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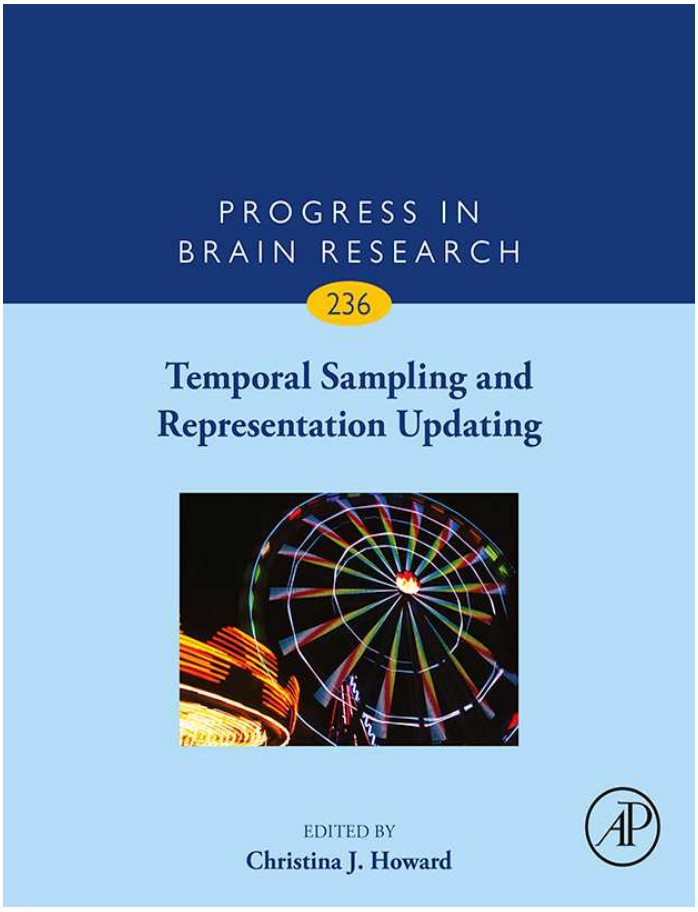

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CHAPTER 3

Perceptual episodes, temporal attention, and the role of cognitive control: Lessons from the attentional blink

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Abstract

The ability to identify a target is usually hindered if it appears shortly after another target. This simple and somewhat intuitive observation is qualified by a multitude of unexpected findings and conflicting theories that originate from the attentional blink paradigm. In this review, the major results, implications, and outstanding questions that stem from the paradigm are presented and discussed. The extant literature suggests that when the temporal domain is densely stacked with numerous stimuli, the entities that underlie attentional selection and cognitive control are brief perceptual episodes. Specifically, attention is deployed over an interval that frequently encompasses several stimuli. Most theories agree that the length and boundaries of this interval are influenced by cognitive control mechanisms. However, there is little agreement as to the extent and nature of this influence. Some theories suggest that control is needed in order to initiate a temporally limited attentional response. Other theories argue that cognitive control is actively suppressing attentional mechanisms in order to terminate the perceptual episode. Another formulation suggests that both ends of the interval are partially controlled and that the exertion of control corresponds to the focusing of attention on a narrow interval. The contents of perceptual episodes, as well as their deficiencies, can shed light on the features that guide attentional deployment, the goals that guide cognitive control, and the interactions between these mechanisms. Electrophysiological recordings are extremely useful when one tries to pinpoint the timing of attentional selection. Other neural indicators can elucidate the factors that define perceptual episodes.

Keywords

Attentional blink, Proactive control, Reactive control, Temporal episode, Attentional set

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The environment provides a constant flux of sensory input to a person that operates within it. Successful goal-directed behavior rests on the ability to detect and act upon the subset of the incoming input that is relevant to the current behavioral goals. Frequently, multiple stimuli should be identified and acted upon. Results from a diverse set of cognitive tasks suggest that participants' ability to report several targets is impaired when they appear simultaneously (e.g., Duncan, 1980; Sperling, 1960) or temporally close to one another (e.g., Pashler, 1994; Raymond et al., 1992). These findings have led various researchers to conclude that targets need to be processed by a limited-capacity system before they could be reported (e.g., Broadbent, 1958; Chun and Potter, 1995; Deutsch and Deutsch, 1963; Driver, 2001; Duncan, 1980; Treisman, 1960; Treisman and Gelade, 1980). According to this framework, an attentional mechanism controls the selection and transfer of to-be-reported targets to the limited-capacity system. Reporting of multiple targets is limited because attentional selection of a target is postponed until the processing of the previously selected targets is over. When the targets are distributed over different points in time the mechanism of selection is usually termed temporal attention.

