Attentional blink and repetition blindness

Karen M Arnell, karnell@brocku.ca Brock University, St. Catharines, Ontario, Canada
Kimron L Shapiro, k.shapiro@bangor.ac.uk Bangor University, Bangor, Wales

Keywords
Attentional blink (AB), Repetition blindness (RB), RSVP, Dual-task, Attention

Abstract
When two masked, to-be-attended targets are presented within half a second of each other, report accuracy for the second target (T2) is impaired relative to when the two targets are presented farther apart in time, or relative to when the first target (T1) can be ignored. This effect is known as the attentional blink (AB). An additional T2 accuracy deficit is observed if T1 and T2 are identical or highly similar on a task relevant dimension. This effect is known as repetition blindness (RB). For both AB and RB, targets are typically imbedded in rapid serial visual presentation (RSVP) streams and the dual-task attention cost lasts approximately half a second. Given the high degree of superficial similarity, AB and RB are often considered to be related phenomena. Although research thus far has suggested that both phenomena reflect limits of the attentional system and how attention is allocated when needing to organize stimuli for entrance into awareness, these two phenomena are dissociable; RB is not simply an enhanced AB. Furthermore, investigations of AB and RB have taken quite different courses over the last two decades. The AB has been investigated extensively with a variety of experimental, behavioral, neurophysiological, and clinical approaches, and has become widely used as a paradigm of convenience with which to study other effects. In contrast, studies of RB have tended to manipulate the nature of the target information to understand the level of representation that supports RB.

Dual-Task Attention Costs
During even the simplest of our everyday interactions we are overloaded with visual and auditory input. The role of attention is to select a subset of relevant input for further processing. However, as attention is a limited resource, this results in competition amongst stimuli. Researchers have examined the time-course and nature of dual-task attention costs by
presenting a sequence of stimuli, rapidly (between 6 to 20/second) in the same location – a
method known as rapid serial visual presentation (RSVP). Using this method, two-to-be-reported
targets (T1 and T2) are imbedded in a stream of distractors, with the number of items between
the two targets varying across trials from 0 (lag 1) to as much as 9 (lag 10) (see Figure 1a). If
participants must attend to both T1 and T2, then accuracy for reporting T2 is impaired when T2 is
presented 2 to 5 items (approximately 200 to 500 ms) after T1, but is quite high when T2 appears
immediately after T1, or more than 500 ms after T1 (see the dual-task condition of Figure 2). This
pattern is known as the Attentional Blink or AB [1]. However, when T1 can be effectively ignored,
T2 report accuracy is high at all T1-T2 lags (see the single-target condition of Figure 1b)
suggesting that attentional, not perceptual, limitations underlie the effect [1].

Figure 1
Panel ‘a’ depicts an RSVP stream where T1 is the lone white letter and T2 is the letter ‘X’. In this
eexample T2 is present in lag 5. At the end of the stream, participants are asked to report the
identity of the white letter and whether the X was present or absent. Panel ‘b’ shows the pattern
of T2 accuracy from Experiment 2 of Raymond, Shapiro and Arnell (1992; figure adapted).

There are several theoretical models of the AB, but most models agree that the AB results
from relatively late post-perceptual limitations on attention and/or working memory. Some models
[2,3] suggest that encoding T1 into working memory creates an information processing bottleneck
where T2 must wait while T1 is encoded, with the fragile T2 representation decaying during the
wait. Other models [1,4] suggest that the presence of a distractor immediately after T1 results
in an inhibition of high-level processing while attention is diverted to T1. A third class of models [5]
suggest that the AB results from retrieval errors from an overcrowded visual short-term memory
buffer that holds fragile representations of targets and some distractors. Other recent models
[e.g., 6,7] have stressed the importance of top-down cognitive control which must be effectively
maintained to efficiently separate targets from distractors.

The term repetition blindness (RB) [8], refers to the deficit in T2 accuracy that is observed at
short target separations when T1 and T2 are identical (e.g., “B” and “B”) or when they share a
dimension important to the task (see Figure 2). RB has also been observed with a variety of
stimuli and presentation contexts [e.g., 8, 9-11].
The most prominent model of RB has been the token individuation hypothesis [8]. According to this hypothesis both the first and second instance of a repetition activate the “type” node for that stimulus such that the representation for a given stimulus becomes activated within a network. The first instance also becomes tokenized, being episodically bound and consciously identifiable in time and space. However, the second instance of the repetition is not tokenized given that type activation from the first instance is still active. Thus, although there is unconscious activation for both instances, there is only conscious awareness of the first.

