THE EFFECTS OF INTERVENING EVENTS BETWEEN THE TWO TARGETS ON THE ATTENTIONAL BLINK

by

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B. A. (Psychology and Geography), Simon Fraser University, 2009

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

In the
Department of Psychology
Faculty of Arts and Social Sciences

SIMON FRASER UNIVERSITY

Summer 2011

APPROVAL

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Degree: **Master of Arts (Department of Psychology)**

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Date Defended: July 22, 2011

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ABSTRACT

Identification accuracy of the second of two targets (T2) is impaired when it is presented shortly after the first (T1). T1-based theories ascribe this attentional blink (AB) to a T1-initiated period of inattention. Distractor-based theories ascribe the AB to a disruption of input control caused by distractors trailing T1. The recent finding that an AB occurs in the absence of inter-target distractors seemingly disconfirms distractor-based theories. The principal goal of the present work was to explore the possibility that the blank inter-target interval itself may have disrupted attention, much like a distractor, thereby causing an AB. The intervening events between T1 and T2 were varied in four experiments (i.e., distractors, repeated T1, unexpected blanks, expected blanks). All produced an AB, disconfirming predictions from distractor-based theories, but lending strong support to the claim of T1-based theories that T1 processing alone is sufficient for the occurrence of the AB.

Keywords: attention; attentional blink; T1-based theories; distractor-based theories; intervening events; inter-target distractors

ACKNOWLEDGEMENTS

The following work is owed to the inspiration, support, and encouragement of many. First and foremost, I would like to thank my supervisors and mentors Dr. Thomas Spalek and Dr. Vincent Di Lollo for their invaluable enthusiasm, expertise and guidance and for giving me the opportunity to work in such a productive and enjoyable lab. I would also like to extend special thanks to my lab mates, Matthew Yanko and Ali Jannati, for their advice, encouragement and friendship and to the many research assistants of the Attention and Memory Lab for their involvement in data collection. I am also incredibly grateful to my friends, and especially my family, for their endless love and support. I appreciate it more than you could know.

This study was supported by a Canadian Foundation for Innovation New Opportunities Grant and a grant from the British Columbia Knowledge Development Fund to Dr. Spalek, by Discovery Grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) to Dr. Spalek and Dr. Di Lollo, and by an NSERC Alexander Graham Bell Canada Graduate Scholarship awarded to the author.

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1.1 Attention and the Attentional Blink

As we go about our daily lives, our visual system encounters an environment that is continually changing across time and space. Even such mundane experiences as watching television, searching for a pair of socks in the laundry, or scanning the road for signs and obstacles, cause massive amounts of rapidly changing stimulation to reach the visual system. Processing all this input to the level of conscious awareness would quickly exceed the systems' processing capabilities. The brain has, therefore, evolved to process fully only a small subset of that input. The means by which this selectivity is implemented is thought to be through the mechanisms subsumed under the rubric *attention*.

Despite William James's (1890) claim that "Everyone knows what attention is", attention is a notoriously difficult concept to define. Some scholars have even gone so far as to say that "nobody knows what attention is" (Styles, 2006, p.1). The difficulty in defining the concept stems from the use of *attention* as an "umbrella" term that encompasses a variety of different processes. Generally, however, it is agreed that attention is involved in the selection and processing of mental or sensory stimuli in order to bring the salient or relevant information into conscious awareness.

Due to its vital role in cognitive processing, attention, and its underlying mechanisms, have been a central focus of research in both cognitive science and neuroscience since the very beginning of the "cognitive revolution" (see e.g., Baars, 1986; Driver, 2001; Dux & Marois, 2009). Initially, incited by the study of radio communication during World War II, much attention research focused on selective and divided attention in the auditory sensory modality (e.g., Broadbent, 1952a, 1952b, 1952c, 1954, 1957, 1958; Cherry, 1953; Treisman, 1964a, 1964b, 1964c, 1964d, 1969). More recently, the focus of investigation has shifted to the visual sensory modality, where the limits of the brain's ability to select and process incoming stimulation has been studied in both spatial and temporal dimensions.

At the outset, much of the research on visual attention focused on the spatial domain (see, e.g., Driver, 1998; Pashler, 1998, for reviews); in recent years, however, interest in the temporal domain has grown immensely (see, e.g., Dux & Marois, 2009; Martens & Wyble, 2010; Shapiro, Arnell, & Raymond, 1997, Shapiro & Luck, 1999; for reviews). The *attentional blink* (AB) phenomenon has been a key tool in the investigation of temporal attention, due to its capacity to reveal the limits of visual attention in the temporal domain.

Temporal attention has typically been studied by displaying a stream of stimuli in *rapid serial visual presentation* (RSVP; Lawrence, 1971; Potter & Levy, 1969; Sperling, Budiansky, Spivak & Johnson, 1971). In RSVP, stimuli are displayed rapidly (e.g., 100 ms each) and sequentially at the same location. Observers are instructed to monitor the stream for one or more targets (e.g., letters) amongst distractor items (e.g., digits). When the requirement is for reporting a single target, the task is quite easy, with near perfect accuracy. This finding may seem to indicate that target processing in RSVP is complete within 100 ms (Gathercole & Broadbent, 1984; Lawrence, 1971; McLean, Broadbent, & Broadbent, 1982). However, evidence to the contrary is provided by tasks requiring the identification of an additional target from an RSVP stream.

If observers are required to report the identity of two target stimuli inserted in an RSVP stream of distractors, accuracy is nearly perfect for the first target (T1), but substantially reduced for the second (T2). The second-target deficit is known as the *attentional blink* (AB; Broadbent & Broadbent, 1987; Raymond, Shapiro & Arnell, 1992). The AB is most pronounced when the temporal separation between the two targets is short (200-300 ms), with performance improving progressively as the separation is increased to about 700 ms (Raymond et al., 1992). In most studies of the AB, the temporal separation between the two targets is varied in steps of about 100 ms, with each step following T1 being denoted as a separate lag. Thus, the term Lag 1 indicates that T2 was presented directly after T1, and the term Lag 3 indicates that two distractors intervened between T1 and T2. A related, although independent phenomenon (Visser, Bischof, & Di Lollo, 1999) is *Lag-1 sparing*: the finding that T2 performance is enhanced when presented directly after T1 (at Lag 1) relative to at subsequent lags (Lags 2 or 3; Potter, Chun, Banks, & Muckenhoupt, 1998).

The AB has been the focus of extensive empirical and theoretical investigation and has developed into a standard paradigm for the study of attention. While the present work focuses primarily on the AB in the visual domain, the AB is a robust effect that has been demonstrated across a variety of sensory modalities, populations and experimental conditions. Its popularity stems, in large part, from the belief that it reflects the temporal limits of our ability to analyze and encode stimuli to the level of conscious awareness (Chun & Wolfe, 2001; Shapiro & Luck, 1999; Sergent & Dehaene, 2004).

1.2 Theoretical Accounts of the Attentional Blink

Many theoretical accounts, both formal (i.e., computational frameworks) and qualitative (i.e., descriptive accounts), have been proposed to explain the processing limitations that are revealed by the AB. Recent comprehensive reviews of the AB literature have been provided by Dux and Marois (2009) and Martens and Wyble (2010). The principal objective of the present introduction is not to review the entire AB literature, but rather to set the stage for the experiments to be reported. The present experiments were designed to distinguish between two classes of theories broadly defined in the foregoing: *T1-based* and *distractor-based*. Theories are assigned to these classes according to the processes or events which they regard as the root cause of the AB. According to T1-based theories, T1 processing alone is sufficient to cause the AB. In distractor-based theories, on the other hand, the requirement to process T1 is not sufficient: the presence of at least one distractor following T1 is regarded as essential. For illustrative purposes, prototypical examples of the two classes of theory are presented, with occasional reference to related theories as the need arises.