The attentional blink (AB) paradigm has been extensively employed in order to study the limited ability to report multiple targets that are distributed in time (for reviews see Dux and Marois, 2009; Martens and Wyble, 2010). In the standard procedure of this paradigm, a rapid stream of stimuli is presented in the center of a screen, one stimulus at a time, and the participant is asked to identify and later report two target stimuli (Fig. 1). The two targets are presented with a varying number of intervening distractors. This intertarget time interval is termed lag. For example, lag-1 means that the second target (T_2) appears immediately after the first target (T_1), whereas lag-2 means that T_1 and T_2 are separated by a single distractor. Identification of T_2 is generally worse when it is temporally close to T_1 (Chun and Potter, 1995; Raymond et al., 1992). However, this identification deficit almost completely disappears when the targets appear successively (i.e., without intervening distractors—lag-1; Chun and Potter, 1995; Di Lollo et al., 2005; Olivers et al., 2007; Potter et al., 2002). This finding, known as *sparing effect*, has been extended to procedures that employ three (e.g., Di Lollo et al., 2005; Kawahara et al., 2006) or four targets (Olivers et al., 2007; Wyble et al., 2011).

The extant findings from the AB literature motivated episodic accounts of performance in this task. Many contemporary theories suggest that for a target to be identified, attention should be deployed to a temporal episode that encompasses the target presentation (e.g., Bowman and Wyble, 2007; Olivers and Meeter, 2008; Raymond et al., 1992; Shih, 2008; Wyble et al., 2009). According to those theories, lag-dependent decrements in performance reflect instances in which a target appears when attention is still deployed to a previous episode and before it can be deployed again. In contrast, sparing effects occur when multiple targets are processed within a single attended episode. This position is reinforced by electrophysiological studies (EEG, MEG) showing unimodal, rather than bimodal, posterior activation (P300 or M300) in response to two successive targets (e.g., Craston et al., 2009; Dell'Acqua et al., 2016; Kessler et al., 2005). Different theories offer different accounts of

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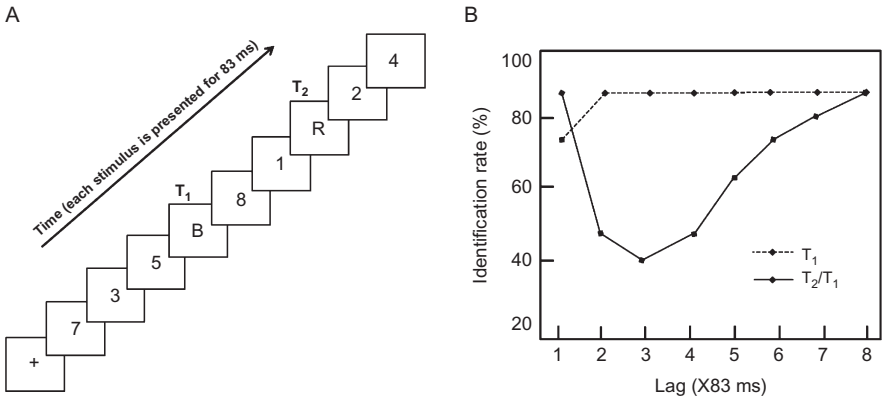

FIG. 1

The standard attentional blink design and typical results. (A) The participant is asked to identify two targets (in this example, letters) among a stream of stimuli that contains many distractors (in this example, digits). Each stimulus is presented for a brief duration (e.g., 83 ms). The lag between the two targets is manipulated (lag-3 is depicted in this figure). (B) Identification of both targets is depicted as a function of the intertarget lag. The identification rate of T_1 is high across all lags accept for a small decrement at lag-1. The identification rate of T_2 drops at lags 2–6 and recovers at lags 7–8. At lag-1, identification of T_2 is high (lag-1 sparing). It is customary to calculate T_2's identification rate contingent on correct identification of T_1.

temporal episodes, the mechanisms that drive their initiation, and the processes that drive their termination. Virtually all the theories suggest an involvement of cognitive control mechanisms in those processes, though the specific mechanisms differ from theory to theory. Here, we review various experimental findings from the AB literature and discuss the implications of those findings to the nature of temporal episodes and the mechanisms that underlie their formation and termination.