Both AB and RB have proved popular as experimental paradigms because they yield a large effect that is easy to obtain and because they have captured the interest of researchers studying perception, attention, and memory. Given the high degree of apparent similarity, AB and RB are often considered to be related phenomena. Chun [12] was able to doubly dissociate AB and RB by showing that AB was sensitive to the discriminability between targets and RSVP distractors while RB was not, but that RB was sensitive to the episodic distinctiveness of T1 and T2 whereas AB was not. Using event-related EEG brain potentials (ERPs), a larger negativity 150 to 300 ms following T2 was observed for repeated T2s compared to unrepeated T2s, suggesting that there may be a higher perceptual threshold for repeated targets compared to unrepeated targets [13]. So, although AB and RB appear similar, they are dissociable. Furthermore, the AB is seen to be at least somewhat distinct from the related phenomena of Inattentional Blindness and the Psychological Refractory Period (PRP). Despite their superficial similarity, the investigations of AB and RB have taken quite different courses over the last two decades, as is reviewed below.

**Approaches to Studying the AB**

The AB has been studied with a wide variety of approaches and there are currently over 400 published studies with “Attentional Blink” in the title, Abstract, or as a key word. While it is not possible to review this vast amount of literature here, the following section uses a selected sample of studies to give an idea of the diversity of approaches to understanding the AB and how these approaches have influenced the questions that have been asked about the AB and the models that have been posited to explain it.

**Stimulus and Task Manipulations**

*Classic Studies and Models*
Most early studies of the AB sought to examine the stimulus presentation conditions and tasks that could elicit an AB. For example, the nature of the RSVP stimuli were manipulated showing that the AB can be observed with a wide variety of stimuli (e.g., letters, digits, words, line-drawings, visual scenes, faces) [e.g., 1, 3, 14]. The AB has been observed when both targets are presented auditorily [e.g., 15] or tactiley [16] and when T1 and T2 are presented in different stimulus modalities (e.g. auditory T1 auditory and visual T2) [e.g., 15]. The AB can also be found when T1 and T2 are presented in different locations and each is masked by a single item [17]. Early task investigations of the AB showed that the AB can be observed regardless of whether T2 must be identified or simply detected in a presence/absence task, and that this was also true for T1 [e.g., 3, 6]. The AB can also be observed when T1 and T2 require the same task (e.g., identify both letter targets amongst the digit distractors), which rules out task switch explanations of the AB [3].

AB studies of this traditional cognitive variety were often interpreted in the context of information processing bottleneck models where the AB was viewed as a fundamental limitation of the human information processing system [3, 4]. According to such models T2 must wait while T1 is encoded into working memory where it can enter conscious awareness. Studies showing that the AB increases with T1 processing demands have provided support for such models [e.g., 4].

**Recent Studies and Models**

Some recent studies have provided challenges to bottleneck models and the idea that the AB represents a fundamental limitation on information processing. For example, researchers [e.g., 7] have shown that the AB is dramatically reduced when three or more targets are presented sequentially (TTT) relative to when two targets are separated by a distractor (TDT), despite the fact that three targets would seem to demand more attentional processing than two. Also intriguingly counterintuitive, is the finding that having participants perform an additional attention-demanding task (e.g., think about holidays, detect yells in music) results in an attenuated AB [18] relative to just asking participants to focus on the RSVP task. Olivers and Nieuwenhuis [18] suggested that participants typically overinvest attentional resources in RSVP distractors and T1, and that performing an additional task allows participants to diffuse their attention across tasks, thereby allowing distractors to be less effective competitors for attentional encoding.

Words with affective or motivational significance can also overcome the AB. For example, the AB is dramatically attenuated when T2 is the participant’s own name [19] or when it is an emotionally arousing sexual or taboo word [20]. The AB is also reduced when T2 is affectively salient to the participant (e.g., spider related words for spider phobics) [21] and when T2 has previously been associated with reward [22]. Although these findings could be taken to suggest that these stimuli require less attention, other studies suggest that these words actually receive more attention. For example, the AB is increased when T1 is a taboo/sexual word and T2 is neutral [23]. Furthermore, when an arousing stimulus is presented as an irrelevant RSVP distractor, it can capture attention and reduce accuracy for a subsequent target [e.g., 24].