1.2.1 T1-based Theories

The class of T1-based theories encompasses a number of individual theories. Specific accounts of the root cause of the AB can be quite diverse, including resource depletion (e.g., Ward, Duncan, & Shapiro, 1996), delayed selection (e.g., Nieuwenstein, Potter, & Theeuwes, 2009), and working memory consolidation (e.g., Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998; Wyble, Bowman, & Nieuwenstein, 2009). Despite individual variations, however, these theories share the common tenet that the AB stems from some process or event directly associated with T1 processing.

The prototypical exemplar of T1-based models is that proposed by Chun and Potter (1995). It is a two-stage model in which the first stage of processing (Stage 1) has no capacity limitations. In Stage 1, stimulus features of all items in an RSVP stream are rapidly analyzed in order to identify potential targets. At this stage, however, identity information is volatile and vulnerable to both decay and overwriting by trailing items. For a durable representation of an item to be available for report, representations must be transferred to a second, high-level processing stage (Stage 2). Stage 2 is said to be serial and capacity-limited in that only a single target can be processed at a time. Therefore, if T2 arrives while Stage 2 is still busy processing T1 (e.g., at a short temporal lag), it is delayed in Stage 1 until Stage 2 is free. During this period of delay, T2 is vulnerable to decay and backward masking by trailing items, and the AB deficit ensues. At longer lags, there is a greater probability that T1 processing will be complete prior to the arrival of T2 and, therefore, the likelihood that T2 will be delayed in Stage 1 is reduced, with consequent performance improvements.

To account for the Lag-1 sparing phenomenon, two-stage models postulate an attentional gate set between the two stages. The gate is said to open quickly on presentation of T1 but to close sluggishly, thereby allowing the item immediately succeeding T1 (i.e., the Lag 1 item) to gain access to Stage 2, along with T1. If the Lag 1 item is T2, both targets are processed at the same time, and Lag-1 sparing results. Thus, according to this model, Lag-1 sparing is time-locked to the onset of T1.

Jolicœur and colleagues (Jolicœur, 1998, 1999; Jolicœur & Dell'Acqua, 1998, 1999) extended the two-stage account of Chun and Potter (1995) to form the central interference theory. This theory purports to explain, not only the AB, but a number of other tasks in which the requirement is for two targets to be identified or detected sequentially, including the psychological refractory period (PRP) task. The PRP refers to the tendency for there to be a delay in the response to the second of two sensory–motor tasks when it is executed in close temporal succession to a prior task (Pashler, 1994; Telford, 1931; Welford, 1952). The architecture of the central-interference model is very similar to that of Chun and Potter's two-stage model with an early, parallel processing stage in which sensory and perceptual encoding occurs and a late higher-level processing stage. This model is often referred to as a bottleneck model because a processing "bottleneck" occurs in the transition from the early capacity-unlimited stage to the second, severely capacity-limited, serial encoding stage. This second stage differs from Chun and Potter's Stage 2 in that both response selection and working memory encoding are said to require this capacity-limited central processing, rather than working memory encoding alone. According to this account, an AB arises when T2 is presented before the capacity-limited stage is free from T1 processing. When this occurs, T2 is delayed prior to the bottleneck, in the first stage of processing, where it is vulnerable to masking (Jolicœur, 1999).

The eSTST model of Wyble and colleagues (2009; see also Bowman & Wyble, 2007 for an earlier version) is one of a number of recent formal models which builds upon Chun and Potter's (1995) two-stage theory. eSTST provides a novel theoretical justification for this architecture by proposing that the AB reflects processes involved in creating episodically distinct representations within working memory. In the first stage (the input layer), abstract identity information about each stimulus (i.e., its type; Kanwisher, 1987) is extracted. However, for a stimulus to be correctly reported, it must gain access to a later processing stage (Stage 2) where its identity information is bound to a token (Kanwisher, 1987) and, thereby, encoded into working memory.

For a type representation to be bound to a token, it must be enhanced by a transient attentional mechanism called the *blaster* which amplifies the strength of the stimulus's type signal. The blaster is triggered upon detection of a target and its activity lasts for approximately 200 ms, provided that no additional targets are presented during this excitatory phase. The excitatory phase is then followed by an inhibitory phase during which the blaster is suppressed while the target undergoes a binding process that produces a corresponding token in working memory. This T1-triggered blaster suppression extends over several hundred ms and mediates the AB deficit by preventing the T2 type from being bound to a token until T1 tokenization is complete. As with the other two T1-based theories described above, this delay in T2 processing leaves it vulnerable to decay and overwriting by trailing items.

T1-triggered blaster suppression can be delayed, however, if T1 is followed directly by another target. The signal of this trailing target is amplified since it falls within the blaster's excitatory phase. This amplification causes the inhibitory phase to be overcome and Lag-1 sparing to ensue. This amplification applies to any number of targets appearing in succession, thereby extending the duration of the attentional episode, and postponing the AB. The inhibitory phase then occurs upon the end of the attentional episode.

In summary, T1-based theories see the AB as arising from T1 processing. Within this class of theory, the only role for distractors presented between T1 and T2 (hereafter referred to as "intervening distractors") are as masks for T1. Masking T1 may increase the difficulty of T1 processing, thereby increasing the length and magnitude of the AB; however, according to this class of theory, distractors play no role in causing the AB: T1 processing alone is sufficient.

1.2.2 Distractor-based Theories

As with the T1-based class of theory, the class of distractor-based theory encompasses a number of different individual theories, each with their own particular accounts of the AB (e.g., Di Lollo, Kawahara, Ghorashi, & Enns, 2005; Olivers, van der Stigchel, & Hulleman, 2007; Olivers & Meeter, 2008; Raymond et al., 1992). What all these accounts have in common, however, is the claim that the period of inattention that is indexed by the AB is triggered not by the requirement to process T1 but rather by the disruptive effect of distractors intervening between the two targets.

The original distractor-based theory is Raymond et al.'s (1992) inhibition model. According to this model, target-defining features (e.g., colour) are detected preattentively. Upon detection of a target-defining feature, an attentional episode is initiated by the opening of an attentional gate which gives the target item access to a sensory store from which it can be selected for identification. This attentional episode continues until target identification is complete, causing the features of any item presented immediately after the target to be processed along with the target's features. The presence of features from both the target and the trailing item in the sensory store has the potential to cause confusion. When intervening distractors have the potential to interfere with target identification, the attentional gate is closed and a suppressive mechanism is initiated to inhibit further visual processing. Raymond et al. likened this process to a gate not only being shut, but also locked. This locking operation makes the initiation of a subsequent attentional episode (e.g., in response to T2) more time-consuming than if the gate had merely been closed. It is the time course of this suppression (i.e., locking) which is said to be indexed by the AB. Locking occurs only when there is a potential for featural confusion. That is, when intervening distractors are present. When the potential for target and distractor featural confusion is not present (i.e., target identification is completed in the absence of intervening distractors), the attentional gate is simply closed allowing a subsequent attentional episode to be initiated rapidly in response to the detection of a target. Under these conditions, no AB occurs since an attentional episode can be initiated rapidly in response to T2.

After a period of over 10 years, during which T1-based theories dominated, the idea that the AB is initiated not by T1 processing in and of itself, but rather by a post-T1 distractor, was developed further with the advent of additional distractor-based models. This renewed interest in distractor-based explanations of the AB was initiated by the finding that no AB is observed when targets appear in succession (e.g., T1, T2, T3; Di Lollo et al., 2005; Kawahara, Kumada, & Di Lollo, 2006; Nieuwenstein and Potter, 2006; Olivers et al., 2007; Olivers & Meeter, 2008; Potter, Nieuwenstein, & Strohminger, 2008). This absence of the AB with successive targets has been termed the "spreading-of-the-sparing" effect (Olivers et al., 2007). This effect is in stark contrast to the findings of conventional AB studies in which substantial ABs are observed when just two targets are separated by a single distractor (T1, D, T2).

