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# Effects of subtle stimulus strength on the attentional blink

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**Abstract.** The attentional blink refers to a type of impairment in detecting a second target (T2) after detecting a first target (T1) in rapid serial visual presentation (RSVP). Until recently, the role of T1 and how it is related to limitations in postperceptual processing such as selective attention and memory have been intensively studied. Here, we focus on the role of T2 and investigate whether an unnoticeable difference in the stimulus strength of T2, as indexed by the contrast of stimuli, can still influence this postperceptual process. We found that T2 performance was modulated by subtle T2 strength differences, although the T2 strength difference was not perceptually noticeable within the RSVP stream. These results suggest that T2 strength is important in the postperceptual stages of T2 processing-consolidation.

**Keywords:** attentional blink, stimulus strength, contrast, just noticeable difference

## 1 Introduction

The attentional blink (AB) (Raymond et al 1992) is a type of impairment in reporting a second target (T2) that lasts for a brief duration (<500 ms) after correctly reporting a first target (T1) in rapid serial visual presentation (RSVP). The AB has been studied intensively as it relates to the deficit that exists in high-level processing such as selective attention (Nieuwenstein and Potter 2006; Vul et al 2008), episodic distinction (Wyble et al 2009), and memory (Wolfe 1997). Both conceptual and computational models suggest that the AB is the result of a bottleneck in postperceptual processing (Chun and Potter 1995; Dehaene et al 2003). Event-related potential (ERP) studies have shown that only the P3 component reflecting postperceptual processes such as memory updating is suppressed, whereas the P1 and N1 components corresponding to sensory processing are not suppressed during the AB (Luck et al 1996; Vogel et al 1998). This explanation of the AB has led researchers to focus on the role of T1 because deficits in postperceptual processes due to T1 being processed cause the reduced level of the identification of T2 (eg Chun and Potter 1995). For example, it has been suggested that conscious awareness of T1 is a boundary condition for the AB (Nieuwenstein et al 2009).

While most AB studies have focused on impairments in postperceptual processing during the AB, low-level features such as the target strength—indexed by the contrast of the target—and the level of discriminability between targets and distractors can influence T2 processing during the AB. Furthermore, Shih (2008) suggested that a sufficiently salient bottom–up strength can automatically influence the amount of the AB. Consistent with this suggestion, the AB is progressively attenuated as the T2 contrast increases, whereas T1 and the distractor contrasts remain constant (Chua 2005). When T2 was chosen from a different stimulus category than the distractors and was thus readily discriminable from the distractors, the AB was greatly attenuated (Chun and Potter 1995). These findings suggest that a salient T2 (due to either a contrast change or a category change) helps participants to report T2, although this action remains under the same attentional limitation. However, even in these studies, low-level features might have influenced high-level stages of visual processing.

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For example, in Chua's (2005) study the contrast difference between targets and distractors was as high as 65.7%. This contrast difference is large enough to produce transients,[1] and the transients can induce exogenous attention in turn (Nakayama and Mackeben 1989). Therefore, it is unclear as to whether attention or the stimulus strength (contrast) influenced the amount of AB in Chua's study.

In the present study we attempted to investigate isolated effects of the stimulus strength on the AB by minimizing the bottom–up attentional effect. Specifically, we asked whether small changes in the T2 strength can modulate T2 performance during the AB. In order to minimize transients produced by contrast changes and ensure that the T2 strength changes were equivalent across participants, we measured the just noticeable differences (JNDs) of stimuli in contrast based on each participant's psychometric function of contrast discrimination. We then tested whether the difference in T2 strength was detectable in RSVP streams to rule out any bottom–up saliency explanation. The results show that the T2 performance depended on the T2 strength. Furthermore, these changes in the T2 strength were not perceptually noticeable from distractors *within* an RSVP stream. These findings suggest that target detection in an RSVP stream is affected not only by attention but also by the target strength.

## 2 Method

### 2.1 *Participants*

Nine Yonsei University students participated in the main experiment. Ten Yonsei University students, including five participants who also participated in the main experiment, participated in the control experiment. Four of the participants received monetary compensation of 20 000 Korean won (about US $20) for their participation, while the rest of them participated voluntarily. They were all naive to the purpose of the experiment. All had normal or corrected-to-normal vision. All aspects of the study were carried out in accordance with the regulations of the Institutional Review Board of Yonsei University.

