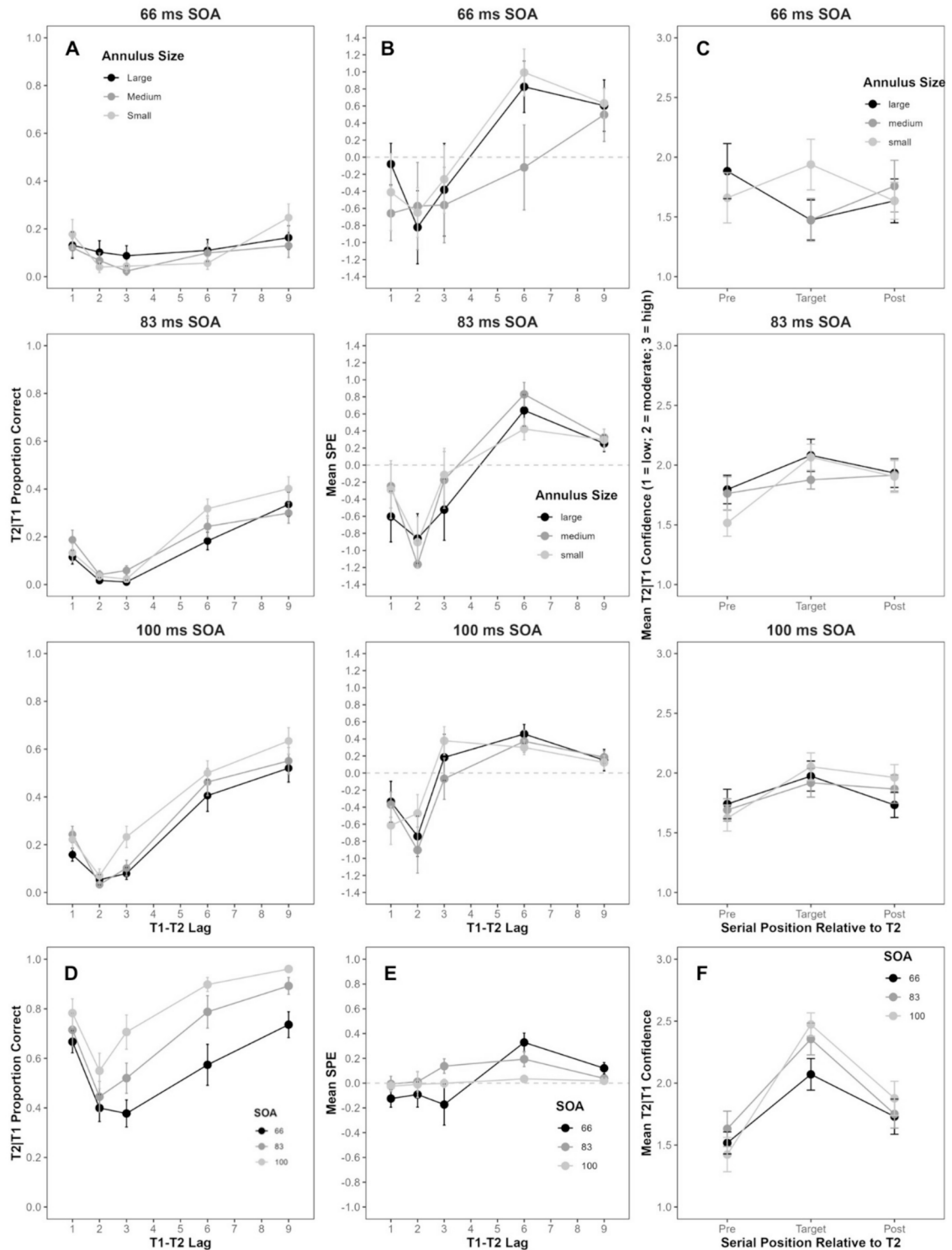


Fig. 8. Results for T2|T1 responses in experiment 3. Correct T2|T1 responses as a function of lag are plotted in panel a for experiment 3a and panel d for experiment 3b. Mean SPE as a function of lag is plotted in panel b for experiment 3a and panel e for experiment 3b. Confidence ratings for T2|T1 responses are plotted in panel c for experiment 3a and panel f for experiment 3b. Error bars represent ± 1 SEM.

