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Nielsen, Simon; Andersen, Tobias

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The Attentional Blink is Modulated by First Target Contrast: Implications of an Attention Capture Hypothesis

Simon Nielsen* (sini@imm.dtu.dk)

Tobias S. Andersen (ta@imm.dtu.dk)

Cognitive Systems Section,
Institute for Informatics and Mathematical Modeling
Richard Petersens Plads, Building 321
Technical University of Denmark
2800 Lyngby, Denmark
*Corresponding author

Abstract

When two targets (T1 & T2) are presented in rapid succession, observers often fail to report T2 if they attend to T1. The bottleneck theory proposes that this attentional blink (AB) is due to T1 occupying a slow processing stage when T2 is presented. Accordingly, if increasing T1 difficulty increases T1 processing time, this should cause a greater AB. The attention capture hypothesis suggests that T1 captures attention, which cannot be reallocated to T2 in time. Accordingly, if increasing T1 difficulty decreases T1 saliency, this should cause a smaller AB. In two experiments we find support for an attention capture hypothesis. In Experiment 1 we find that AB magnitude increases with T1 contrast – but only when T1 is unmasked. In Experiment 2 we add Gaussian noise to targets and vary T1 contrast but keep T1 's SNR constant. Again we find that AB magnitude increases with T1 contrast.

Keywords: Attentional Blink; Attention Capture; First Target Interference; Temporal Attention; Spatial Attention; Human Vision.

Introduction

The attentional blink (AB) is widely used to study temporal attention and refers to the finding that observers often fail to report the second of two targets (T1 & T2) presented in rapid succession. Raymond, Shapiro and Arnell (1992) reported that accuracy of T2 report is a u-shaped function of the lag between T1 and T2 onset. They systematically varied the time between a white letter target (T1) and a black probe (T2, an 'X') embedded in a rapid serial visual presentation (RSVP) stream of black letter distractors. When T2 was presented within 500 ms of T1 observers rarely detected the probe. The AB has predominantly been examined in the RSVP paradigm where stimuli are presented central at fixation. However, Duncan and colleagues (Duncan, Ward & Shapiro, 1994; Ward, Duncan & Shapiro, 1996) used the *two-target* paradigm where two masked targets are presented consecutively in different locations. They observed a phenomenon similar to the AB, which they referred to as the attentional dwell time. Later Ward, Duncan and Shapiro (1997) argued that the dwell time effect may be the consequence of the location switch and not comparable to the AB. To examine this they introduced the *skeletal* paradigm where two consecutive masked targets are presented in the same location. The authors found a dwell time similar to what they observed with the two-target paradigm, and suggested that all three paradigms (RSVP, two-target, skeletal) tap a common attentional limitation - an assumption that is adopted in this study.

One theory offered to explain the AB is the bottleneck theory (Chun & Potter, 1995; Jolicoeur, 1998). This theory assumes two processing stages and suggests that the AB occurs due to slow second stage processing causing a perceptual bottleneck. The first processing stage is rapid, analyzing target features such as color and form. However, the first stage representation is volatile and susceptible to both decay and interference from other objects. In the second stage objects are consolidated and transferred to more durable memories necessary for conscious report. This stage is slow and capacity limited. According to the bottleneck theory the AB occurs when T2 requires second stage processing while T1 occupies the second stage.