### 2.2 *Apparatus and stimuli*

Stimuli were created and controlled using MATLAB and PsychToolbox (Brainard 1997; Pelli 1997) on a PC. Stimuli were displayed on a 21 inch linearized Samsung SyncMaster monitor in a dark room. The distance between the monitor and participants was approximately 90 cm, and the refresh rate of the monitor was 85 Hz. We created 1792 luminance steps to manipulate the contrast of the stimuli using a bit-stealing technique (Tyler 1997). Stimuli appeared on a gray background (51.34 cd $m^{-2}$).

Stimuli were uppercase English alphabet letters (for the distractors) and digits (for T1 and T2) in Helvetica font. The average size of the letters and digits was 1.63 deg × 2.09 deg and 1.31 deg × 2.09 deg, respectively. Gaussian noise was added within a 1.9 deg × 1.9 deg square that had the same center as the stimuli. The root mean square contrast of the noise was approximately 3.8%. We excluded certain letters (B, I, O, Q, Z) and digits (0, 1, 5, 8) to reduce the similarity between the targets and distracters in the RSVP.

### 2.3 *Design and procedure*

Prior to the main experiment, we used the method of constant stimuli to measure each participant's psychometric function of contrast discrimination. We measured this function to equate the strength of T2 changes across participants and to ensure subtle T2 changes.

[1] We mean transients to contrast changes between T2 and T2 + 1. In an RSVP stream there are always onsets and offsets of stimuli, but the stimulus and the blank are likely to be blended due to temporal summation (Hood and Finkelstein 1986).

The contrast of letters was a Weber contrast against a gray background. The standard contrast was 34%, and the test contrasts consisted of seven contrasts around the standard contrast: three that were below the standard (constant distance in log scale), the standard contrast, and three contrasts above the standard (constant distance in log scale). The lowest contrast varied from 24.92% to 25.79% and the highest varied from 44.82% to 46.40%, depending on the participants, to reflect their levels of performance. Two digits used in the main experiment were randomly selected for the standard and the test stimulus. The standard and the test contrast were presented sequentially in the center of the display, and the order of presentation was counterbalanced across trials. The stimulus duration was 118 ms, and the interstimulus interval (ISI) was 259 ms. These two intervals were demarcated by high-pitched tones. Participants pressed 1 if the contrast in the first interval was at a higher level and pressed 2 otherwise. There were 50 trials for each test contrast (350 trials in total). $JND_L$, the point of subject equality (PSE), and $JND_H$ were defined as the contrasts resulting in 25%, 50%, and 75% "higher" responses, respectively.

In the main experiment there were two independent variables: the T2 strength and the lag. Three levels of stimulus strength were used for T2, $JND_L$, PSE, and $JND_H$, as acquired from the contrast discrimination experiment.(2) The contrasts of T1 and the distractors were always fixed at the PSE. The lag, the time difference between T1 and T2 onsets, had five levels (1, 3, 4, 7, and 10, corresponding to 59, 177, 236, 413, and 590 ms, respectively). One experimental session (270 trials) consisted of 18 blocks of 15 trials (3 stimulus strength × 5 lags). The trial order was counterbalanced such that all 15 trials within each block were randomized and presented before the next block started. There were 30 practice trials before the main session. Each participant completed four sessions (one session per day).

Figure 1a shows the time line of the main experiment. Participants initiated each trial by pressing the space bar. Each trial began with a fixation cross, which was presented for 400 ms. Twenty stimuli followed the fixation cross at the center of the display. The T1 serial position was randomly selected from serial positions 5 through 7. Each stimulus was presented for 47 ms with an ISI of 12 ms. The participants' task was to report the identities of T1 and T2.

The purpose of the control experiment was to test whether the contrast difference between T2 and the distractors in the main experiment was perceptually noticeable in an RSVP. We used a display identical to that used in the main experiment but asked participants to detect changes in contrast, either higher or lower, rather than report the identity of the targets. We assumed that contrast changes would not be perceptually noticeable in the more difficult display of an RSVP because the contrast values were hypothetically just noticeably different from one another according to the predefined psychometric functions. We used $d'$ as our dependent measurements in this experiment. When T2 was presented at the PSE, those trials were considered stimulus-absent trials; and when T2 was presented at the $JND_L$ and $JND_H$ levels, those trials were considered stimulus-present trials. Only trials in which participants indicated that a contrast difference was present were used in the analysis (when T2 was presented at the PSE, these constituted false alarms; and when T2 was presented at either the $JND_L$ or $JND_H$ level, these were hits). $d'$ was then calculated by creating $z$-scores for the hits and false alarms and subtracting them from one another.