The temporary loss of control (TLC) model (Di Lollo et al., 2005) was developed to account for the finding that no AB occurs with successive targets, that is, without intervening distractors. This theory proposes that target selection is governed by an input filter endogenously configured to pass targets and reject distractors (see also Ghorashi, Zuvic, Visser, & Di Lollo, 2003; Kawahara et al., 2006; Visser, Bischof, & Di Lollo, 2004). Within this model, a central processor is charged with both actively maintaining this input filter (by issuing continuous signals to the filter) and encoding targets into working memory. Critically, however, the central processor can execute only one of these operations at a time. When a target is detected, the central processor switches from the task of issuing maintenance signals to the input filter to the task of processing the target. As a consequence, while T1 is being encoded into working memory, the filter becomes vulnerable to exogenous disruption and resetting by stimuli which do not match the filter's current configuration (i.e., by distractors). If the item following T1 is another target, the filter will not be reconfigured since targets fit with the existing filter configuration. Targets will thus be allowed immediate access to working memory encoding (subject to the capacity limits of working memory), thereby avoiding the AB. If, however, the item following T1 is a distractor, the filter is disrupted and exogenously reconfigured. Any targets appearing after this disruption, while T1 is still being encoded, will not match the filter's configuration and, therefore, will have to wait for working-memory encoding until T1 processing is complete. It is only then that the input filter can be reconfigured by the central processor to once again pass targets. During this delay, T2 is vulnerable to both the decay and masking which causes the AB.

The Boost and Bounce (BB) model of Olivers et al. (2007; Olivers & Meeter, 2008), places similar emphasis on the role of intervening distractors in causing the AB. In the BB model, there are two stages of processing. All items in the RSVP stream undergo sensory processing during which their perceptual features and semantic and categorical information are activated; however, only a small subset of these items gain access to the second, working memory encoding stage. For an item to be encoded into working memory where it is available for report, it must be attentionally enhanced, or "boosted", by a gating mechanism. Those stimuli that match the attentional set established by task instructions are boosted, whereas those stimuli that do not (i.e., distractors) are inhibited, or "bounced", to prevent them from being encoded into working memory. On a typical RSVP trial, detection of T1 would initiate a boost of attention, gaining it access to working memory. Due to the sluggish temporal characteristics of the boosting mechanism, however, the item that immediately follows T1 is also boosted, regardless of its identity (i.e., target or distractor). If this item is another target (i.e., T2), it initiates another boost of attention and is encoded into working memory along with T1. If the item immediately following T1 is a distractor, however, a strong but transient suppression (bounce) is initiated with the aim of preventing distractor input from being encoded into working memory. This bounce inhibits the processing of the next few items. If one of those items happens to be T2, then an AB results as the distractor-induced inhibition prevents T2 from receiving the boost it needs to undergo working-memory encoding.

While the TLC model claims that it is an impairment of attentional control that gives rise to the AB, the BB model proposes that it is the strengthening of attentional control which gives rise to the AB deficit. Regardless of these differences, however, all theories belonging to this distractor-based class, share the claim that T1 processing alone is insufficient for the occurrence of the AB. Instead, they all claim that it is the presence of distractors intervening between the two targets which is essential for the occurrence of the AB.

1.3 What is the Root Cause of the AB: T1 processing or Distractor Interference?

As discussed in the preceding sections, the root cause of the AB is still a matter of great debate, with T1-based theories claiming that the AB arises as a consequence of T1 processing, while distractor-based theories attribute the cause of the AB to the disruptive effect of the presence of intervening distractors during T1 processing. A resolution of this debate would certainly further our understanding of the mechanisms underlying the AB and reveal implications for the temporal limits of our ability to process stimuli to the level of conscious awareness. However, in spite of the significant gains that could ensue from a better understanding of the root cause of the AB, Dux and Marois (2009, p.1697) have noted that "there have been few attempts to distinguish, in both the theoretical and experimental literatures, between the factors that cause the AB (i.e., are essential for its occurrence) and those that merely modulate its magnitude".

Studies that have attempted to get at the root cause of the AB have typically done so in one of two ways: (a) by manipulating T1 difficulty or T1 processing, or (b) by manipulating the events that intervene between the two targets. These two approaches are spelled out below.

1.3.1 Manipulations of T1 processing

Numerous studies have manipulated the demands of T1 processing in order to examine its effect on the magnitude of the AB. Some researchers have claimed that the evidence stemming from such manipulations can provide a basis for distinguishing between T1-based and distractor-based theories (e.g., Burt, Howard, & Falconer, 2010; Dux & Marois, 2009). For example, Burt et al. (2010) note that T1-based theories predict that manipulations of T1 difficulty should affect the magnitude of the AB, since the requirement to process T1 is said to act as the root cause of the AB. In contrast, they claim that in distractor-based theories T1 difficulty is said either to have no effect or an incidental effect on the AB since the disruptive events which are said initiate the AB occur subsequent to the presentation of T1. However, this claim could be disputed on the grounds that, manipulations of T1 difficulty need not be regarded as mediating the AB for a number of different reasons outlined below.

First, the evidence that manipulations of T1 processing modulates the AB is mixed (see Dux & Marois, 2009; Olson, Chun, & Anderson, 2001; Visser, 2007). Manipulations of T1 processing by varying the number of T1 response alternatives (Jolicœur, 1998, 1999), T1 working memory encoding load (Ouimet & Jolicœur, 2007; Akyürek, Hommel, & Jolicœur, 2007; Colzato, Spape, Pannebakker, & Hommel, 2007), or the masking strength of the distractor immediately following T1 (Chun & Potter, 1995; Dux & Coltheart, 2005; Grandison, Ghirardelli, & Egeth, 1997; McAuliffe & Knowlton, 2000; Seiffert & Di Lollo, 1997; Visser, 2007) have all yielded modulations in the magnitude of the AB. However, not all T1 manipulations have been shown to affect the magnitude of the AB. For example, Ward, Duncan, and Shapiro (1997) found the AB to be unaffected by T1 difficulty in a task that required discriminating T1 stimuli of different sizes. In the same vein, Shapiro, Raymond, and Arnell (1994) found the magnitude of the AB to be unaffected by the nature (detection or identification) of the T1 task. McLaughlin, Shore, and Klein (2001) also found that varying the perceptual quality of T1 did not affect the magnitude of the AB, and Akyürek and Hommel (2005, 2006) found the magnitude of the AB to be unaffected by the number of items held in working-memory.

There are several potential reasons why such mixed results have been obtained. Visser (2007) suggests that some studies may have failed to find modulations of AB magnitude with T1-difficulty manipulations because masking of T1 may interrupt T1 processing, thereby equating T1 processing across difficulty levels. Olson et al. (2001) also suggest that only manipulations that affect T1 difficulty prior to its encoding in working memory are capable of modulating the magnitude of the AB. Therefore, they suggest that the mixed results may have been caused by differences in the stage at which the T1 processing manipulation had its effect, with only those manipulations that had their effects prior to T1 encoding leading to modulations of AB magnitude. Moreover, Olivers and Meeter (2008) and McLaughlin, Shore, and Klein (2001) have noted that many of the experiments involved either location or task switching between the two targets. It is possible that what appear as modulations in the magnitude of the AB by manipulations of T1-difficulty are actually modulations in switch costs. On this reasoning, it is possible that in those experiments the AB magnitude was, in reality, unchanged. In addition, they note that speeded responses to T1 were required in some experiments, which, together with task switching, makes the procedure a PRP paradigm, rather than an AB paradigm. And the PRP may involve very different mechanisms to the AB (but see Jolicœur and Dell'Acqua, 1998).

However, even if the reason for these mixed results could be determined, it could still be argued that manipulating T1 processing as a means of distinguishing between T1-based and distractor-based theories may not be an ideal strategy. First, while evidence of T1 processing manipulations modulating the magnitude of the AB is clearly consistent with T1-based models, these findings are not necessarily inconsistent with distractor-based models. Clearly, T1 processing does not have as central a role in distractor-based theories as in T1-based theories. This is not to say, however, that T1 processing has no role at all in distractor-based theories. In fact, distractor-based models predict that T1 processing plays an essential role in the AB: it is only during T1 processing that distractors can disrupt attention and cause an AB. It could be argued, therefore, that some distractor-based theories would in fact predict modulations of the AB with manipulations of T1 difficulty. For example, the TLC model would predict that input control would be lost for a longer period of time when T1 difficulty is higher. This is because input control cannot be re-established until T1 processing is complete. Because the factor of T1 difficulty plays a role in both classes of theory, that factor cannot be used to discriminate between them. What is needed is a factor that is said to affect the AB in one class of theory but not in the other. The presence/absence of distractors intervening between T1 and T2 is such a factor.