reported for only correct reports of T1. Anecdotally, however, CRs for post-target errors when T2 appeared at lag 1 appear to increase with faster presentation rates. A 3 (SOA) \times 5 (lag) mixed ANOVA was conducted on T1 CRs for correct T1 reports. There was a main effect of lag, $F(1.79, 62.77) = 44.56, p < 0.001, \eta_p^2 = 0.560$, such that T1 CRs were lower when T2 appeared at lag 1 ($M = 2.111$) than at lag 2 ($M = 2.373; p < 0.001$), lag 3 ($M = 2.434; p < 0.001$), lag 6 ($M = 2.530; p < 0.001$), and lag 9 ($M = 2.570; p < 0.001$). In addition, T1 CRs were lower when T2 appeared at lag 2 than lag 3 ($p = 0.017$), lag 6 ($p < 0.001$), and lag 9 ($p < 0.001$); lower when T2 appeared at lag 3 than lag 6 ($p = 0.006$) and lag 9 ($p < 0.001$); but not different between lag 6 and lag 9 ($p = 0.876$). A main effect of SOA, $F(2, 35) = 3.48, p = 0.042, \eta_p^2 = 0.166$, revealed lower CRs for the 66 ms SOA condition ($M = 2.110$) than the 100 ms SOA condition ($M = 2.608; p = 0.049$), but no differences between the 83 ms SOA condition ($M = 2.493$) and either the 66 or the 100 ms SOA conditions ($ps > 0.19$). The interaction was not significant ($p = 0.997$).

4.3.1. T2|T1 responses

4.3.1.1. Performance measures. Experiment 3a. Only trials in which T1 was correctly responded to are included in the following analyses (T2|T1). T2|T1 PC is plotted in Fig. 8a. A 3 (SOA) \times 3 (Annulus Size) \times 5 (lag) mixed ANOVA was conducted on T2|T1 PC. First, a main effect of lag revealed the typical AB effect, $F(2.98, 143.38) = 93.93, p < 0.001, \eta_p^2 = 0.662$. Planned comparisons revealed that T2|T1 PC was greater when T2 appeared at lag 1 ($M = 0.157$) than at lag 2 ($M = 0.046; p < 0.001$) and lag 3 ($M = 0.067; p < 0.001$), but lower than lag 6 ($M = 0.279; p < 0.001$) and lag 9 ($M = 0.377; p < 0.001$). In addition, T2|T1 PC was lower when T2 appeared at both lag 2 and lag 3 than at both lag 6 and lag 9 ($ps < 0.001$) and lower at lag 6 than at lag 9 ($p = 0.002$). A main effect of

