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Seeing the light: Adapting luminance reveals low-level visual processes in the attentional blink

Barry Giesbrecht,[a,*] Walter F. Bischof,[b] and Alan Kingstone[c]

[a] Center for Mind and Brain, University of California, One Shields Avenue, Davis, CA 95616, USA
[b] Department of Computing Science, University of Alberta, Edmonton, AB, Canada T6G 2E8
[c] Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, BC, Canada V6T 1Z4

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Abstract

It is widely assumed that high-level visual processes subserve the attentional blink (AB). Recent evidence from studies of visual masking during the AB that were designed to directly test the contributions of high-level masking effects, however, have failed to provide empirical support for this position. The implication is that low-level visual processes are crucial to the AB. We tested this idea by manipulating adapting luminance in a standard AB paradigm. Consistent with the involvement of low-level neural mechanisms, the AB effect interacted with adapting luminance such that an AB was revealed only under photopic (light adapted) viewing conditions.

1. Introduction

Visual scenes contain a vast amount of information, more than can be consciously perceived at any given point in time. Attentional mechanisms aid in the selection of a subset of the information, but this selection comes at a cost. For example, when two masked targets are presented in a rapid sequence, attending to the first hinders the ability to attend to the second for about 500 ms. This attentional blink (AB) represents the dwell-time of visual attention vis-à-vis capacity limitations in high-level stages of visual information processing (for a review of the AB literature see Shapiro, Arnell, & Raymond, 1997). Recent human electrophysiological evidence supports this notion by implicating post-perceptual neural processes as being involved in the AB, including those previously shown to be involved in working memory (e.g., Vogel & Luck, 2002; Vogel, Luck, & Shapiro, 1998).

Evidence for the involvement of high-level post-perceptual mechanisms in the AB is generally accepted and included in all theoretical accounts of the AB. But a direct test of this position has only recently been conducted—and it failed to find positive evidence in support of a strictly high-level interpretation (Giesbrecht, Bischof, & Kingstone, 2003). The implication is that low-level visual processes may also be critical to the AB.

We tested this idea by manipulating adapting luminance in an otherwise typical AB paradigm. The same observers were tested under photopic (light adapted) and scotopic (dark adapted) viewing conditions. It is well established that an early visual response to a stimulus is very different under scotopic and photopic viewing conditions, and that low-level masking effects are mediated by visual responses that operate at early stages of the visual system (e.g., no later than primary visual cortex) and under photopic, but not scotopic, viewing conditions (Di Lollo & Bischof, 1995). Thus one can manipulate viewing conditions to decouple the involvement of early- and late-stage processes in viewing visual displays. For example, if mostly low-level visual processes mediate the masking effects that are critical to observing the AB, then the AB should be observed under photopic, but not scotopic, viewing conditions. If, on the other hand, the masking effects are subserved by mostly high-level visual processes, then the AB should

* Corresponding author. Fax: 1-530-792-1489.
E-mail addresses: giesbrecht@ucdavis.edu (B. Giesbrecht), alan.kingstone@ubc.ca (A. Kingstone).

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be observed in both photopic and scotopic viewing conditions. Based on the results of Giesbrecht et al. (2003) we predicted that an AB should be observed under photopic, but not scotopic viewing conditions. The results were consistent with this prediction and support the notion that low-level visual processes mediate masking of unattended information during the AB.

2. Method

2.1. Participants

Ten right-hand students with normal vision participated in this experiment.

2.2. Stimuli

Stimuli were displayed on a Tektronix 608 oscilloscope with P15 phosphor. Viewing distance was 57 cm, set by a headrest. Alphanumeric stimuli subtended .8° of visual angle. Targets were selected randomly without replacement from the English alphabet (I, O, Q, and Z were excluded due to their similarity to 1, 0, 2, and 7). Distractor items were digits (0–9) and were selected randomly with replacement, with the constraint that the selected digit was not one of the two immediately preceding items. The number of distractors preceding the first target was determined randomly on each trial and varied between 7 and 15. The luminance of the stimuli in the photopic viewing condition was 10 cd/m^2 and the luminance in the scotopic condition was 1 cd/m^2 (based on measurements of a 1.5 × 1.5 cm (44 × 44 dots) patch of dots).

2.3. Design

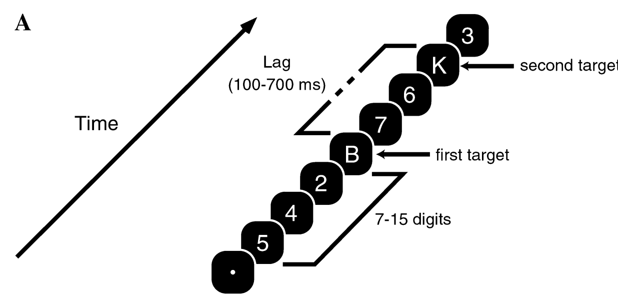
The experiment consisted of two 90 min sessions that differed in the level of light adaptation. In the scotopic session, participants were dark adapted for 40 min in a room sealed from light. In the photopic session, participants were adapted to a low-level of ambient light. All participants took part in each of the adaptation sessions that were separated by at least 1 week (order counterbalanced across subjects). First and second targets (T1 and T2, respectively) were separated by temporal lags of 100, 200, 300, 400, 500, 600, or 700 ms, which will also be referred to as lags 1–7, respectively. In addition, the stimulus onset asynchrony (SOA) between the second target and mask was varied and it was 0, 50, 100, or 200 ms. The T2-mask SOA manipulation was included to test a secondary hypothesis not central to the thesis of the present work. As such, only the results from the 100 ms SOA, which is the SOA typical in most studies of the AB, are reported here.