**Participant Manipulations and Individual Differences**

Studies of the AB have also frequently looked for differences in AB magnitude across different participant groups, either because the researchers want to understand the nature of the AB, or because the researchers want to understand the nature of a given disorder or condition. Although there are literally dozens of studies examining differences in the AB as a function of participant groups, some examples include reports that the AB is larger for elderly participants [25], schizophrenics [26], unilateral neglect patients [27], ADHD patients [28], and Alzheimer’s patients [29]. On the other hand, Green and Bavelier [30] have reported a reduced AB for action video game players. We caution the reader to be careful when using this literature however, given that researchers have sometimes confounded overall accuracy of T2 with the size of the AB (see Box 1).
Box 1: Estimating the AB

The term “AB” as such refers to the transient attention cost that lasts approximately half a second after an attended target. Thus, by definition in order to observe an AB, T2 accuracy must be higher at relatively long T1-T2 lags (intervals greater than 500 ms) than at shorter lags (intervals between 100 and 500 ms). However, when one examines the AB literature they find many examples where researchers have claimed to increase the AB in one condition or group relative to another condition or group, yet the slope of the T2 accuracy functions across lags is the same in both conditions, one just has a lower overall T2 accuracy (see reference 31 for a discussion of this problem in relation to the AB and dyslexia literature). In such cases there is a significant main effect of condition (showing that overall T2 accuracy was modulated), but no significant interaction (showing that the slope of the T2 accuracy function across target separations was not modulated, which is what reflects the AB). In order to say the AB has increased one must observe a slope difference in the two conditions such that a lag by condition ANOVA is significant.

This problem can also be observed when researchers performing correlations or regressions with the AB, estimate the magnitude of the AB with a single number that confounds the slope and overall T2 accuracy. For example, using the sum of the difference between T2 accuracy at each lag and 100% will confound AB magnitude as estimated by the slope with overall T2 accuracy, as may summing the difference between T1 accuracy and T2 accuracy across lags, or simply using short lag T2 accuracy. This is problematic given that individual differences studies of the AB have shown that separate types of predictors modulate the slope of the line and the height [14,32,33]. We take this opportunity to remind researchers and readers of AB studies that the AB has only been modulated or estimated accurately when the slope across lag has been isolated and differs as a function of group or condition.

Although the AB is a robust phenomenon, individuals do vary in the size of their AB, showing reliable AB magnitudes over time, even across changes in the AB task and display [34]. Researchers have recently begun to use these individual differences to understand the mechanism of the AB. For example, counter to what bottleneck models of the AB would predict, individual differences in cognitive processing speed (as indexed by choice manual response time tasks and vocal naming tasks) [14], and fluid intelligence (as indexed by Ravens Matrices) [32,33] do not predict individual differences in AB magnitude, even though they do predict individual differences in overall T2 accuracy (see Box 1 for why these are not the same thing). However, individual differences in executive control of working memory [32,33] and the ability to keep irrelevant material out of working memory [35,36] do predict individual differences in AB magnitude where a higher working memory score and a more selective working memory are associated with smaller AB magnitudes.

Interestingly, dispositional affect and personality have been shown to predict individual differences in AB magnitude. Arnell and her colleagues have observed that high negative trait affect [37], high scores on the Beck depression inventory [38], and high scores on the neuroticism dimension of the Big-5 NEO-PI personality inventory [39] predict larger ABs, whereas high positive trait affect [37], and high scores on the extraversion and openness to experiences personality dimensions [39] predict smaller ABs. Slagter and colleagues have also reported a reduced AB following 3 months of meditation training [40]. These results are consistent with the overinvestment hypothesis of Olivers and Nieuwenhuis [18] given that negative affect and neuroticism have been associated with focusing of attention [e.g., 41] and positive affect, extraversion, and openness to experience have been associated with broad, flexible and diffuse attention [e.g., 42]. In general, results of individual difference studies of the AB suggest that individual differences in the AB do not reflect information processing speed limitations as much as they reflect differences in efficient executive control of multiple pieces of information.
Neurophysiological Investigations

With their excellent temporal resolution, event-related brain potentials (ERPs) have proven useful for understanding the AB. Vogel, Luck and Shapiro [43] examined ERPs time-locked to T2 and showed convincingly that the both early P1/N1 ERP components (reflecting perceptual processing) and the N400 component (sensitive to semantic processing) were fully intact during the AB, even when T2 could not be reported. In contrast, the P3 component (sensitive to stimulus identification/categorization) was dramatically attenuated during the AB. The authors concluded that although T2 receives full perceptual and semantic activation during the AB it is not encoded into working memory during the AB, resulting in a lack of awareness for T2. Martens and his colleagues [44] showed that non-blinkers (individuals who reliably show no AB) produced an early large discrete P3 to T1, whereas blinkers showed a more prolonged P3. Kranczioch and her colleagues [45] have recently used the P3 to provide evidence that T1 and T2 compete for resources such that there is a trade-off between their amplitudes at short lags. They also showed that synchronization and desynchronization in alpha and beta frequency ranges was related to T2 accuracy, and suggest that the interaction of synchronization and desynchronization may control the amount of inhibition applied to irrelevant distractors, thus modulating the AB.