The bottleneck theory predicts that making T1 identification more difficult prolongs second stage processing and consequently increases the AB (Chun & Potter, 1995). This prediction has led to several studies examining how T1 difficulty influences the AB. Target difficulty can be approached in either a data limited or resource limited fashion (Norman & Bobrow, 1975). Data limited methods vary T1 difficulty by varying stimulus attributes whereas resource limited methods do it by varying the task or introducing distractors to occupy attentional resources. Here we limit analysis to studies using a data limited approach. McLaughlin, Shore and Klein (2001) varied T1 exposure duration in three conditions mixed within blocks in the skeletal paradigm and observed no effect on the AB between conditions. Shore, McLaughlin and Klein (2001) replicated this study only this time they varied T1 exposure between blocks and found that increasing T1 exposure decreased AB magnitude in accordance with the bottleneck theory. A study by Christmann and Leuthold (2004) reported similar results. They varied T1 contrast in three conditions between blocks in an RSVP stream and found that increasing T1 contrast decreases AB magnitude. That the effect of T1 difficulty should depend so strongly on whether it is varied within or between blocks may seem surprising, but Shore et al. (2001) suggested that observers voluntarily allocate more resources to T1 when they expect it to be difficult to see, which is the case in a block of trials when T1 is difficult to see. This leads to fewer resources being allocated to T2 and hence to a larger AB. When T1 difficulty varies between trials, observers have no expectation of whether the next T1 will be difficult or not and hence do not change their allocation of attentional resources between the targets, which is why there is no effect of T1 difficulty on the AB. Contrary to the predictions of the bottleneck theory, Chua (2005) found that AB magnitude increased with T1 contrast in three conditions in a RSVP paradigm. Chua (2005) concluded that a high contrast T1 captures attention, and that this T1 attention capture prevents reallocation of resources to T2 in time for its appearance.

Test of Attention Capture Hypothesis

In summary it appears that there are two competing effects influencing the AB when varying T1 difficulty in a data limited fashion. Making T1 easier to perceive either by T1 exposure duration (Shore et al., 2001) or T1 contrast (Christmann & Leuthold, 2004) may decrease AB magnitude. This may be due to a bottleneck effect or to reallocation of attentional resources as the effect depends strongly on T1 difficulty being varied between blocks. However, making T1 easier to perceive by increasing T1 contrast, may increase AB magnitude by virtue of T1 attention capture, which increases with T1 saliency (Chua, 2005).

Here we test the attention capture hypothesis in a new set of experiments using the two-target paradigm (see Figure 1). We vary T1 contrast, which may vary T1 capture and thereby AB magnitude. We use an adaptive staircase procedure to control T1 difficulty in individual adjustments sessions allowing us to systematically examine how T1 difficulty affects the AB. In Experiment 1 we vary T1 difficulty by T1 contrast in two conditions, such that T1 accuracy in an easy condition is approximately 20% higher than in a hard condition. According to the bottleneck theory a smaller AB should be observed in the easy T1 condition, whereas the attention capture hypothesis carries the opposite prediction. Experiment 1 is subdivided into Experiment 1A and 1B, which differs by the presence or absence of T1's mask respectively. T1's mask is omitted in Experiment 1B because we are uncertain of how it affects the AB under these conditions. In Experiment 2 we aim to keep T1 difficulty constant between two conditions but vary T1 contrast. If this varies T1 saliency we may tease apart the effect of T1 capture from the effect of T1 difficulty. According to the bottleneck theory, no difference in AB effect should be observed between T1 conditions since difficulty is kept constant. The attention capture hypothesis however suggests that if T1 contrast increases T1 saliency this causes an increase in AB magnitude.

Experiment 1

We varied T1 difficulty by T1 contrast in two conditions such that T1 accuracy was 20% higher in an easy condition than in a hard condition. T1's mask was present in Experiment 1A and absent in Experiment 1B.

Methods

Observers

We tested 19 naïve observers, 8 females and 11 males between 18 and 28 years of age with a median age of 22 all with normal or corrected to normal vision. Observers were students at the Technical University of Denmark participating for an hourly fee, except for 2 who participated out of collegial interest.

Design

We varied three factors in this experiment, T1 mask [Present, Absent], SOA [100, 200, 300, 400, 600], and T1 difficulty [Easy, Hard]. T1's mask varied between Experiment 1A (Present) and 1B (Absent). SOA and T1 difficulty conditions were combined in a full factorial design. The sequential order of conducting Experiment 1A and 1B was counterbalanced across observers. Each letter in the target set appeared as T1 and T2 with identical frequency. We used an adaptive staircase procedure (accelerated stochastic approximation; Treutwein, 1995) and adjusted proportions correct for each observer to 0.5 in the T1 Hard condition, 0.8 in the T1 Easy condition, and 0.5 in the T2 condition i.e. to the same level as the T1 Low condition. Experiment 1 was structured in two (Experiment 1A) or three (Experiment 1B) individual-adjustment sessions of approximately 40 trials, one training session of 20 trials and four experimental blocks each of 120 trials. For each experiment the four experimental blocks yields 480 trials and thus 48 repetitions in each SOA x T1 difficulty condition.