(2) The difference in stimulus strength in the main experiment did not correspond to JND because the timing of stimulus display was different from that in the contrast discrimination experiment (see Results and Discussion for further discussion). We use the term "JND" throughout this paper to emphasize that the difference in the stimulus strength was equivalent across participants.

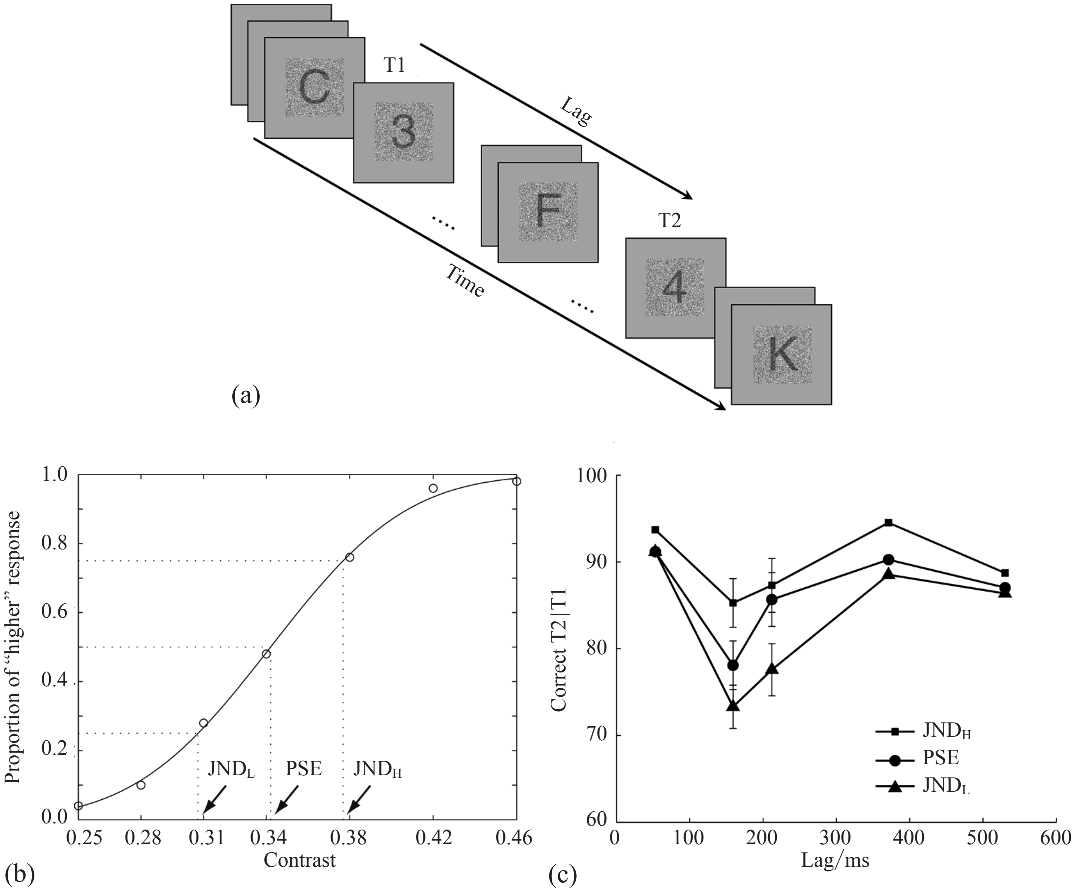


**Figure 1.** (a) The time line of the main experiment. Lag is defined as the time difference between T1 and T2 onsets. (b) An example result of a contrast discrimination task from one participant. The proportion of "higher" responses is depicted for each test contrast. The standard contrast was 34%. To find a psychometric function, a cumulative Gaussian distribution function was fitted to the data (Finney 1971). $JND_L$, PSE, and $JND_H$ were defined as the contrasts that result in 25%, 50%, and 75% "higher" responses, respectively. (c) T2 performance given a correct T1 response as a function of the lag (square: $JND_H$, circle: PSE, triangle: $JND_L$). Error bars represent the standard error of mean.