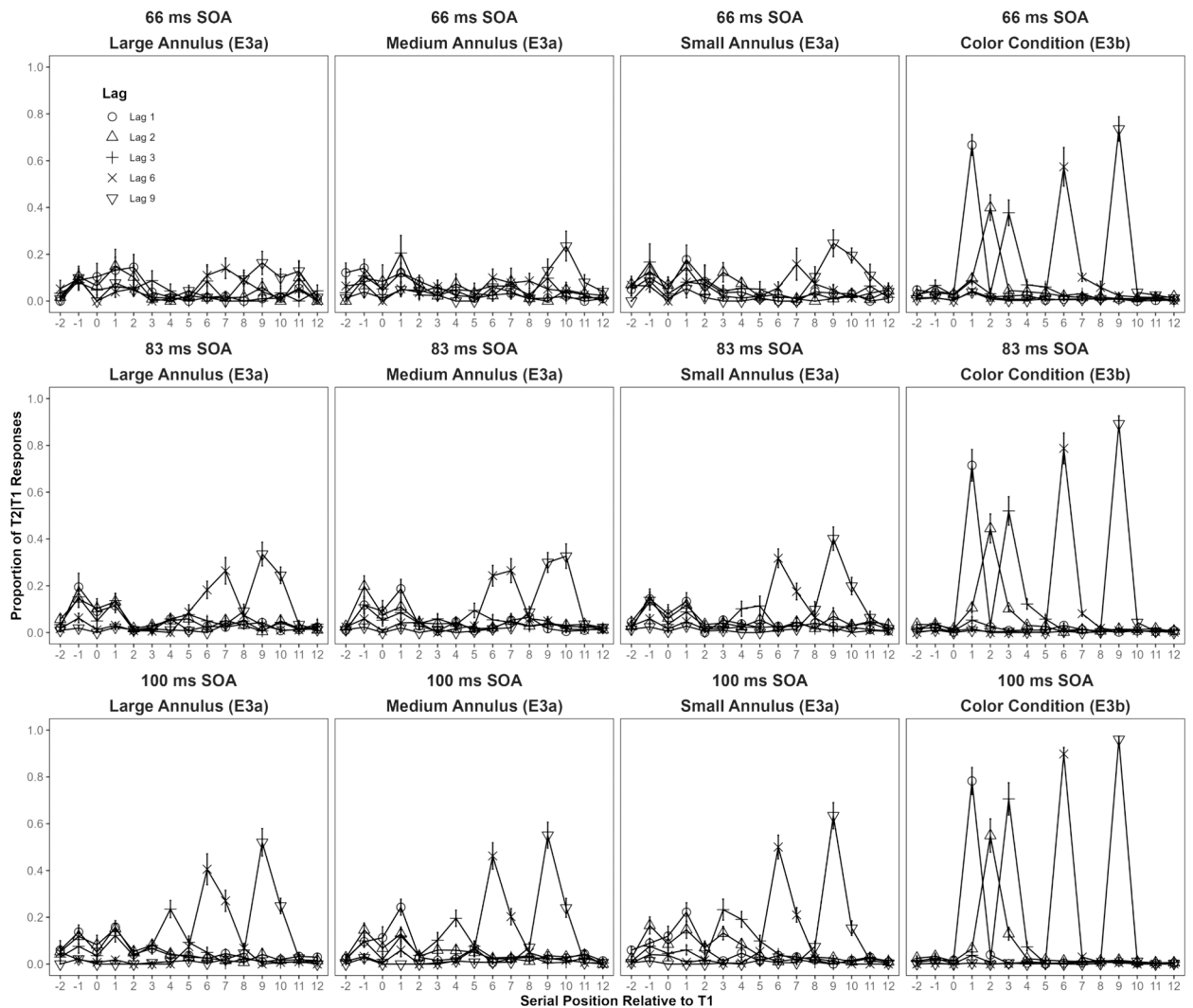


Fig. 9. Serial positions of T2|T1 responses in experiment 3. All T2|T1 responses are plotted with respect to their serial position relative to T2 (0 on the abscissa) for experiment 3a (left three columns) and experiment 3b (right column), plotted separately for each SOA and annulus size. Error bars represent ± 1 SEM.

SOA was observed, $F(2, 48) = 27.32, p < 0.001, \eta_p^2 = 0.532$, such that T2|T1 PC was greater for the 100 ms SOA condition ($M = 0.296$) than the 66 ms SOA condition ($M = 0.099; p < 0.001$) and the 83 ms SOA condition ($M = 0.160; p < 0.001$), but not different between the 66 ms and 83 ms SOA conditions ($p = 0.111$). In addition, a main effect of annulus size was observed, $F(1.93, 93.00) = 7.53, p = 0.001, \eta_p^2 = 0.136$, such that T2|T1 PC was greater when the annulus was small ($M = 0.212$) than when the annulus was large ($M = 0.163; p = 0.001$) or medium ($M = 0.181; p = 0.017$), but not different between the large or medium annulus sizes ($p = 0.566$). Finally, the interaction between SOA and lag was significant, $F(5.97, 143.38) = 12.68, p < 0.001, \eta_p^2 = 0.346$, indicating that with faster presentation rates was a prolonged attentional blink in terms of T1-T2 lag. That is, T2|T1 PC did not appear to recover at lag 6 for the 66 ms SOA condition.

Patterns of errors for T2|T1 reports cannot be meaningfully interpreted through inferential statistics of mean SPE due to many participants never reporting a stimulus from the 7-stimulus window surrounding T2 at certain lags (in particular participants from the 66 ms SOA condition, but also from other conditions). This overall poor performance can be observed in Fig. 9. However, inspection of Fig. 8b and Fig. 9 reveals a similar trend to that observed by Vul et al. (2008b) in which faster presentation rates was associated with a greater proportion of post-target errors when T2 appeared at lags 3, 6, and 9.

Finally, no effects concerning order reversals were observed, $ps > 0.17$. The overall proportion of order reversals was 0.081, which is similar to that of the annulus color condition of experiment 2.