Given its relatively poor temporal resolution, fMRI has not been the neurophysiological tool of choice for studying the AB. Nonetheless, the handful of fMRI studies of the AB that do exist agree that the AB is associated with activation in a fronto-temporo-parietal network that has been linked to the executive control of attention, working memory and awareness [46-48]. Any conflicting findings between labs, in terms of whether there is more BOLD response when the T2 target is correctly identified or when it is missed, are likely due to differences in task difficulty as a direct correlate of the lag between targets [48].

Magnetoencephalography (MEG) combines the temporal precision of ERPs with the spatial resolution of fMRI. As with EEG, MEG also allows for frequency-based analysis of the data. Gross et al. [49] examined long-range synchronization using MEG and observed long-range phase synchronization in the beta band during the AB task in the same fronto-parieto-temporal attentional network that was implicated with fMRI studies. They observed that when T2 could be reported at short lags there was more synchronization to T2 and de-synchronization to T1 and T2 masks than on trials when T2 could not be reported. They postulated that synchronization and de-synchronization represent states of the network that facilitate and suppress, respectively, the processing of targets and masks, which act in concert to gate relevant information to awareness.

There have also been investigations of how pharmacological mechanisms may modulate AB performance. For example, Nieuwenhuis and his colleagues [50] noted that the time course of the AB is very similar to the time course of the refractory period that follows the release of norepinephrine during the increase in locus coeruleus activity in response to a target. In an individual differences study of the AB, Colzato and her colleagues observed that greater spontaneous eye blink rate was associated with smaller ABs [51]. Greater spontaneous eye blink rate is associated with greater dopaminergic activity [52], and also with greater extraversion [53]. Greater extraversion is also associated with better working memory performance [54]. Therefore, there appears to be a consistent pattern of positive interrelationships between extraversion, working memory performance and spontaneous eye-blink response, (via dopaminergic activity), and each of these measures is negatively associated with AB magnitude.

Approaches to Studying RB

Stimulus and Task Manipulations

Although there are fewer RB studies than AB studies, RB is still well studied with approximately 100 published studies with “Repetition Blindness” in the title, abstract, or as a key word. However, unlike the AB, the vast majority of RB studies have sought to examine the nature
of representations and tasks that can support the effect, with few studies of special populations or individual differences, and few investigations with affective stimuli or neurophysiological measures.

RB has been observed with a variety of stimuli, such as words [8], letters [11], and object pictures [10,55]. RB has also been found with non-object pictures that had no pre-existing representations [9], and for words with the similar orthography but different phonology [56], suggesting that visual/orthographic similarity can support RB. Cross-case RB has been demonstrated using letters [8,11] and RB has been observed for bilingual participants when the two targets were presented in different languages (e.g., caballo and horse) [57] showing that semantic representations can underlie RB. RB has been reported for words with the same or similar phonology, but with no orthographic overlap (e.g., I–eye) showing that phonological representations can also underlie RB [11]. Repetition deafness (difficulty reporting the second instance of an auditory target) has also been reported when stimuli have been presented rapidly in rapid auditory presentation [58], further supporting the notion that phonological codes can support RB. However, semantic, orthographic and phonological RB are not observed as reliably as RB for identical targets. Bavelier [55] has suggested that RB can be found if two items are encoded in short-term memory along dimensions on which they are similar, and that RB is especially likely if repetition of type information is integrated into a token relatively early in processing.

RB has also been observed with a variety of tasks. The most common task has participants name all RSVP stream items [e.g., 8, 55]. RB has even been found with this task when the repeated targets are presented in the context of an RSVP sentence where omitting the repetition renders the sentence nonsensical (e.g., “When the dog ran away he ran after it.” is often reported as “When the dog ran away he after it.”) [8]. RB can also be observed when participants are asked to report just the critical targets from amongst the distractors, when they are asked to report the number of times an item or class of items was presented, or when reporting whether a given item was present or absent [e.g., 9,59]. However, no RB, and sometimes even priming, is observed when the first instance of the repetition is not attended for report (and assumed to be typed but not tokenized) [8,60]. RB is also reduced when the two targets are emphasized as distinct from each other. For example, RB is reduced if the first and second instances of the repetition are separated spatially [61], when the intervening RSVP distractors are removed [62], if irrelevant sounds accompany the two targets [63], or the targets are presented with distinctive color cues [12].