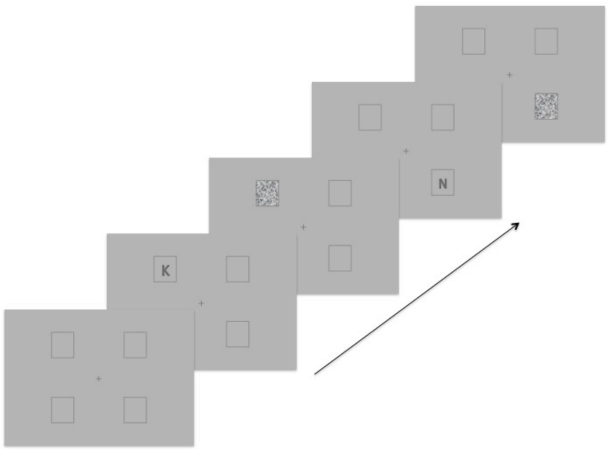

Figure 1: Two-target paradigm. T1 and T2 onsets are separated by a varying *stimuli onset asynchrony* (SOA). Targets appear in different boxes and have different identities. Masks are presented after a inter stimulus interval (ISI) of 100 ms. The task for the observer is to report the identity of both targets.

Stimuli

Target stimuli were 20 capital letters from the English alphabet chosen to emphasize a homogenous yet still varied target set. For this reason [C, I, Q, U, W, Y] were excluded either because they diverge substantially (e.g. L vs. W) or resemble other letters (e.g. O vs. Q). Stimuli were presented as dark on a 25.6 cd/m^2 grey background with 8.2 cd/m^2 fixation cross and boxes. Table 1 shows target luminance and contrast statistics obtained in the individual adjustment sessions. Standard deviations are thus the standard error of mean across observers. Pattern masks were moderate-density black dots with luminance levels of 0.0 cd/m^2. On each frame a dot patterns was randomly generated and displayed. This creates a masking effect perceived as if targets dissolved.

Table 1: Luminance, contrast and SNR levels for Experiment 1 and 2. Weber's contrast measures are used. Negative contrasts imply towards dark visa versa.

		Luminance		Contrast		SNR	
		Mean	Std	Mean	Std	Mean	Std
Experiment 1A							
T1	Easy	2.11	2.70	-0.96	0.05		
	Hard	10.29	4.01	-0.82	0.07		
T2		10.29	4.01	-0.82	0.07		
Experiment 1B							
T1	Easy	3.19	3.64	-0.95	0.06		
	Hard	11.29	4.27	-0.81	0.07		
T2		8.87	5.18	-0.85	0.09		
Experiment 2							
T1	Low	54.20	0.54	-0.07	0.01	0.51	0.13
	High	45.94	1.61	-0.21	0.03	0.51	0.13
T2		51.99	0.94	-0.11	0.02	1.47	0.42

Apparatus

A computer running the PsychoPy psychophysics software (Peirce, 2007) controlled stimulus presentation on a 15-inch View Sonic CRT monitor with a vertical refresh rate of 100 Hz. Observers conducted the experiment with a distance of approximately 75 cm from the monitor, yielding a stimulus angle of 1.37 degrees for targets and 1.76 degrees for masks.

Procedure

The AB was examined in the two-target paradigm with four boxes arranged on an imaginary rectangle and a fixation cross in the centre. Two targets were presented such that they had different identities and appeared in different locations. In Experiment 1A both targets were masked whereas in Experiment 1B T1's mask was omitted. Observers initiated a trial by pressing space after which a blank interval of 100 ms followed. T1 was then presented for 10 ms. After 100 ms T1 was followed by a pattern mask of 250 ms duration in Experiment 1A. In Experiment 1B a blank interval took the place of the pattern mask. T2 was presented for 10 ms after a variable SOA interval from T1 onset. An ISI of 100 ms then followed before T2's mask was presented for 250 ms. Observers were required to input the identity of T1 and T2 on the keyboard in an unspeeded, forced choice fashion with no regard to the presentation order of targets. The experiments were conducted in a dimly lit room. Prior to a session, observers adapted to the dim lighting for 5 minutes. Experiment 1A and 1B were conducted on different days, with approximately two weeks in between.