Experiment 3b. Responses to T2|T1 are depicted in Figs. 8 and 9. A 3 (SOA) \times 5 (lag) mixed ANOVA was conducted on T2|T1 PC. A main effect of lag $F(2.75, 96.55) = 62.66, p < 0.001, \eta_p^2 = 0.642$, revealed the typical AB effect. That is, PC was higher when T2 appeared at lag 1 ($M = 0.722$) than lag 2 ($M = 0.465; p < 0.001$) and lag 3 ($M = 0.534; p < 0.001$), not different than when T2 appeared at lag 6 ($M = 0.753; p = 1.000$), and lower than when T2 appeared at lag 9 ($M = 0.863; p < 0.001$). In addition, PC was lower when T2 appeared at lag 2 than lag 3 ($p = 0.003$), lag 6 ($p < 0.001$), and lag 9 ($p < 0.001$). Similarly, PC was lower when T2 appeared at lag 3 than lag 6 ($p < 0.001$) and lag 9 ($p < 0.001$) and lower for lag 6 than lag 9 ($p < 0.001$). The main effect of SOA was also significant, $F(2, 35) = 5.98, p = 0.006, \eta_p^2 = 0.255$, indicating that PC was lower for the 66 ms SOA condition ($M = 0.551$) than the 100 ms SOA condition ($M = 0.779; p = 0.004$), but no differences were observed for the 83 ms SOA condition ($M = 0.672; ps > 0.24$). Finally, the SOA \times lag interaction reached significance $F(5.51, 96.55) = 2.27, p = 0.048, \eta_p^2 = 0.115$, with a trend such that that “recovery” from the AB effect occurred with fewer intervening nontargets with slower presentation rates.

Next, a 3 (SOA) \times 5 (lag) mixed ANOVA was conducted on mean SPE. A main effect of lag, $F(2.67, 5.34) = 4.94, p = 0.004, \eta_p^2 = 0.124$, revealed that participants tended towards a pre-target pattern at short lags (lags 1 and 2), but a post-target pattern for longer lags (lags 6 and 9), as can be seen in Fig. 8e. An interaction effect between SOA and lag, $F(5.34, 93.48) = 2.16, p = 0.060, \eta_p^2 = 0.110$, did not reach significance.

Finally, the prevalence of order reversals when T2 appeared at lag 1 differed depending on SOA conditions, $F(2, 35) = 5.52, p = 0.008, \eta_p^2 = 0.240$. Specifically, order reversals were more prevalent for the 66 ms SOA condition ($M = 0.154$) than the 100 ms SOA condition ($M = 0.062; p = 0.007$) but were not different between the 83 ms condition ($M = 0.122$) and either the 66 or the 100 ms conditions ($ps > 0.12$).

4.4. Confidence ratings

Experiment 3a. Meaningful conclusions concerning CRs for T2|T1 responses cannot be made. However, Fig. 8c depicts a similar trend to that observed in experiments 1 and 2, in particular for the small and medium annulus sizes and the 83 and 100 ms SOA conditions. That is, participants appeared to be similarly confident in their post-target responses as their correct responses, but less confident in their pre-target responses.

Experiment 3b. T2|T1 PC when the color of the letter defined a target was high enough that inferential tests on T2|T1 confidence as a function of lag are indeed possible for this experiment. A 3 (SOA) \times 5 (lag) mixed ANOVA was conducted on T2|T1 PC. Only a main effect of lag was reliably observed, $F(2.95, 103.50) = 64.42, p < 0.001, \eta_p^2 = 0.648$, such that CRs were lower when T2 appeared at lag 1 ($M = 1.952$) compared to lag 3 ($M = 2.175; p = 0.003$), lag 6 ($M = 2.445; p < 0.001$), and lag 9 ($M = 2.559; p < 0.001$); lower when T2 appeared at lag 2 ($M = 1.959$) compared to lag 3 ($p < 0.001$), lag 6 ($p < 0.001$), and lag 9 ($p < 0.001$); lower at lag 3 compared to lag 6 ($p < 0.001$) and lag 9 ($p < 0.001$); and lower at lag 6 than at lag 9 ($p = 0.002$). No effects concerning SOA were significant ($ps > 0.06$).