1 THE NATURE OF TEMPORAL EPISODES

Until recently, temporal episodes were consistently construed as attentional in nature. That is, most existing theories describe an episode of heightened (or focused) attention (e.g., Olivers and Meeter, 2008; Olivers and Nieuwenhuis, 2005; Shih, 2008; Wyble et al., 2009). From this perspective, experimental results from AB studies indicate which factors influence the initiation and termination of an attentional episode and how attention influences the processing of stimuli. A recent theoretical alternative suggests that under the rapid rates of stimulus presentation that characterize the AB procedure, episodic representations are naturally formed (Snir and Yeshurun, 2017). According to this account, temporal episodes are perceptual, not attentional. At any given time point during an RSVP, a grouped representation of

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multiple previously seen stimuli is formed. This representation changes gradually as time goes by: features of new stimuli are added, while features of old stimuli diminish. A "snapshot" of this dynamic representation could be selected by attentional mechanisms, facilitating individuation and identification of its constituents. From this perspective, experimental results from AB studies indicate what information is represented in grouped representation and what determines the timing of attentional selection.

A related, though distinct, line of inquiry concerns the involvement of temporal integration processes in the AB procedure (e.g., Akyürek and Hommel, 2005; Akyürek and Wolff, 2016; Hommel and Akyürek, 2005). Some of those studies employ a target set that includes two targets (e.g., "/" and "\") that could be integrated to form a third target ("X"). It has been shown that when these two targets appear temporally close to one another, participants report their integrated combination on a substantial proportion of the trials (e.g., Akyürek and Wolff, 2016; Akyürek et al., 2013; see also Visser and Enns, 2001). This finding suggests that temporal integration processes could ease the deployment of attention over an episode, that the deployment of attention facilitates temporal integration processes, or both.

As stated earlier, the centrality of temporal episodes to target identification in the AB procedure was substantiated by participants' enhanced ability to identify targets when presented temporally close to one another, as compared to more disperse presentation conditions (e.g., Di Lollo et al., 2005; Olivers et al., 2007; Wyble et al., 2011). In contrast, inquiries regarding the representational contents of temporal episodes are primarily informed by participants' diminished ability to accurately report various aspects of the attended episode. Three prominent types of deficiencies are mentioned in the literature (Fig. 2). First, when the targets are temporally adjacent, participants frequently report them in a different order than the presented order (e.g., T_1 is reported as T_2 and vice versa; e.g., Akyürek and Hommel, 2005; Hilkenmeier et al., 2012; Olivers et al., 2011a; Spalek et al., 2012). Second, participants often associate a feature of a target with another stimulus (e.g., the color of T_1 is associated with a preceding distractor; Botella et al., 2004; Chun, 1997; Goodbourn et al., 2016; Vul et al., 2008). Third, even though the identification rates of trailing targets (i.e., T_2, T_3, etc.) is enhanced when they share an episode with the first target (i.e., T_1), T_1's identification rate deteriorates under those conditions (e.g., Dell'Acqua et al., 2012; Dux et al., 2008; Potter et al., 2002). The interpretation of those findings depends on the way temporal episodes are construed. If thought of as attentional episodes, those findings are sometimes understood as unfortunate by-products of attentional deployment. In contrast, the perceptual account of temporal episodes views those deficiencies as inherent limitations of the grouped representations that are formed during RSVPs (Snir and Yeshurun, 2017).

1.1 ORDER REVERSALS

The attentional account of temporal episodes suggests that the distribution of attention over several targets determines the proportion of order reversals (Hilkenmeier et al., 2012; Reeves and Sperling, 1986; Spalek et al., 2012). According to this

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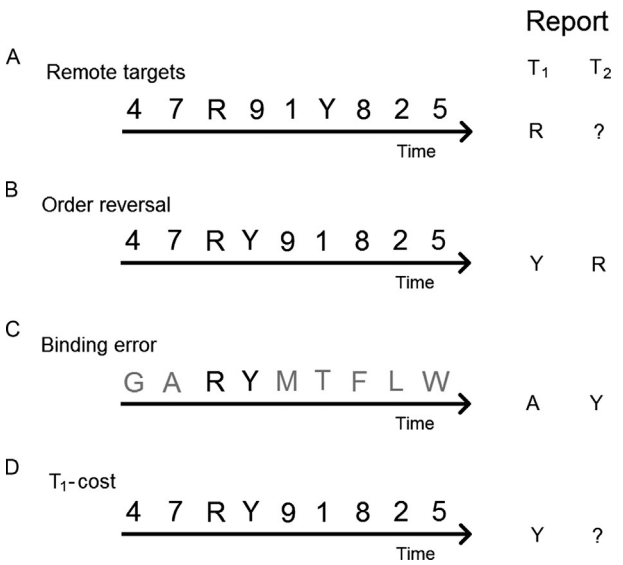