Results

Experiment 1A

One observer showed no difference in T1 accuracy between T1 conditions and was for this reason excluded from the experiment. Thus 18 observers were used in the analysis. The average of proportions corrects for T1 across SOA was 0.83 (std 0.02) for the T1 Easy condition and 0.64 (std 0.03) for the T1 Hard condition, showing that T1 difficulty was significantly varied [$F(1,17) = 48.14$, $p < 0.001$]. T2 results are plotted in Figure 1. An AB is evident from a significant main effect of SOA [$F(4,68) = 13.61$, $p < 0.001$]. However there is neither a main effect of T1 difficulty [$F(1,17) = 0.73$, $p = 0.41$] nor a T1 difficulty x SOA interaction effect [$F(4,68) = 1.24$, $p = 0.30$] indicating that T1 difficulty has little effect on the AB.

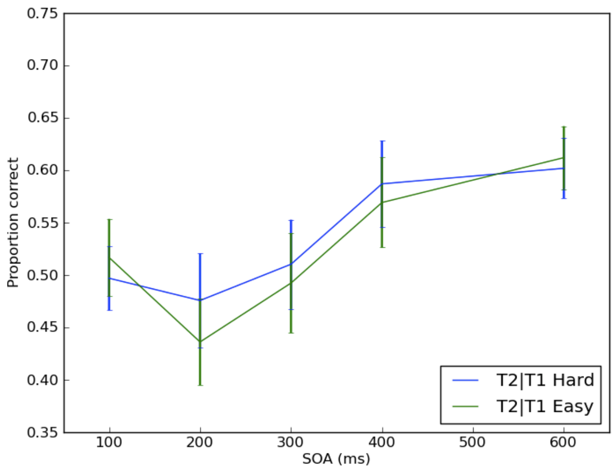

Figure 3: T2 Results in Experiment 1A (T1 masked). T2 accuracy conditioned by correct T1 report (T2|T1) is plotted for the T1 Hard and the T1 Easy condition.

Experiment 1B

The average of proportions corrects for T1 across SOA was 0.84 (standard error 0.02) for the T1 Easy condition and 0.62 (standard error 0.02) for the T1 Hard condition showing that T1 difficulty was significantly varied [$F(1,17) = 72.78$, $p < 0.001$]. T2 results are plotted in Figure 2. An AB is evident from a main effect of SOA [$F(4,68) = 18.70$, $p < 0.001$]. There is no main effect of T1 difficulty [$F(1,17) = 0.60$, $p = 0.45$] however a T1 difficulty x SOA interaction effect was found [$F(4,68) = 8.03$, $p < 0.001$]. This justified a post-hoc analysis revealing a main effect of T1 difficulty at SOA 200 ms [$F(1,17) = 25.89$, $p < 0.001$].

Summary

When T1 was masked (Experiment 1A) we found no effect of T1 difficulty on the AB. However, when T1 was unmasked (Experiment 1B) AB magnitude increased with T1 contrast at SOA 200 ms.

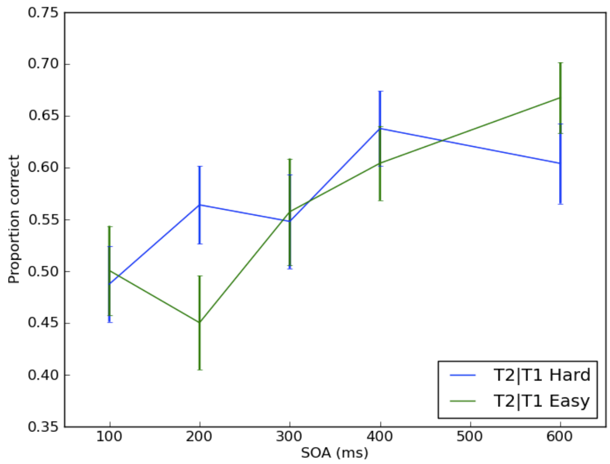

Figure 4: T2 Results in Experiment 1B (T1 unmasked). T2 accuracy conditioned by correct T1 report (T2|T1) is plotted for the T1 Hard and the T1 Easy condition.