As before, because many participants never reported stimuli either before or after T2 as T2 at certain lags, inferential tests cannot be performed on confidence in errors broken down by lag. However, aggregating over lag allows for analysis of confidence in errors relative to the target. A 3 (SOA) \times 3 (SPE: pre-target, target, post-target) mixed ANOVA revealed a main effect of SPE, $F(2, 70) = 94.14, p < 0.001, \eta_p^2 = 0.729$, such that CRs were greater for correct target identification ($M = 2.289$) than either pre-target errors ($M = 1.679; p < 0.001$) or post-target errors ($M = 1.770; p < 0.001$), but not different between pre- and post-target errors ($p = 0.137$). In addition, there was an interaction effect between SOA and SPE $F(4, 70) = 2.75, p = 0.035, \eta_p^2 = 0.136$, but this was primarily driven by lower CRs for correct responses for the 66 ms SOA condition compared to the slower conditions.

4.5. Discussion

The presentation rate manipulation strongly influenced T1 responses for the annulus color condition in experiment 3a, but interestingly, only marginally for the color condition of experiment 3b. For experiment 3a, participants in the 66 ms SOA condition in particular performed very poorly (on average, just over 20 % correct for T1), suggesting that an RSVP task using a spatially displaced cue is too difficult at this presentation rate. Although this T1 PC is consistent with the 60 ms condition of Vul et al. (2008b), because performance was so poor, results should be interpreted cautiously. Interestingly, there was an exception for the color condition in

which presentation rate strongly influenced T1 responses. In addition, participants very frequently reported the T2 stimulus as T1 with increased in frequency with faster presentation rate specifically for the color condition. Anecdotally, this increase in frequency with presentation rate, and corresponding increase in order reversals, was accompanied by greater confidence in those errors. Why these effects were observed for the color condition but not the annulus color condition is worthy of further discussion to be made later. The observation of a strong influence of SOA when a spatially displaced cue defines target, but not the color of the letter, further supports the conclusion that these tasks are fundamentally different.

Confidence in T1 responses were not observed to be different depending on presentation rate for the annulus color condition, although the trend was for lower confidence in the fastest condition. This lower confidence for the fastest condition was observed in the color condition. In addition, for the color condition, confidence in T1 responses increased with increasing lag. On the other hand, consistent with the prediction that how spatially displaced a target-defining feature is from the response feature will influence performance, T1 PC was marginally lower for the large annulus than the other two sizes. This decrease was accompanied by an increase in post-target errors specifically. Although this weakens arguments concerning the influence on annulus size on T2|T1 processing as opposed to target processing in general, the difference in T1 PC was marginal (41 % compared to 43 % or 46 % for the medium and small annuli), therefore conclusions concerning T2|T1 can still soundly be made with some caution.

The results concerning T2|T1 PC for experiment 3a are consistent with the conclusions of Vul et al. (2008a) that the attentional blink is time-dependent; increasing presentation rate resulted in an extended AB in terms of number of distracters between T1 and T2. Additionally, with faster presentation rates was a substantially stronger post-target pattern as shown in Fig. 9. This is quite apparent by inspecting the ratio of correct responses to post-target errors when T2 appeared at lags 3, 6, and 9 for the 83 ms and 100 ms SOA conditions. For the color condition on the other hand, although there was a moderately faster “recovery” from the AB with slower presentation rates, this effect was not as strong as that of experiment 3a. Similarly, although presentation rate appeared to strongly influence how far T2|T1 responses were from the target in experiment 3a, this effect was quite small when the color of the letter defined the target. This different pattern possibly indicates a different underlying mechanism for intrusion errors depending on target-defining features, and is consistent with the observation of lower confidence for errors than correct responses that was not different depending on presentation rate. However, because these two conditions were tested on different samples of participants, conclusions should be made cautiously.

The annulus size manipulation did not influence mean SPE as expected, but instead appeared to influence both pre- and post-target errors as can be observed in Fig. 9 and by the lack of an effect on *mean* SPE in Fig. 8b. Another way of looking at the results is by inspecting the relative ratio of correct responses to post-target errors. In particular, for the 83 ms and 100 ms SOA conditions when T2 appears at lags 6 and 9 (and 3 to some extent), faster SOA appears to result in a much larger post-target pattern of errors when the annulus size was medium compared to small. It is noteworthy that despite the fact that the small annulus nearly touched the letter stimuli and was therefore (presumably) effectively always within the focus of attention, there was still a strong effect of SOA on the error pattern, much stronger than that of the color condition. Therefore, *how close* the blue color is to the response feature does not well explain the differences observed between the annulus color and color conditions.