1.3.2 Manipulations of Events Intervening Between the Targets

Manipulating the events intervening between the two targets has the potential to provide evidence capable of distinguishing between the two classes of theory. T1-based theories predict that an AB should occur, regardless of the presence or absence of intervening distractors, just so long as T1 requires processing is required. Distractor-based theories, on the other hand, predict that an AB should be in evidence only when distractors intervene between the two targets.

Several studies set out to determine whether intervening distractors are necessary for the occurrence of the AB by replacing the intervening distractors with a blank interval of the corresponding duration (e.g., Brisson, Spalek, & Di Lollo, 2011; Nieuwenstein et al., 2009; Raymond et al., 1992; Visser, 2007). These studies have yielded somewhat mixed results, with Raymond et al. (1992) failing to find an AB when the targets are separated only by a blank interval, while the others have observed an AB with the same inter-target blank (Brisson, Spalek, & Di Lollo, 2011; Nieuwenstein et al., 2009; Raymond et al., 1992; Visser, 2007).

The ABs observed without intervening distractors would seem to demonstrate that the presence of distractors during the inter-target interval is not essential for the AB -- a finding that is counter to the central assumption of distractor-based models. However, this need not be regarded as decisive evidence against those models. The possibility remains that the blank inter-target interval may be distracting in and of itself. That is, it is possible that there is something about the blank interval, besides merely the absence of distractors, which played a role in causing the observed ABs. For example, the blank interval may be a source of distraction, similar to distractor items. It is this possibility that is explored in the present thesis.

1.4 Objective

As is clear from the foregoing, evaluating the effects of the events intervening between the two targets has important theoretical implications. The principal goal of the present study was to identify any factors associated with the inter-target blank that could bring about an AB. Were any such factors to be identified, distractor-based theories would remain viable on the grounds that those factors would act in a manner equivalent to intervening distractors in disrupting attention.

2: EXPERIMENT 1

In this initial experiment, a typical attentional blink RSVP paradigm, complete with distractors intervening between the two targets, was employed. There was no theoretically motivated rationale for the current experiment since both T1-based and distractor-based theories predict that an AB should be observed when distractors are presented after T1, albeit for different reasons. T1-based theories predict that an AB should occur as T1 processing alone is said to be sufficient for the occurrence of an AB. Distractor-based theories also predict that an AB should be in evidence since attentionally disruptive distractors intervene between the two targets. Rather, the principal purpose of the present experiment was to confirm that the AB obtained with a threshold-tracking procedure known as PEST (Parameter Estimation by Sequential Testing; Taylor & Creelman, 1967 – see below) is equivalent to the AB obtained with conventional accuracy measures. A second, just as important, objective was to establish a baseline to which to compare the results of subsequent experiments.

2.1 Methods

2.1.1 The PEST Procedure

The conventional measure in AB experiments is accuracy of T2 identification. That measure, however, is subject to ceiling constraints imposed by the 100% limit of the response scale. The effect of such a response ceiling on the experimental outcome can be significant (e.g., Ghorashi, Enns, Spalek, & Di Lollo, 2009; Jannati, Spalek, & Di Lollo, 2011). Ceiling constraints can be avoided, however, by using the dynamic threshold tracking procedure known as PEST (Taylor & Creelman, 1967). In the present experiment, the PEST procedure was used to find the critical inter-stimulus interval (ISI_C) between T2 and the trailing mask at which any given participant could identify T2 approximately 80% of the time.

To arrive at ISI_C, the T2-mask ISI was varied dynamically by PEST as follows. The ISI was reduced on trials in which the participant's response accuracy exceeded the 80% criterial level, and was increased when accuracy was too low. A Wald (1947) sequential likelihood-ratio test determined whether the accuracy of the immediately preceding run of responses was greater than or less than 80%. The Wald routine was called only on trials in which T1 had been identified correctly. The PEST end run consisted of 12 trials after three reversals in the direction of adjustment of the ISI had been recorded. ISI_C was used as the dependent measure to index the AB.

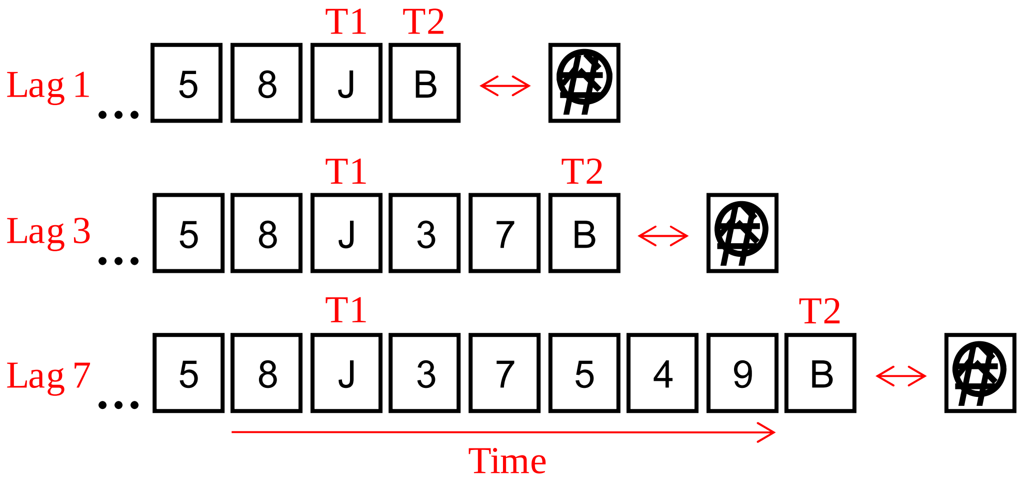
2.1.2 Participants

Fourteen undergraduate students participated for course credit. All reported normal or corrected-to normal vision and were naïve to the purpose of the experiment. In this and all subsequent experiments, participants gave written informed consent prior to the experiment. The Office of Research Ethics at Simon Fraser University approved this study.

2.1.3 Apparatus and Stimuli

Stimuli were displayed on an NEC AccuSync CRT monitor with a resolution of 600 x 800 pixels at a refresh rate of 140 Hz. All stimuli were black (20-point Helvetica font; RGB 0, 0, 0; 0.9 cd/m^2) and were presented in the centre of the screen against a grey background (RGB 90, 90, 90; 15.0 cd/m^2). The RSVP stream contained a variable number of digit distractors (2-9) and two uppercase letter targets (T1 and T2) selected randomly without replacement from the English alphabet, except I, O, W, and M. All subtended approximately 0.6 degrees vertically. Following Nieuwenstein et al. (2009), T2 was followed by a pattern mask consisting of a white square in which a circle, pound sign, and three additional line segments were drawn in black (see Figure 1). The experiment was programmed in E-Prime (Version 2.0; Psychological Software Tools, Pittsburgh, PA).

Figure 1. **Schematic representation of the sequence of events in Experiment 1. Each square represents one ~ 7 ms frame, except for the mask which was presented for 400 ms. The small gap between each square represents a blank ISI of ~ 93 ms. The T2-mask ISI was governed by PEST that converged to 80% correct T2 identifications.**



2.1.4 Design and Procedure

The experiment was run in a dimly lit room. At the beginning of the session, participants were required to read the instructions displayed on the screen, and were invited to ask questions. All displays were viewed from a distance of approximately 60 cm. At the beginning of each trial, a small fixation cross was presented in the centre of the screen. Participants initiated each trial by pressing the space bar, at which point the fixation cross disappeared and the RSVP sequence began.