Experiment 2

In Experiment 1 we varied T1 difficulty by T1 contrast and found that an easy T1 increased AB magnitude when T1 was unmasked. This is the opposite of what the bottleneck theory predicts. However, increasing T1 contrast also increases T1 saliency - and an increase in T1 saliency is likely to increase T1 attention capture, which may explain the increase in AB magnitude. In Experiment 2, we aim to tease apart the T1 capture effect from the effect of T1 difficulty. We do so by keeping T1 difficulty constant while varying the signal-to-noise ratio. Between two T1 conditions we add Gaussian noise with different standard deviation and keep T1 difficulty constant across conditions measured by T1's signal to noise ratio (SNR). Targets with noise, where the noise have a large standard deviation, requires a high contrast to achieve a given accuracy level relative to targets with noise sampled with a small standard deviation. This allows us to increase T1 contrast independently of T1 difficulty. If this causes an increase in T1 saliency, we may be able to isolate the effect of T1 capture from the effect of T1 difficulty. Since we found no AB effect of T1 difficulty in Experiment 1 when a pattern mask followed T1 we let T1 be unmasked in Experiment 2.

Methods

The experimental configurations in Experiment 2, was similar to those in Experiment 1 with the following exceptions: We tested 22 naïve observers, 8 females and 14 males between 20 and 35 years of age with a median age of 24 all with normal or corrected to normal vision. Observers were students at the Technical University of Denmark participating as part of the introductory cognitive psychology course at the department. We varied two factors: Six SOA conditions [100, 200, 300, 450, 600, 900] and two T1 contrast conditions [High, Low]. In the adjustment sessions proportion correct for T1 was set to 0.6 in both the T1 High and the T1 Low condition. T2 was set to 0.8. Gaussian noise was added to targets. The noise was sampled from a contrast distribution with its mean corresponding to the display background luminance, which was 58.33 cd/m^2. The noise standard deviation was 0.3 in the T1 High condition and 0.1 in the T1 Low condition. Thus in order to achieve the same level of T1 accuracy in both T1 conditions, observers required a high T1 contrast in the T1 High condition compared to the T1 Low condition. We measured T1 difficulty by T1's SNR, and to ensure that T1 difficulty was equal between T1 conditions, we used the average of the SNR levels obtained in the T1 High and T1 Low adjustment sessions. Figure 3 shows sample stimuli for the two T1 conditions with identical SNR and different T1 contrast levels. Targets plus noise were displayed at a visual angle of 1.76 degrees. Fixation cross and boxes was presented at 46.66 cd/m^2. Luminance, contrast and SNR statistics are shown in Table 1.

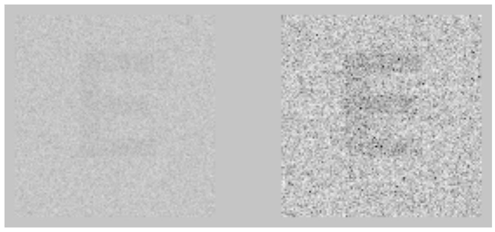

Figure 5: Sample stimuli from Experiment 2 showing the T1 Low (left) and T1 High (Right) contrast conditions. The stimuli have the same signal-to-noise ratio, but different contrasts. Rendering in print may affect the signal-to-noise ratio. Left. SNR: 0.49, standard deviation for noise: 0.3, target contrast: -0.21, target contrast energy 1544. Right. SNR: 0.49, standard deviation for noise: 0.1, target contrast: -0.07, target contrast energy: 173.

Results

Three observers were excluded from the study because they showed a difference in T1 accuracy between T1 conditions of more than 18% averaged across SOA. Thus 19 observers were used in the analysis. The average of proportions corrects for T1 across SOA was 0.76 (standard error 0.04) for the T1 Low condition but 0.80 (standard error 0.03) for the T1 Low condition. Despite the increase in T1 accuracy was marginal, it was consistent across observers thus leading to a T1 effect of difficulty [$F(1,18) = 12.89$, $p = 0.002$]. This indicates that T1's SNR may not optimally determine T1 difficulty under these conditions.