Although conclusions concerning T2|T1 confidence ratings should be made with caution, it is once again noteworthy that confidence in post-target responses for the 83 and 100 ms SOA conditions in experiment 3a resemble those of experiment 2. An interesting observation was made for experiment 3b, however. Although participants were less confident in their correct T2|T1 responses during the AB than when T2 appeared at later lags, participants were not more confident in their correct T2|T1 responses when T2 appeared at lag 1 (lag 1 sparing). This is consistent with the observations of Recht et al. (2019) who used an annulus as a target-defining feature. Together, these findings are also consistent with Livesey and Harris' (2011) conclusion that the mechanisms underlying lag 1 sparing are possibly different than those underlying the AB. The present observation that the prevalence of order reversals and confidence in incorrect reports of T2 as T1 when T2 appears at lag 1 are different depending on target-defining features might also suggest that the mechanisms underlying lag 1 sparing are partially different depending on target feature.

5. General discussion

The present series of experiments demonstrates, at minimum, that erroneous reports of nearby stimuli during the AB might be due to different processes depending on how targets are defined. Experiment 1 demonstrated, through a simple between-subjects comparison, that the average distance between reported T2s and the actual T2s was greater when the target was defined by the presence of an annulus than the color of the letter, possibly suggesting that a more positive mean serial position error cannot be directly interpreted as the extent that attention is delayed. That is, if a unitary attention process that is responsible for target selection is delayed while “encoding” T1, it would likely be similarly delayed for both target-defining conditions. In fact, the response feature of the stimuli was the same between conditions, therefore, some other mechanism is likely responsible for the differences in T2 responding. In addition, although the results of Recht et al. (2019) that participants were confident in their post-target errors were replicated in the present study for the annulus condition, that was not the case when the color of the letter defined the target, further corroborating postulation of different underlying mechanisms.

To further investigate the specific conditions that give rise to the differences, in experiment 2 the target-defining annulus was masked by presenting annuli around each RSVP letter and making the targets blue annuli. Largely similar results to the annulus condition were observed, suggesting that the lack of masking for the annulus defined targets was not the principal driver of the difference. Instead, because the distance between the annuli and the letters resulted in more errors in experiment 3a, perhaps spatial displacement of the target defining feature from the response feature explains much of difference between annulus-defined and color-defined conditions. This is consistent with an earlier postulation that “temporal binding” is greatly facilitated by spatial but not

necessarily temporal synchronicity (Keele et al., 1988). However, in experiment 3, T2/T1 proportion correct never approached the level of color-defined conditions even when annuli were almost touching the letter. This observation, in conjunction with the findings that presentation rate strongly influenced both T2/T1 PC in terms of how prolonged the AB was and mean SPE for the annulus color condition, but not the color condition, instead suggest that whether the target-defining feature is a feature of the response stimulus is more relevant. This would also be consistent with the observation of high confidence for correct responses in the color condition.

The preceding summary and interpretations of results concern specifically responses to the T2 stimulus, not T1. That is, despite the generally poorer performance for T1 for the annulus conditions than the color condition, and the poor performance for the fastest presentation rate, the error patterns and confidence ratings were quite similar among conditions. This pattern means that responding to T1 interacts with the manipulations of the present study to influence T2 responding. Why the pattern of errors and confidence in those errors are different depending on target defining feature for T2, but not T1, should be discussed within existing theoretical accounts.