The number of distractors preceding T1 was determined randomly on each trial and varied between 5 and 8, inclusive. On any given trial, the distractors were selected randomly, with replacement, from the set of digits 2–9, with the constraint that the selected digit was not one of the two preceding items.With the exception of the mask, each item in the RSVP stream remained on the screen for approximately 7 ms. T1 and all distractors were followed by an ISI of approximately 93 ms during which the screen remained blank, yielding a presentation rate of 10 items/sec. The ISI between T2 and the mask was governed by PEST to yield ISI_C at which T2 could be identified on approximately 80% of the trials. The pattern mask for T2 was presented for 400 ms. Examples of the stimuli and the sequence of events on any given trial are illustrated in Figure 1.

At the end of each trial, the participants were prompted to identify the targets by pressing the corresponding keys on the keyboard. They were instructed to report the letters in any order, and they were allowed to guess if uncertain. The fixation cross then reappeared, indicating readiness for the next trial.

Each participant took part in one session, consisting of three blocks of trials. In each of the blocks, there were three independent and randomly intermixed PEST runs, one for each of the three lags. Thus participants could not anticipate the inter-trial lag on any given trial. The assumption was made that the criterial level of performance had been approximated after three reversals in the direction of adjustment of the ISI. A separate estimate of ISI_C for each lag was obtained in each block by averaging the T2-Mask ISIs over the last 12 trials following the third PEST reversal. The final score (ISI_C) was the median of the three ISI_C estimates.

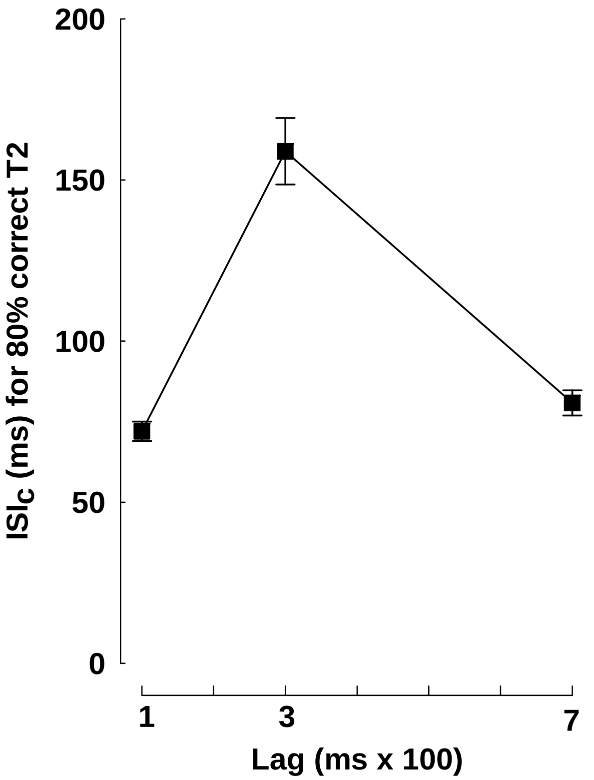
It should be noted that low ISI_C scores in the present work correspond to high T2 accuracy scores in conventional AB studies. Higher ISI_C scores indicate that a longer mask-free interval is required to identify T2 to the PEST criterial level (80% in the present work). In this sense, higher ISI_C scores reflect poorer performance (slower rate of processing) than lower ISI_C scores. This, of course, is the opposite pattern to that obtained with accuracy as the dependent measure.

2.2 Results and Discussion

The average of the ISI values from the 12 trials following the third PEST reversal was obtained for each of the three blocks. The median of these values, averaged across observers separately for each lag, are illustrated in Figure 2. A one-way within-subjects analysis of variance (ANOVA) performed on the ISI_C data illustrated in Figure 2 yielded a significant effect of Lag, $F(2,26) = 69.17$,

$MS_e = 463.50$, $p < .001$, partial $\eta^2 = .842$. Planned comparisons between the means for Lags 1 and 3 indicated that significant Lag-1 sparing was obtained, $t(13) = 8.62$, $p < .001$. Similar comparisons between Lags 3 and 7 confirmed that a significant AB was obtained, $t(13) = 8.86$, $p < .001$.

Figure 2. **Median critical ISI (ISI_C) as a function of lag in Experiment 1 in which distractors were presented between the two targets. ISI = inter-stimulus interval; ms = milliseconds. Error bars indicate standard error of the mean.**



The AB illustrated in Figure 2 is consistent with the results of conventional studies of the AB which use accuracy as the dependent measure. This correspondence is in keeping with the outcome of previous studies which have consistently found the pattern of results obtained with the PEST procedure to parallel that obtained with accuracy as the dependent measure, so long as accuracy was not at ceiling (e.g., Jannati et al., 2011; Ghorashi, Enns, Klein, & Di Lollo, 2010; Ghorashi et al., 2009).

The finding that the AB was in evidence with intervening distractors replicates the findings of in conventional AB studies (e.g., Shapiro, Raymond, & Arnell, 1994) and is consistent with hypotheses stemming from both T1-based and distractor-based theories. The two hypotheses are decoupled in Experiment 2 in which the intervening distractors were replaced with blanks of a corresponding duration, as was done by Nieuwenstein et al. (2009).

3: EXPERIMENT 2

In Experiment 2, the distractors intervening between the two targets were replaced with blank frames of corresponding duration, such that the screen was blank for the duration of the inter-target interval. The purpose of the present experiment was to replicate the findings of Nieuwenstein et al. (2009, Experiment 1) using ISI_C as the dependent measure. This condition was included because the two classes of theory make different predictions as to the presence or absence of the AB: T1-based theories predict that an AB should occur since T1 processing is required. Distractor-based theories, on the other hand, predict that no AB should be in evidence since there are no distractors intervening between the two targets to disrupt attention.

3.1 Method

3.1.1 Participants

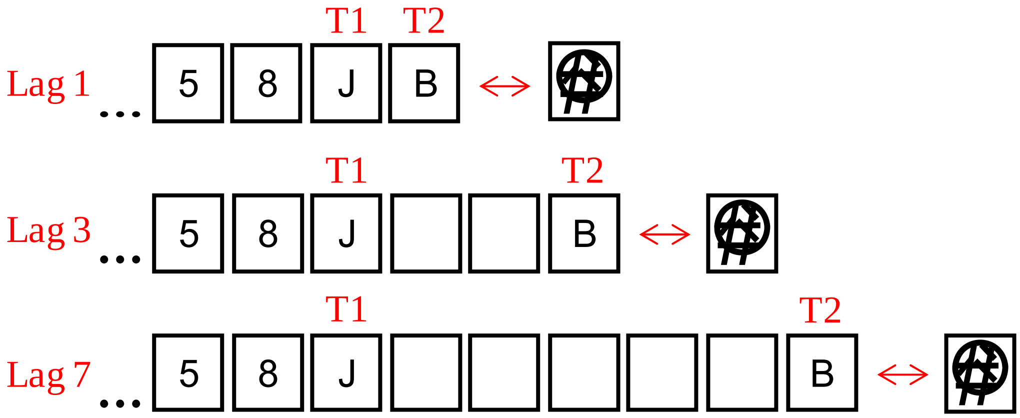
Nineteen undergraduate students participated for course credit. All reported normal or corrected-to normal vision and were naïve to the purpose of the experiment.

3.1.2 Design and Procedures

Apparatus, design, and procedures were the same as in Experiment 1, with the exception that the distractors intervening between the two targets in Experiment 1 were replaced with blank frames of a corresponding duration (see

Figure 3). That is, there was a blank inter-target interval of approximately 93 ms at Lag 1, 293 ms at Lag 3, and 693 ms at Lag 7.