## 3 Results and discussion

We first plotted the proportion of "test higher" responses against the different levels of test contrasts and measured each participant's psychometric function by fitting a cumulative Gaussian function to these data (figure 1b). We defined PSE, $JND_L$, and $JND_H$ based on the psychometric function. In a given trial, T1 and the distractor strength were set to the PSE (34 ± 0.6%) and the T2 strength was one of three values [$JND_L$ (30 ± 0.8%), PSE, $JND_H$ (38 ± 1.1%)]. By doing this, differences in the T2 strength were rendered equivalent across participants and the transients produced by the differences were minimized.

Next, we analyzed the main experiment to determine whether the amount of the AB depended on the T2 strength. Figure 1c shows the T2 performance as the percentage of the correct T2 given a correct T1. A 3 (T2 strength) × 5 (lags) factor repeated-measures ANOVA showed a significant main effect of lag ($F_{4,32} = 10.672$, $p < 0.001$), confirming that our procedure successfully produced an AB. Critically, there was a significant main effect of T2 strength ($F_{2,16} = 35.081$, $p < 0.001$). The T2 performance was lowest when the T2 strength was lowest ($JND_L$) and progressively increased as the T2 strength increased during the AB.

There was also significant interaction between the T2 strength and the lag ($F_{8,64} = 2.614$, $p < 0.05$) caused by the different levels of T2 performance during the AB depending on the T2 strength.

Finally, we analyzed the results of the control experiment to test whether the contrast difference in the main experiment was perceptually noticeable. The average $d'$ ($0.002 \pm 0.06$) was not significantly different from 0 ($t_9 = 0.03$, $p = 0.98$), suggesting that the participants were not able to detect the contrast changes in an RSVP. This result did not depend on the target contrast (high or low). Why did our participants perform at a chance level in this experiment, where the difference in the stimulus strength was set to JNDs? First, the stimulus onset was not predictable in the control experiment because the T2 position was randomized. On the other hand, JNDs were measured using the two-interval forced-choice method, where the onset of two stimuli was demarcated by auditory cues. Temporal uncertainty pertaining to stimulus onset in the control experiment could have reduced the contrast discrimination sensitivity (Lasley and Cohn 1981). Second, the result may have been due to the effect of visual masking on stimulus processing in an RSVP (Brehaut et al 1999; Enns and Di Lollo 2000; Giesbrecht and Di Lollo 1998; Seiffert and Di Lollo 1997). In the contrast discrimination experiment only two stimuli were presented without a trailing mask. Moreover, the stimulus onset asynchrony (SOA) was long (377 ms) compared with the SOA (59 ms) in the RSVP streams.

We found that a difference in the stimulus strength can influence the amount of the AB. Although previous studies found that a degraded T2 increased the AB (Chua 2005; Jannati et al 2011; Kawahara et al 2001), they suggested that the AB was increased due to further impairments in attentional selection resulting from the degradation of the T2 rather than the degradation itself (ie reduced T2 strength). In our study the stimulus strength modulated the AB, even when its change was perceptually unnoticeable. Thus, impairments of attentional selection cannot fully explain our results.

How could these subtle changes in the stimulus strength affect T2 performance during the AB? The difference in the T2 strength in our experiment suggests that there are no differences in the perceptual stages of T2 processing because these differences are subtle to the point that they are perceptually unnoticeable. We suggest that the manipulation of the stimulus strength in this case was sufficient enough to modulate the stimulus strength during the memory consolidation process (Chun and Potter 1995; Shih 2008). Both the two-stage (Chun and Potter 1995) and attention cascade models (Shih 2008) assume that T2 decays rapidly in the consolidation stage when T1 is being processed in that stage. When T2 was higher than T2 ($JND_H$), T2 could survive in the consolidation processor (Shih, 2008) until T1 consolidation was finished. On the other hand, when T2 was lower than T2 ($JND_L$), T2 decayed even faster in the consolidation processor while T1 was being consolidated, which resulted in the lowest level of performance.

Overall, our results show that the T2 performance can be modulated by subtle differences in the T2 strength during the AB. More importantly, the T2 strength does not have to be salient to affect the amount of the AB.

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