Although accounts of the AB differ in many assumptions, one popular postulation is that the attentional mechanism responsible for the AB is a single, unitary system that either is or is not allocated to incoming sensory information. This attentional mechanism has been postulated to be a top-down system controlling an input filter that may be disrupted upon detection of a nontarget (Temporary Loss of Control: Di Lollo et al., 2005), overexerted to the consolidation process and therefore unable to process an incoming T2 (Threaded Cognition: Taatgen et al., 2009; see also Willems & Martens, 2016), or conversely, delayed in its reengagement to the incoming task even though it has already consolidated T1 (Nieuwenstein et al., 2005; Nieuwenstein, 2006). Other accounts also propose this attentional bottleneck as the hypothesized locus of the AB, but instead suggest that whether the attentional mechanism is allocated to incoming stimuli is under the control of bottom-up processing of stimulus properties which interact with the relevance of a stimulus feature (Olivers & Meeter, 2008) or similarly to both the relevance and the salience of the feature (Shih, 2008; Shih & Reeves, 2007). Under most accounts, whether T2 is correctly responded to is explained by dynamics in the attentional mechanism. This framework of a unitary attention system that either is or is not applied to incoming sensory information works well to explain dichotomous correct vs incorrect T2 responses; however, it is less clear how it can explain intrusion errors.

The general post-target pattern for T2 when T2 appears approximately 200 ms after T1 is considered to be due to *delayed* attention to the RSVP task resulting from concurrent or recent engagement to the T1 stimulus (Recht et al., 2019; Vul et al., 2008a, 2008b). Why a delayed attention mechanism would select the nontarget for report is not clear under the assumption of a delayed attentional system – the stimulus being attended to is still not a target and would presumably still be rejected for report. Similarly, the fact that stimulus salience can orient attention back to incoming RSVP stimuli (Shih & Reeves, 2007), but perhaps at a delay such that the T2 + 1 stimulus is attended to more, does not itself predict intrusion. In addition, the “bounce” of attention due to the nontarget T1 + 1 stimulus in Olivers and Meeters’ (2008) account would presumably also occur to the T2 + 1 nontarget. This should result in another rejection, not a perceptual grouping of the two stimuli. To explain intrusion errors in terms of a delayed attention process requires either an additional binding mechanism (e.g., Botella et al., 2011; Wyble et al., 2009) or a more generalized attention mechanism responsible for both selection and binding (and possibly maintenance in working memory, see Wheeler & Treisman, 2002).

The results from the present study are even less clearly explained by popular accounts because the proposed attentional mechanism is not considered to be specific to a single stimulus feature, but rather generalized to all visual processing. If consolidation of T1 results in a delay of attention, that delay would be similar regardless of how targets are defined because the response features (in this case, letters) are the same. An argument that perhaps color is more salient than a spatially displaced cue, and therefore attention is more quickly or strongly allocated back to the RSVP stimuli is not sufficient as that salience was controlled for with the annulus color condition in experiment 2. Another possibility is that attention is diffused over a larger spatial area in the annulus and especially the annulus color conditions than the color condition, which would intuitively predict poorer performance and lower confidence in responses – i.e., there “less” attention to any given stimulus feature in the RSVP stream and therefore there is poorer performance. This would be partially supported by the results of the annulus size manipulation in experiment 3a, however it would not be consistent with prior evidence that “broader” attention, defined in several ways, tends to result in better T2 responding (Dale & Arnell, 2010; Willems & Martens, 2016).

Breaking down RSVP stimuli into parallel processed “features” corresponding to the response dimension or the target-defining dimension, as has been done by Botella et al. (1992; 2001; 2004; 2011) offers a plausible explanation. Perhaps participants were attending to *either* the spatial region surrounding the response feature *or* the response features, which, according to prior entry (Shore et al., 2001; Spence & Parise, 2010), would lead to faster detection of a target-defining feature or response feature. Interestingly, where participants are attending would result in different patterns of errors. Faster detection of the target-defining feature would result in pre-target intrusion errors because the correspondingly slower identification of the letters would be incorrectly joined to the target-defining feature, whereas faster identification of letters would result in a post-target pattern because the delayed detection of the target-defining feature would be incorrectly joined to a later and faster-processed letter. This hypothesis is plausible in the present study considering different strategies may have been adopted by different participants or the same participant at different points in the experiment which could explain the prevalence of both pre-target and post-target errors. However, why participants would be more confident specifically in their post-target errors and for only the annulus conditions is unclear under this hypothesis.