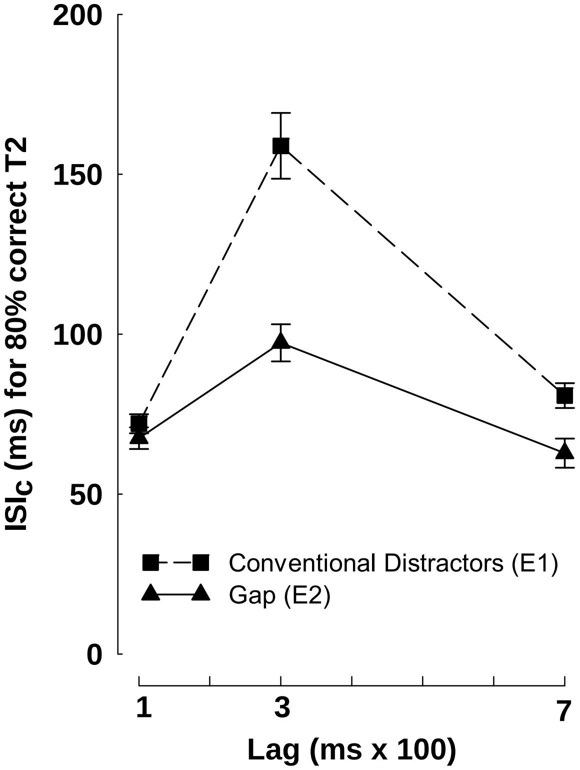
Figure 3. **Schematic representation of the sequence of events in Experiment 2. Each square represents one ~ 7 ms frame, except for the mask which was presented for 400 ms. The small gap between each square represents a blank ISI of ~ 93 ms. The T2-mask ISI was governed by PEST that converged to 80% correct T2 identifications.**



3.2 Results and Discussion

The average of the ISI values from the 12 trials following the third PEST reversal was obtained for each of the three blocks. The median of these values, averaged across observers separately for each lag, are illustrated as ISI_C in Figure 4. A one-way within-subjects analysis of variance (ANOVA) performed on the ISI_C data illustrated in Figure 4 yielded a significant effect of Lag, $F(2,36) = 48.01$, $MS_e = 138.21$, $p < .001$, partial $\eta^2 = .727$. Planned comparisons between the means for Lags 1 and 3 indicated that significant Lag-1 sparing was obtained, $t(18) = 6.30$, $p < .001$. Similar comparisons between Lags 3 and 7 confirmed that a significant AB was obtained, $t(18) = 10.90$, $p < .001$, albeit an AB of a smaller magnitude than that found in Experiment 1 in which intervening distractors were present, $t(31) = 5.21$, $p < .001$.

Figure 4. **Median critical ISI (ISI_C) as a function of lag in Experiment 2 in which a blank inter-target interval (gap) was presented between the two targets. ISI = inter-stimulus interval; ms = milliseconds. Error bars indicate standard error of the mean. The results of Experiments 1 have been added to the figure for ease of comparison. E = Experiment.**



This finding that an AB occurs without intervening distractors replicates the findings of Nieuwenstein et al. (2009) with accuracy as the dependent measure. This pattern of results is consistent with T1-based models, which predict that T1 processing is sufficient for the occurrence of the AB, but seemingly not with distractor-based theories which hypothesize that intervening distractors are necessary for the AB. While the present results appear to provide conclusive evidence against distractor-based models, the possibility remains distractor, and thereby caused an AB. If this was indeed the case, then distractor-based models would still provide viable explanations of the AB as the blank interval could be regarded as a form of distractor.

The following two experiments were designed to test two possible ways in which the blank inter-target interval could have disrupted attention: (1) The lack of visual stimulation during the inter-target interval may have caused attention to wander; (2) The blank interval might have come as a surprise to participants, thereby disrupting attention.

4: EXPERIMENT 3

Experiment 3 was designed to explore the possibility raised by Nieuwenstein et al. (2009) that some extraneous factor related to the lack of visual stimulation during the inter-target interval played a causal role in the AB observed with no inter-target distractors. Nieuwenstein et al. did not advance any reasons why a lack of visual stimulation could disrupt attention and, thereby, lead to an AB. One possibility is that because there was nothing to hold attention to the location of the RSVP stream, and because there were no items being presented that required processing, attention may have diffused or wandered, either in external space or inward to other mental processes, causing attention to be unavailable upon the presentation of T2.

In the present experiment, the aim was to present visual stimulation during the inter-target interval, while at the same time avoiding the presentation of distractors. The intent was to determine whether it is the lack of visual stimulation during the inter-target interval that is causing the AB in experiments in which no items are displayed between the two targets. The reasoning is that if no AB is observed under such conditions, then it could be concluded that that the likely determining factor was the lack of visual stimulation during the inter-target interval. This finding would present a life-line to distractor-based theories, providing the possibility that the blank inter-target interval could be considered as a form of distractor, and that such distraction is necessary for the occurrence of the AB. If, however, an AB is observed even under such conditions, then this would provide further evidence against distractor-based theories, but in keeping with T1-based theories.

A condition in which visual stimulation was presented but distractors were avoided during the inter-target interval was implemented by displaying repetitions of T1 in the place of the inter-target distractors presented in conventional AB studies (see Figure 5). Blank intervals were still present, with brief 93 ms ISIs intervened between the repetitions of T1. These brief blank intervals should not be sufficient to induce an AB, however, because ABs have failed to be observed when similar brief blank intervals are displayed between successive targets (e.g., Di Lollo, Kawahara et al., 2005; Kawahara et al., 2006; Nieuwenstein and Potter, 2006; Olivers et al., 2007; Olivers & Meeter, 2008; Potter et al., 2008).

4.1 Method

4.1.1 Participants

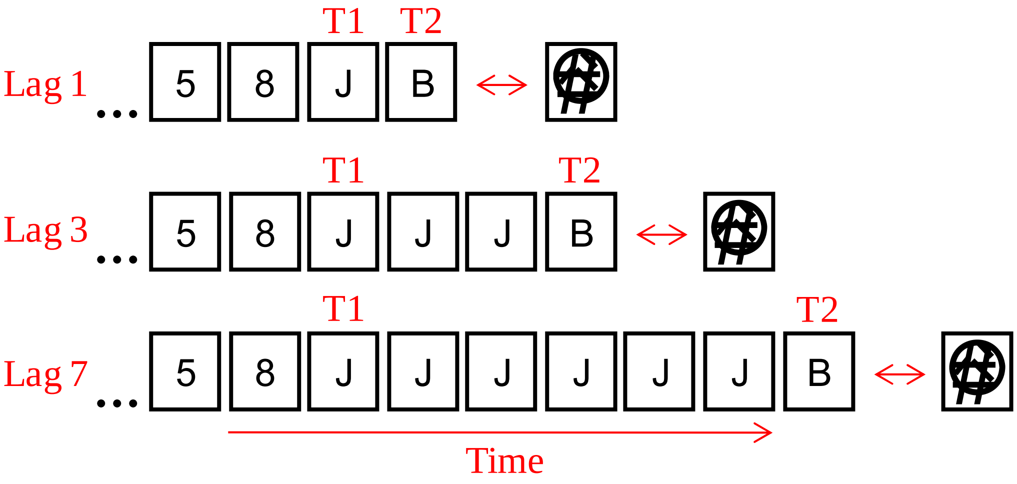
Eighteen undergraduate students participated for course credit. All reported normal or corrected-to normal vision and were naïve to the purpose of the experiment.

4.1.2 Design and Procedures

Apparatus, design, and procedures were the same as in Experiment 1, with the exception that the distractors intervening between the two targets were replaced with repetitions of T1 (see Figure 5). That is, on Lag 1 trials, T1 was presented once, while T1 was presented three times at Lag 3 and seven times at

Lag 7. The typical 10 items/sec presentation rate (item displayed for 7 ms followed by a 93 ms blank screen) was maintained throughout the RSVP stream such that T1 appeared to flicker at Lags 3 and 7.