2.4. Procedure

During adaptation an experimenter seated in an adjacent room checked on the participants at regular intervals by talking to them over an intercom; this ensured that subjects were comfortable and that they kept their eyes open during the adaptation period. At the beginning of each trial a small fixation dot was presented in the center of the screen, indicating where the items would be presented. Participants initiated each trial by pressing a button on a button box held in their right hand. After a 500 ms delay, the items were presented. Each item was displayed for 32 ms and was separated from the next item by a blank interstimulus interval (ISI) of 68 ms, yielding a presentation rate of 10 items/s (see Fig. 1A).

Participants named the identity of the two targets into a microphone mounted near their chin. The experimenter entered the responses. Participants were instructed to be as accurate as possible, but to guess if necessary.

A



B

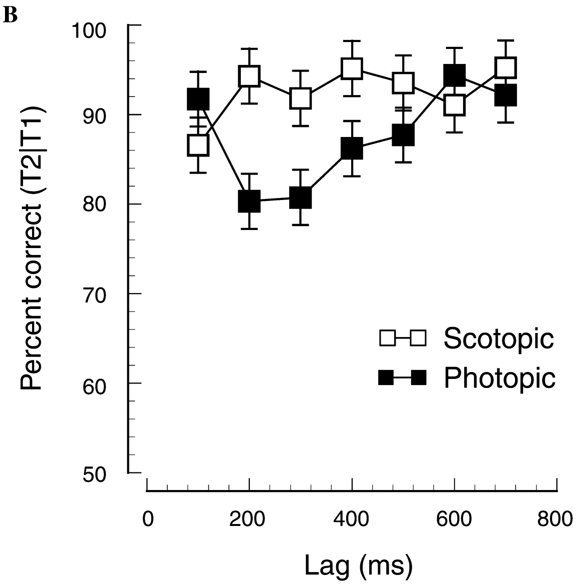


Fig. 1. (A) A schematic representation of the display sequences. (B) Results. Shown are mean percentages of correct identifications of the second target, given accurate identification of the first target, as a function of the temporal lag between the first and second targets and viewing condition. Error bars represent standard errors of the mean.

3. Results

One participant failed to comply with task instructions and was excluded from analysis. Mean percent correct identification of the first target collapsed across all conditions was 94.7%. The level of T1-accuracy did not change with adaptation condition (photopic mean = 95.4%; scotopic mean = 94.0%; $t(8) = 1.00$, $p > 0.34$), thus any AB differences between viewing conditions cannot be due to differences in T1 task difficulty.

Estimates of T2 identification accuracy are based on those trials in which the response to the T1 was correct (see Fig. 1B). In the photopic viewing condition, accuracy averaged across lags was 87.6% and was lowest at lags 2 (80.3%), 3 (80.7%), and 4 (86.2%). This U-shaped function of T2-accuracy identification is indicative of the typical AB effect. In contrast to the photopic condition, accuracy in the scotopic condition was 92.5%, but did not change as a function of the temporal lag between T1 and T2. Thus, it appears that the AB is sensitive to adapting luminance and is observed only under photopic viewing conditions.

The results shown in Fig. 1B and described above were analysed in a 2 (adaptation condition) × 7 (lag) repeated-measures ANOVA. This analysis did not reveal a statistically significant effect of adaptation condition in overall level of performance ($F(1, 8) = 2.42$, $p > 0.15$, $MSE = 313.13$), nor of temporal lag between the targets ($F < 1$). Critically, however, the predicted interaction between adaptation condition and temporal lag was significant ($F(6, 48) = 2.73$, $p < 0.03$, $MSE = 85.22$). Planned comparisons between the scotopic and photopic viewing conditions during the typical AB period (200–500 ms lags) revealed that the adaptation × lag interaction was being driven by significantly higher identification accuracy in the scotopic condition at lags 2 ($p < 0.002$), 3 ($p < 0.007$), and 4 ($p < 0.003$).

4. Discussion

All models have assumed that the AB represents a failure to encode high-level information regarding the second target, and as such it is likely subserved only by higher-order (e.g., neocortical) neural systems. However, the first direct test of this position failed to provide it with empirical support (Giesbrecht et al., 2003), suggesting that lower-lever visual processes may be involved. The present study tested this alternative and data supporting it were obtained, with identification of the second target being compromised under photopic but not scotopic viewing conditions.

We argue that this interaction supports the notion that low-level visual processes subserve the mechanisms that mediate the degradation of the unattended second target (e.g., Giesbrecht et al., 2003). This interaction cannot be attributed to different levels of condition difficulty or attentional demand between viewing conditions because (i) the photopic and scotopic conditions were equated in all respects except for the adapting luminance, (ii) performance on the first target was the same in the two conditions demonstrating equivalent attentional demands between conditions, and (iii) overall performance on the second target was not significantly different in the two conditions. It was *only* the interaction between viewing condition and lag that was significant.

The AB is critically dependent on the dynamic interaction between attentional systems and memory encoding mechanisms, a notion that is captured by all models of the AB and one which we do not dispute. However, the present results clearly demonstrate that the AB also represents fundamental contributions from low-level visual processes. By providing a more complete understanding of limited capacity processing, as it occurs during the AB, and how it relates to the dynamic interaction between low-level perception, attention, and memory, researchers will be able to elucidate more completely the neural mechanisms that subserve the transition of visual information into awareness.

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