T2 results are plotted in Figure 4. An AB was evident from a main effect of SOA [$F(5,90) = 2.56$, $p = 0.03$]. T1 contrast x SOA produced no interaction effect [$F(5,90) = 0.49$, $p = 0.79$], however a main effect of T1 contrast [$F(1,18) = 5.54$, $p = 0.03$] was observed. This justified a post-hoc analysis showing a main effect of T1 contrast at SOA 300 ms [$F(1,18) = 6.87$, $p = 0.02$]. In summary, we varied T1 contrast with little influence of T1 difficulty and found that AB magnitude increased with T1 contrast at SOA 300 ms.

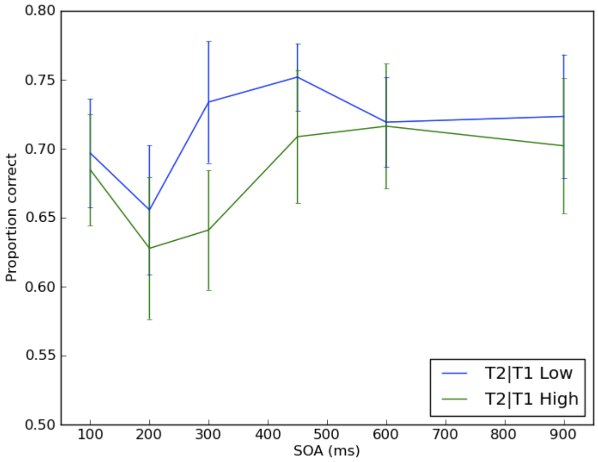

Figure 6: T2 Results in Experiment 2. T2 accuracy conditioned by correct T1 report (T2|T1) is plotted for the T1 High and the T1 Low condition.

Discussion

This study indicates that attention capture to T1 modulates the AB. In Experiment 1B we varied T1 difficulty by T1 contrast and found that an easy T1 increased AB magnitude compared to a hard T1. This is the opposite of bottleneck predictions, and of what Christmann and Leuthold (2004) and Shore et al. (2001) found. However, the finding is in line with Chua (2005) and supports the attention capture hypothesis suggesting that a salient T1 engages attention such that it cannot be reallocated to T2 in time. We did not observe an AB effect of T1 contrast when T1 was masked (Experiment 1A). This finding may explain why other studies using pattern masks did not report AB effects of T1 difficulty (McLaughlin et al., 2001; Nielsen, Petersen and Andersen, 2009; Ward et al., 1997). But how should we understand the effect of T1's mask? Pattern masks are typically jumbled feature constructs shown in high contrast to interrupt target processing after offset. It is likely that they engage attention in a similar fashion as targets and thereby interferes with the effect of T1 difficulty. A study by Chua (2005) lends support to this suggestion. Chua (2005) found that a to be ignored 5-dot singleton construct, appearing before a single target in an RSVP stream produced an AB, and that AB magnitude increased with singleton contrast. Thus it is likely that T1's mask captured attention in a similar fashion as the singleton in Chua (2005), and that this capture effect interfered with the capture effect of T1 contrast in Experiment 1A.

To test the effect of attention capture further, in Experiment 2 we varied T1 contrast in two conditions but kept T1's SNR constant between conditions. Again we found an effect on AB magnitude that increased with T1 contrast. The purpose with this paradigm was to keep T1 difficulty constant by keeping its signal-to-noise ratio constant. In this, we did not succeed as the high contrast T1 was marginally easier to perceive as measured by the proportion of correct T1 identifications. Hence one might suggest that bottleneck effects could have influenced this result. However, as in Experiment 1, our results were opposite of what the bottleneck theory would predict as we found a stronger AB when T1 contrast was high, which happened to also be the condition where it was marginally easier as seen in a higher proportion correct. Hence, our findings unanimously support a strong effect of T1 saliency on the AB.

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