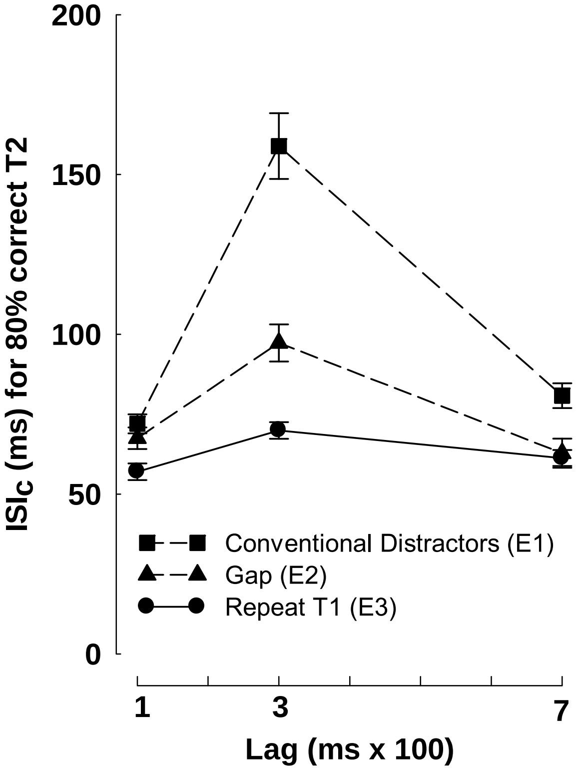
Figure 5. **Schematic representation of the sequence of events in Experiment 3. Each square represents one ~ 7 ms frame, except for the mask which was presented for 400 ms. The small gap between each square represents a blank ISI of ~ 93 ms. The T2-mask ISI was governed by PEST that converged to 80% correct T2 identifications.**



4.2 Results and Discussion

The average of the ISI value from the 12 trials following the third PEST reversal was obtained for each of the three blocks. The median of these values, averaged across observers separately for each lag, are illustrated as ISI_C in Figure 6. A one-way within-subjects analysis of variance (ANOVA) performed on the ISI_C data illustrated in Figure 6 yielded a significant effect of Lag, $F(2,34) = 20.85$, $MS_e = 37.48$, $p < .001$, partial $\eta^2 = .551$. Planned comparisons between the means for Lags 1 and 3 indicated that significant Lag-1 sparing was obtained, $t(17) = 6.92$, $p < .001$. Similar comparisons between Lags 3 and 7 confirmed that a significant AB was obtained, t(17) = 4.56, *p* < .001, albeit smaller than that obtained in Experiment 2 with a blank inter-target interval, t(35) = 6.92, *p* < .001.

Figure 6. Median critical ISI (ISI$_C$) as a function of lag in Experiment 3 in which T1 was repeated for the duration of the inter-target interval. ISI = inter-stimulus interval; ms = milliseconds. Error bars indicate standard error of the mean. The results of Experiments 1 and 2 have been added to the figure for ease of comparison. E = Experiment.



The highly significant AB observed in the present experiment in which repetitions of T1 were presented throughout the inter-target interval suggests that an AB can be observed without intervening distractors even when there is visual stimulation throughout the inter-target interval. This finding suggests that it was not the lack of visual stimulation that caused the AB in experiments in which there was an inter-target blank (e.g., Experiment 2; Brisson et al., 2011;

Nieuwenstein et al., 2009) and provides further evidence against distractor-based theories which state that the presence of distracting events intervening between the two targets is necessary for the occurrence of the AB. This finding, however, is entirely consistent with T1-based models since the requirement to process T1 is still present and, according to this class of theory, this is sufficient for producing an AB.

5: EXPERIMENT 4

Experiment 4 was designed to explore the possibility that in experiments without intervening distractors the blank inter-target interval might be perceived as an unexpected deviation from the 100-ms temporal rhythm established in the leading RSVP stream. As such, the temporal gap might come as a "surprise" thereby disrupting attention and causing an AB. In other words, the inter-target blank (i.e., the 293 ms gap at Lag 3) may be surprising to observers because it is not in keeping with the steady 10 items/sec presentation rate (93 ms gaps) of the leading RSVP stream. In a manner similar to the development of a "steady state" in the brain (Regan, 1989), this presentation rate could establish an expectation, whether conscious or unconscious, that a new item will be presented every 100 ms. When, instead of a new item, a blank screen continues to be presented after T1, this could violate the observer's expectations causing attention to be disrupted and an AB to ensue.

This possibility was not addressed by Experiment 3 in which repetitions of T1 were presented throughout the inter-target interval. While the repetitions of T1 allowed the presentation sequence to be maintained, the repetitions themselves would have been unexpected since, in the leading stream, none of the distractor items were presented more than once in a row. Like an extended blank interval, this unexpected repetition may also have disrupted attention thereby leading to an AB.

In the present experiment, the presentation rate of the leading stream was adjusted by replacing the 93 ms inter-item blank interval with a 293 ms blank inter-item interval such that the inter-item interval in the leading stream matched the inter-target interval at Lag 3. If the deficit observed at Lag 3 in Experiment 2 were due to the unexpected duration of the blank interval, no such deficit should be observed in the present experiment. This is because the duration of the blank at Lag 3 matched the duration of all the ISIs during the leading RSVP stream. It needs to be noted, at least in passing, that the long gap preceding T2 at Lag 7 would not be expected to produce a deficit in T2 identification because the additional length of the gap would allow the system to recover from the initial "surprise".

In brief, if it is a violation of expectations that led to the AB in Experiment 2, no AB should be observed in the present experiment, consistent with distractor-based, but not with T1-based, models. If however, an AB is observed, this would provide further evidence in support of T1-based models.

5.1 Method

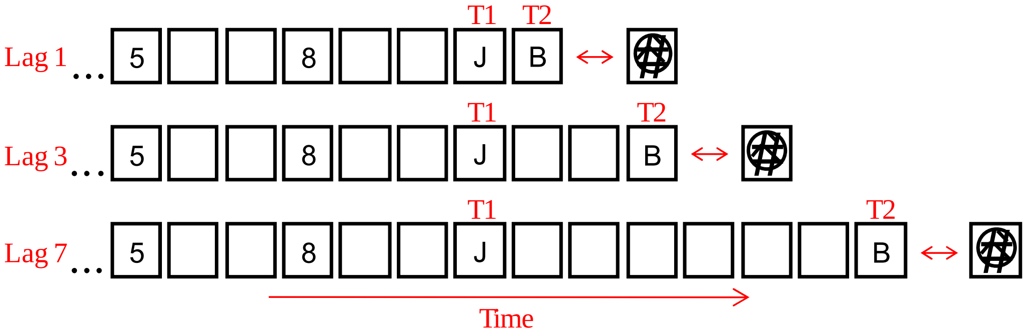
5.1.1 Participants

Sixteen undergraduate students participated for course credit. All reported normal or corrected-to normal vision and were naïve to the purpose of the experiment.

5.1.2 Design and Procedures

Apparatus, design, and procedures were the same as in Experiment 2, with the exception that the typical 10 items/sec presentation rate (item displayed for 7 ms followed by a 93 ms blank screen) was changed for all leading (i.e., pre-T1) items in the RSVP stream. The 93 ms blank inter-item interval was replaced with a 293 ms blank such that, in the leading stream, a new item appeared every 300 ms (see Figure 7). The blank inter-target interval was unchanged from Experiment 2 (i.e., 93 ms, 293 ms, and 693 ms for Lags 1, 3, and 7, respectively). The T2-mask ISI was governed by PEST.

