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Review

The attentional blink: Past, present, and future of a blind spot in perceptual awareness

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A B S T R A C T

A survey of the attention literature reveals the prominence of the attentional blink (AB)—a deficit in reporting the second of two targets when presented in close temporal succession. For two decades, this robust attentional phenomenon has been a major topic in attention research because it is informative about the rate at which stimuli can be encoded into consciously accessible representations. The pace of discovery and theoretical advancement concerning the AB has increased rapidly in the past few years with emphasis on new neurophysiological evidence and computational accounts of attentional processes. In this review we extract the central questions and the main lessons learnt from the past, and subsequently provide important directions for future research.

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1. Introduction

The human mind is severely limited in processing concurrent information at a conscious level of awareness. While reading this text, only a small sub-set of the available information that is coming through the senses is granted access to the brain processes that form the basis of consciously accessible working memory representations. Attention is a cognitive mechanism that helps to select and process important or interesting information (hopefully this text) while irrelevant information (conversations from nearby colleagues, incoming e-mail, etc.) is largely ignored. But when something is selected (e.g. a large billboard), how long does attention dwell on that information before selecting and processing another object or event (a red traffic light)?

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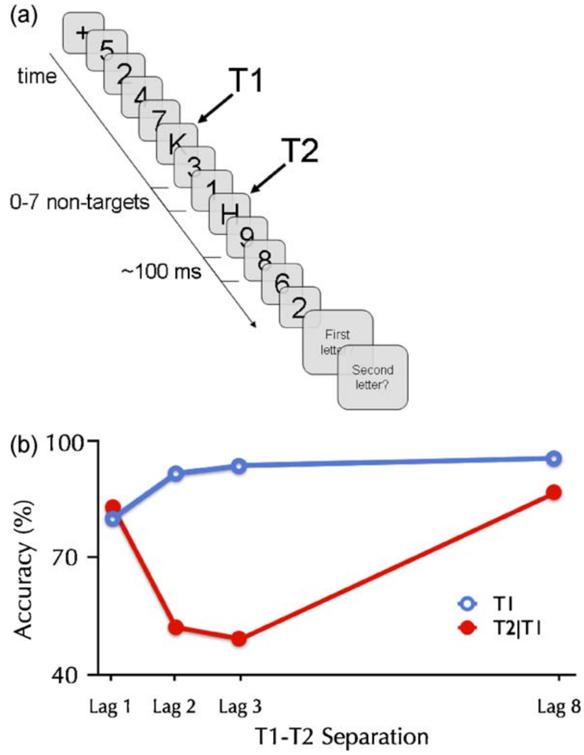

Fig. 1. The basic attentional-blink paradigm.
(a) The attentional-blink paradigm as it is most commonly used originates from a classic paper by Chun and Potter (1995). As shown in panel A, a rapid serial visual presentation (RSVP) stream of digits (the non-targets or distractors) is sequentially presented in the middle of the screen, typically at a rate of about 10 items/second. Subjects are instructed to identify two unspecified letters (the targets, referred to as T1 and T2, respectively) embedded within the stream. The paradigm requires subjects to give their responses after presentation of the stream, at their own pace, so that additional interference effects arising from speeded responses are avoided. The primary measure of interest is the percentage of correct T2 reports from trials in which T1 was accurately identified (T2|T1), thereby ensuring that T2s are not missed due to a coincidental lapse of attention. When subjects are instructed to ignore the T1 stimulus, T2 is usually reported accurately regardless of the lag between the two targets (Raymond et al., 1992). This suggests that the AB is the result of attending to T1 and consolidating it into working memory (Chun and Potter, 1995), rather than a perceptual deficit.
(b) Subjects often fail to report T2 when it is presented within 200–500 ms after T1, whereas when the interval is longer, both targets are usually reported in the order in which they were presented. Importantly, when T1 and T2 are presented within about 100 ms SOA, subjects quite often report both targets. This paradoxical finding, referred to as lag-1 sparing (Potter et al., 2002) and discussed later in this paper, has proven to be quite an important aspect of the AB.