Although there have been only a couple of studies examining emotional stimuli using the RB approach, as with the AB, words with affective or motivational significance do modulate RB. For example, RB is decreased when it is the participants own name [59]. RB was also reduced for orthographically similar words when the second target was a taboo word [64]. It is possible that emotionally significant words receive more attention, thereby increasing their distinctiveness. However, an increase in RB has also been reported for threat words [65], so the nature of the RB modulation may depend on the exact stimuli and task demands. Interestingly, Raymond and her colleagues have reported semantic RB for two different consumer brands within the same product type (e.g., Tide and Cheer) when using pictures, showing how RB can be applied to issues regarding consumer brand associations [66].

While a wide variety of patient and special populations have been tested with the AB paradigm, there are surprisingly few studies of special populations and RB. One exception is that RB has been shown to be much larger for healthy elderly participants relative to a university aged sample [67]. Another example is that RB has been observed to be larger for schizophrenia patients and their first degree relatives compared to the general population [68]. Simultanagnosia patients show reduced report for one of two stimuli presented simultaneously, (as do extinction patients if one of the two stimuli are presented in the left visual field), and this difficulty increases when the two objects are the same or highly similar semantically suggesting that the same RB-based individuation difficulties may underlie these conditions [69,70].

Also in contrast to the AB, to our knowledge there have been no fMRI or MEG studies of RB, and only two published ERP investigations [13,71]. The first ERP and RB study [71] showed that trials where the second target word was incorrect (regardless of whether or not it was
repeated) showed little to no P3 to the second target. Moreover, repeated trials where all words were reported correctly showed early (220 ms) posterior positivity to the second target, reflecting repetition facilitation - effects that were absent in the repeated trials where the second target was incorrect. A more recent ERP study [13] also showed differential activation 150 to 300 ms following the second target for repeated T2s compared to unrepeated T2s, but the authors suggested there may be a higher perceptual threshold for repeated targets compared to unrepeated targets. In both cases however, the ERP results provide clear evidence for on-line encoding difficulties for repeated targets.

As discussed above, the token individuation hypothesis has been the dominant theoretical model of RB, and it suggests that no conscious episodic token is created for the second instance of a repetition [8]. In contrast, memory based theories of RB attribute RB to “off-line” retrieval problems, or reconstruction or response biases occurring after all stream items (including repeated targets) have been consciously encoded [e.g., 72,73]. For example, cues presented after the stream, but before recall, have been shown to reduce the amount of RB relative to no-cue conditions [72]. There is strong evidence for both on-line encoding difficulties and that off-line manipulations can modulate RB, and although they are often presented as such, these two theoretical options are not mutually exclusive. Participants may fail to fully consolidate a token in short-term memory for a repeated target as a result of encoding difficulties. However, at retrieval, participants may be able to construct a complete token on some proportion of trials when aided by contextual cues.

**Conclusion**

The AB and RB are dissociable. However, both phenomena appear to reflect the operation of attentional control mechanisms that work to limit access to conscious awareness. Indeed, it is interesting to note the similarities between a recent type-token computational model of the AB [74] and a very recent type-token computational model of RB [75].

While investigations of RB have tended to be more focused in terms of method and the nature of the questions, a wide variety of behavioural and neurophysiological approaches have been used to investigate the AB. This diversity of approaches has served the AB well and has fundamentally shaped our understanding of it. Importantly, individual differences studies of the AB, in combination with the use of affect and personality measures, have shifted recent theoretical models away from an information processing bottleneck basis. The shift has been in the direction of models of attention and working memory executive control, where participants’ affect, personality, and task conditions influence their search style and their resultant AB. At the same time fmRI and MEG studies have revealed that the AB is associated with activation in a fronto-temporo-parietal network; in turn linked to the same constructs of executive control of attention, working memory and awareness. The interplay between measures of cognition, affect and personality, pharmacology, and neuroimaging continues to emerge and be a major driving force in modern approaches to studying the AB. RB also lends itself to this more divergent approach, and we call on researchers to apply a wider variety of methods to the study of RB. It is through such a diversity of measures that real progress can be made in understanding the AB, RB and related cognitive phenomena.

**Notes**

**References**


35. Arnell, K. M. & Stubitz, S. M. (in press). Attentional blink magnitude is predicted by the ability to keep irrelevant material out of working memory. *Psychological Research.*


**Further Reading**


**Cross-References**

COGSCI-260: Change Blindness/Inattentional Blindness

COGSCI-263: Divided Attention

COGSCI-281: Selective Attention under Load

**Supplementary Information**

Click here to insert Supplementary information text