Figure 7. **Schematic representation of the sequence of events in Experiment 4. Each square represents one ~ 7 ms frame, except for the mask which was presented for 400 ms. The small gap between each square represents a blank ISI of ~ 93 ms. The T2-mask ISI was governed by PEST that converged to 80% correct T2 identifications.**

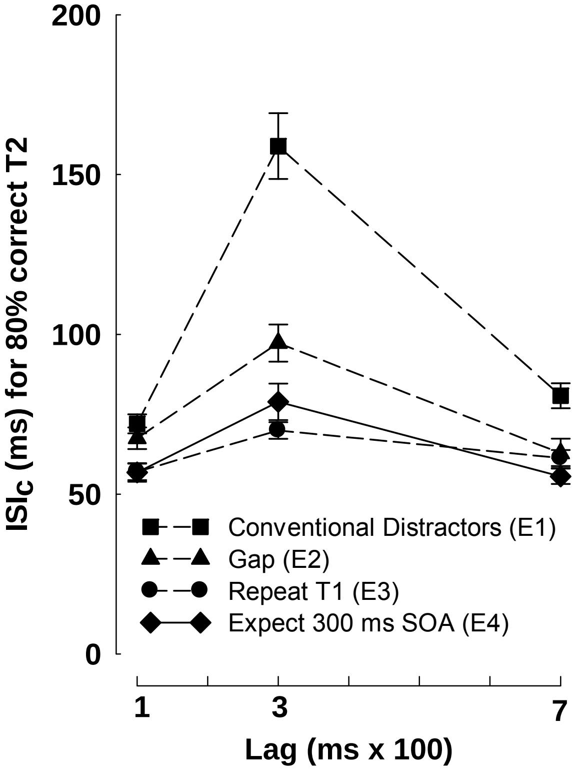


5.2 Results and Discussion

The average of the ISI value from the 12 trials following the third PEST reversal was obtained for each of the three blocks. The median of these values, averaged across observers separately for each lag, are illustrated as ISI_C in Figure 8. A one-way within-subjects analysis of variance (ANOVA) performed on the ISI_C data illustrated in Figure 8 yielded a significant effect of Lag, $F(2,30)$ =

13.08, $MS_e = 210.42$, $p < .001$, partial $\eta^2 = .466$. Planned comparisons between the means for Lags 1 and 3 indicated that significant Lag-1 sparing was obtained, $t(15) = 4.58$, $p < .001$. Similar comparisons between Lags 3 and 7 confirmed that a significant AB was obtained, $t(15) = 3.60$, $p = .003$.

Figure 8. **Median critical ISI (ISI_C) as a function of lag in Experiment 4 in which the SOA of all items in the leading stream was 300 ms (7 ms stimulus, 293 ms blank ISI). ISI = inter-stimulus interval; ms = milliseconds. Error bars indicate standard error of the mean. The results of Experiments 1, 2, and 3 have been added to the figure for ease of comparison. E = Experiment.**



The highly significant AB observed in the present experiment in which the blank inter-target interval at Lag 3 was consistent with the presentation rate of the leading stream, suggests that the AB observed without intervening distractors in Experiment 2 did not arise from a violation of expectations. In fact, the magnitude of the AB in Experiment 2, in which the inter-target blank at Lag 3 could have violated expectations, and the magnitude of the AB in the present experiment, in which a violation of expectations should not have occurred, were not significantly different, t(33) = 1.63, *p* = .113. This suggests that the surprisingly long gap at Lag 3 in Experiment 2 did not cause the AB. These findings provide further evidence against distractor-based theories and suggests that T1 encoding alone is sufficient for the occurrence of an AB, consistent with T1-based theories.

6: GENERAL DISCUSSION

The AB has been the focus of extensive empirical and theoretical investigation and has developed into a standard paradigm for the study of attention. This is due, in large part, to the belief that the AB reflects the temporal limits of our ability to analyze and encode stimuli to the level of conscious awareness. In spite of the wealth of empirical studies, the root cause of the AB is still a matter of debate. Two broad classes of theory have been proposed: T1-based and distractor-based. Each of the two classes contains many individual variations. All the theories within each class, however, share a common tenet. T1-based theories claim that T1 processing alone is sufficient to produce an AB. Distractor-based theories, on the other hand, claim that T1 processing by itself is not sufficient to cause an AB. Rather, they claim that it is the disruptive effect of distractors presented during T1 processing that is essential. The experiments reported in the present work were designed to distinguish between these two classes of theory.

The starting point was the finding by Nieuwenstein et al. (2009) that an AB occurs when the distractors intervening between the two targets were replaced by blanks. On the face of it, this finding is obviously inconsistent with distractor-based accounts. On the other hand, the possibility must be considered that the blank inter-target interval itself may have disrupted attention, much like a distractor, thereby causing an AB. The principal goal of the present study was to identify any factors associated with the inter-target blank that might bring about an AB.

In Experiment 1 a threshold-tracking procedure not subject to ceiling constraints (PEST) was used to replicate the findings of conventional AB experiments, in which distractors intervene between the two targets and accuracy of T2 identification is used as the dependent measure. In the present work, the dependent measure was the critical T2-mask ISI (ISI_C) required to identify T2 on 80% of the trials. Predictably, and consistent with both classes of theory, a significant AB was observed. In Experiment 2 different predictions stemming from the two classes of theory were tested. Following Nieuwenstein et al. (2009), but with ISI_C as the dependent measure, the intervening distractors were replaced with blank frames of a corresponding duration. Thus, only a blank screen was presented for the duration of the inter-target interval. An AB was again observed, consistent with T1-based predictions but not with those of distractor-based models. The next two experiments were designed to test two possible ways in which the blank inter-target interval might have disrupted attention, leading to an AB: (1) The lack of visual stimulation during the inter-target interval may have caused attention to wander; (2) The blank interval might have come as a surprise, thereby disrupting attention. The outcomes of both experiments favoured T1-based theories.

Considered collectively, the results of the present experiments disconfirm predictions from distractor-based theories and lend strong support to the claim of

T1-based theories that T1 processing alone is sufficient for the occurrence of the AB.

6.1 Concluding Comments and Future Prospects

The T1-based class of theory encompasses a number of different individual theories, such as two-stage (e.g., Chun & Potter, 1995), bottleneck (e.g., Jolicœur & Dell'Acqua, 1998), resource depletion (Ward, Duncan, & Shapiro, 1996) and formal (e.g., Wyble et al., 2009) models. All these theories are capable of accounting for the results of the present work, since they all share the common tenet that the AB results from the requirement to process T1. They are not, however, equally capable of accounting for all of the findings in the AB literature.

Two-stage, bottleneck, and resource depletion models have all been seriously challenged by the finding that an AB does not occur when targets appear in succession (e.g., Di Lollo et al., 2005; Kawahara et al., 2006; Olivers, et al., 2007; Olivers & Meeter, 2008; but see Dell'Acqua, Jolicœur, Luria, & Pluchino, 2009; Dux, Asplund, & Marois, 2008, 2009 for an alternative interpretation and Olivers, Spalek, Kawahara, & Di Lollo, 2009; Olivers, Hulleman, Spalek, Kawahara, & Di Lollo 2011 for rebuttals). Recently, however, several formal T1-based theories have been proposed, such as the attentional cascade (Shih, 2008), threaded cognition (Taatgen, Juvina, Schipper, Borst, & Martens, 2009), and eSTST (Wyble et al., 2009) models. As well as predicting the present results, these models are capable of accounting for the spreading-of-the-sparing effect with sequential targets. In their recent review of the AB literature, Dux and Marois (2009) concluded that the eSTST model of Wyble et al. (2009) is capable of accounting for the largest number of empirical findings.

In part, the superiority of the eSTST model stems from its ability to account not only for identification accuracy results, but also for the perception of temporal order throughout the period of the AB (Spalek, Lagroix, Yanko, & Di Lollo, in press). In addition, it is the only model to make formal and explicit predictions regarding the effects of leading and intervening distractors. The model is not without flaws, however. For example, in a recent study in which the presence of leading and intervening distractors were systematically manipulated to assess the effects on both identification accuracy and temporal order, the eSTST model was generally successful at predicting the results in both measures except for the case in which no distractors are included in the RSVP stream (Spalek et al., in press). The eSTST model predicted that Lag-1 sparing should be in evidence while a Lag-1 deficit was actually observed. In spite of such flaws, the eSTST model seems to provide one of the most comprehensive accounts of the AB phenomenon.

Pursuing the present conclusion that it is some process or event directly associated with T1 processing that causes the AB, future research should focus on determining exactly which of these aspects leads to the deficit. Visser (2007) and Olson et al.'s (2001) examination of the stage of T1 processing at which the magnitude of the AB is modulated suggests a promising line of inquiry. In the present work, the AB of the largest magnitude was observed in Experiment 1 in which distractors intervened between the two targets. The magnitude of the ABs observed with no intervening distractors (Experiments 2 and 4) were not significantly different from one another, but were of a larger magnitude than in Experiment 3 in which repetitions of T1 filled the inter-target interval. How these manipulations affected the difficulty of T1 processing is a promising avenue for further research.

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