In hundreds of experiments it has been shown that when two targets are to be identified amongst a rapid stream of non-target stimuli (see Fig. 1a), most individuals show a surprisingly long-lasting effect—an attentional blink (AB)—in reporting the second target (Broadbent and Broadbent, 1987; Raymond et al., 1992; Weichselgartner and Sperling, 1987). By systematically varying the serial position of the second target (T2) relative to a prior target (T1), as shown in Fig. 1a, the time course of interference can be measured as a function of the targets' temporal separation (also referred to as lag, stimulus onset asynchrony (SOA), or target onset asynchrony (TOA)).

There are at least three important reasons why the AB has come to such prominence in the attention literature (Box 1). Firstly, the AB reflects a remarkably long-lasting attentional deficit. For several decades, a central question in attention research was how long an object that must be identified continues to occupy attentional capacity. The AB lasts for several hundred milliseconds, suggesting that the time that attention 'dwells' on a target is an order of magnitude longer than previously assumed (Duncan et al., 1994).

Secondly, this long-lasting interference effect, which is referred to as the AB in analogy to eye blinks (Raymond et al., 1992), is very robust and can be obtained under a wide variety of task conditions and in the great majority of subjects. Typically, the AB is obtained using a rapid stream of sequentially presented alphanumerical stimuli (Fig. 1a), but it can also be obtained with other types of stimuli such as words (Barnard et al., 2004; Luck et al., 1996), symbols (Chun and Potter, 1995), or pictures (Evans and Treisman, 2005), and with auditory (Duncan et al., 1997) or tactile stimuli (Hillstrom et al., 2002). Consequently, the effect is thought to reflect a very general property of perceptual awareness with broad implications for understanding how the brain perceives any task-relevant stimulus.

Thirdly, not only has the AB proven to be an effective means to study the time-course of attention and memory consolidation, it has also provided researchers with a tool to study one of the most interesting topics in cognitive neuroscience, human consciousness. Investigating how brain processes contribute to conscious information processing is assisted by virtue of the fact that the AB renders a stimulus, which would otherwise be quite easy to see according to its masking and physical characteristics, markedly less visible. Furthermore, the AB does not occur on every trial with a short target interval (see Fig. 1b): for example, within data from a single subject, an AB might occur on half of the trials (so that the subject cannot identify the second target), whereas on the other half of trials no AB occurs (reflected by successful identification of both targets), although identical stimuli are used in the trials. Contrasting these blink and no-blink trials while using identical stimuli and instructions allows one to explore the neural and behavioral consequences of conscious perception (Kim and Blake, 2005; Kranczioch et al., 2005; Marois et al., 2004; Martens et al., 2006b; Sergent et al., 2005; Sergent and Dehaene, 2004).

In recent years the underlying cause of the AB has emerged as a topic of intense debate following a series of important publications that have challenged many of the established theories in the field. This review will discuss the prominent features of the emerging theoretical landscape and the behavioral and neuroscientific data which underlie them. We will then relate these ideas to several computational models that have helped to link the behavioral and neural correlates of the AB into formalized frameworks. Finally, we conclude with a discussion of other interesting developments and new directions in the field.

2. Changing perspectives on the AB

2.1. Central capacity limitations

After discovery of the AB (Broadbent and Broadbent, 1987; Raymond et al., 1992; Weichselgartner and Sperling, 1987), the initial research impetus was to understand at what processing stage a blinked target is lost. Convergent evidence from behavioral (Maki et al., 1997; Martens et al., 2002; Potter et al., 2005; Shapiro et al., 1997a,b; Visser et al., 2005) and neuroimaging studies (Luck et al., 1996; Marois et al., 2004; Nieuwenhuis et al., 2005; Pesciarelli et al., 2007; Rolke et al., 2001; Sergent et al., 2005) suggested that even unreported targets are processed to a late stage in the processing pathway. For instance, it was shown that a blinked target word can facilitate the processing of a subsequently presented word that is semantically related to the blinked target (Martens et al., 2002; Shapiro et al., 1997a). Moreover, blinked words were found to induce electrophysiological activity associated with semantic processing (Luck et al., 1996). This conclusion was buttressed by the finding that the AB is also a fairly central