Botella et al. (1992) proposed that feature integration within RSVP tasks occurs with near-simultaneous detection of response features and a target-defining feature. By manipulating the assumed processing time of response and target-defining features, Botella and colleagues (1992) showed that responses could be biased towards either a pre- or post-target pattern, although correct identification is generally most common. To account for errors for a second target under the assumption of delayed attention after processing a first target, Botella and colleagues (2001; 2011) propose that the T1 + 1 stimulus elicits a suppressive mechanism, consistent with Olivers and Meeter’s (2008) “bounce”, that reduces the processing of all stimuli – targets and nontargets alike – for a brief period of

time. This, in turn, limits the ability of a hypothesized attentional binding mechanism to properly join response and target-defining features. When this mechanism fails, a “sophisticated guessing” strategy is adopted based on the activation strength of any response feature. The delay in attention tends to bias this response to more strongly activated post-T2 stimuli. Importantly, Botella et al. (2011) used colored letters as stimuli and, consistent with the present study, observed more instances of participants indicating that they were unsure or guessing. The confidence results of the present study show that participants are similarly confident in their post-target responses as their correct responses when an annulus defines a target, possibly suggesting that either the failed binding mechanism in Botella and colleagues’ account is specific to when targets are defined by a spatially conjoined feature but not spatially displaced cues.

A limitation of the present study was that providing a confidence rating for a specific SPE (correct response; pre-target error; or post-target error) required that participants make such a response and therefore analyses concerning confidence ratings were quite limited. This was noticed after experiment 1; however, a clear solution was not apparent. For example, although substantially increasing the total number of trials would also increase the number of instances in which a specific error or correct response was made for a specific T1-T2 lag, this increase would be artificial and likely include many more guesses (performance was at floor for T2|T1 responses at lags 2 and 3 for the annulus conditions). Therefore, interpretations would also be limited. Extending the range of SPEs included in the computations would similarly be an artificial inflation of confidences in pre- and post-target errors. If future research is interested in continuing with this measure of confidence in an AB task, a better approach might be to provide specific options of stimuli, some of which appeared before and some of which appeared after the target and asking participants to select from them and rate their confidence. This would better balance the confidence measure and allow for more inferential statistics.

Another limitation concerns the interpretation of confidence ratings. Recht et al. (2019) reported strong positive correlations between the frequency of correct reports and confidence ratings as well as the frequency of specific SPEs and confidence judgements. We propose an interpretation that confidence ratings might reflect judgements of extent that target features are “bound” into one percept. An alternative interpretation, consistent with Recht and colleagues’ (2019) interpretation, might be that although meta-cognitive processes involved in confidence ratings are dissociated from behavioral performance, they in fact rely on the same “evidence signal” (for a discussion of different models, see Maniscalco & Lau, 2016). This was not experimentally tested in the present experiment, but is an important consideration when interpreting results.

Finally, because in the present study participants were not able to indicate “I don’t know” as a response and were instead instructed to guess, the mean SPE metric includes some of these random guesses and is therefore larger. Including an “I don’t know” response for cases in which the participants were distracted could reduce this influence.

The confidence ratings utilized in the present study might be relevant to current discussions of whether or the extent that (“conscious”) perception during the AB is graded or discrete. In a two-target RSVP task in which participants indicated the color of two targets along a gradient, Asplund et al. (2014) and Karabay et al. (2022) demonstrated that perception of T2 occurs in an all-or-none, discrete manner. However, perception of T2 is better characterized by a graded impairment when T1 and T2 switch visual fields (Karabay et al., 2022) or share a common target-defining feature (as opposed to when the task switches between T1 and T2; Sy et al., 2021). These measures utilize the degree of error on a continuous dependent variable for a single stimulus as a measure of conscious perception; however, a confidence rating as just described might be useful. Although the unbalanced nature of the present research does not allow strong conclusions for this question, the fact that overall confidence ratings were lower for the annulus color condition than the other conditions for T2|T1 responses could indicate that phenomenal consciousness for T2|T1 was lower in this case. Utilizing the forced alternative method just described would make confidence ratings a viable measure to address the question of graded vs discrete consciousness – if confidence ratings are bimodal, perhaps an all-or-none model better characterizes the phenomenal experience.

The observations of different patterns of errors and associated confidences in those errors when target letters are defined by different stimulus features demonstrate the necessity of careful consideration of RSVP stimuli when interpreting results and forming theoretical accounts of the AB. The results of the present study potentially suggest that different underlying mechanisms contribute to absolute performance and intrusion errors when targets are defined by different features.

CRediT authorship contribution statement

Matthew Junker: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Reza Habib:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Within the manuscript is a DOI to an OSF repository with the data. I can send the raw data on request.

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