FIG. 2

Common report deficiencies in the AB procedure. (A) When the targets are remote, trailing targets are often missed. Many theories assume that the trailing target (T_2) is missed because attentional mechanisms are preoccupied with a temporal episode that surrounds the first target (T_1). (B) When the targets are close enough, attention could be deployed to a temporal episode that encompasses both of them, enabling identification of both targets. However, participants often report the targets in the wrong order. (C) When the target-defining feature (e.g., color) is distinct from the reported feature (e.g., letter identity), participants often report a nearby distractor. Ostensibly, the target-defining feature was incidentally bound to the distractor in those instances. (D) When successive targets are employed, T_1 identification deteriorates, and often only T_2 is reported. Arguably, the two targets are processed within the same episode in this setup. Being the first (and only) target to be identified, T_2 is frequently reported as T_1. *Note.* The figure depicts only two-target streams, but comparable results have been reported with three-target streams.

account, when a target receives more attentional resources than an adjacent target, it gains prior entry to consciousness and, as a result, is reported before its neighbor (i.e., the law of prior entry; Titchener, 1909). Hilkenmeier et al. (2012) examined this possibility using a two-target AB procedure that included T_1 cues and T_2 cues that, by design, drew attention to their corresponding target. As expected, the proportion of order reversals increased when T_2 cues appeared in the stream and decreased when T_1 cues appeared in the stream, compared with a no-cue control condition. In a related study, Spalek et al. (2012) examined the proportion of order reversals in a (successive) T_2–T_3 pair that appeared at different lags after T_1. A blink-like pattern emerged whereby order reversals were more common when T_2 appeared "within the blink" (i.e., 200 ms after T_1) and decreased at longer lags. Ostensibly,

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the deployment of attention was delayed during the blink, altering the relative (rather than absolute) amount of attention T_2 and T_3 received in favor of T_3.

The perceptual account of temporal episodes suggests that order reversals reflect the limited serial information that is represented in an episodic representation (Snir and Yeshurun, 2017; cf. Akyürek et al., 2013). The perceived order of the targets may be determined by the order in which they are extracted from the selected snapshot. The extraction order is influenced by the specific timing of snapshot selection because the relative representational quality of different targets is determined by this timing. In other words, because the representational quality of items decreases as more time passes from their onset, if the timing of snapshot selection is closer to T_2's onset than T_1's onset, T_2 may gain consciousness access before T_1 due to its stronger representation. Thus, from this perspective, the cues employed by Hilkenmeier et al. (2012) and the lag manipulation of Spalek et al. (2012) may have affected the proportion of order reversals by altering the timing of snapshot selection.

1.2 BINDING ERRORS

Most AB studies employ streams of stimuli where the to-be-reported feature (e.g., letter identity) is naturally bound to the target-defining feature (e.g., letters; Chun and Potter, 1995; Di Lollo et al., 2005). However, when the two are dissociated, participants often report distractors that are adjacent to targets (e.g., Goodbourn et al., 2016; Popple and Levi, 2007; Raymond et al., 1992; Vul et al., 2008). For instance, when participants are asked to identify the red letters in an all-letter stream, they often report the identity of black letters that are temporally adjacent to T_1 and T_2 (Goodbourn et al., 2016). Extant theories of the AB detail the perceptual and attentional processes that occur after targets are differentiated from distractors (cf. Di Lollo et al., 2005; Olivers et al., 2007; Wyble et al., 2011). As a result, binding errors are usually not explicitly mentioned in those models. This approach is questioned by studies that demonstrate how the deployment of attention affects binding errors (e.g., Botella et al., 2004; Goodbourn et al., 2016; Vul et al., 2008). For instance, Vul et al. (2008) examined the distribution of binding errors around T_2 when it appeared at different lags after T_1. When T_2 appeared 200–500 ms after T_1, the proportion of binding errors increased and they tended to involve distractors that succeeded T_2. Vul et al. (2008) suggested that when T_2 appears within the blink, it is processed within a temporal episode that is suppressed, delayed, and diffused (cf. Goodbourn et al., 2016).

As far as we know, there has not been a specific analysis of binding errors that characterize episodes that contain two or more targets (i.e., when sparing occurs). If targets are processed within a common episode, target-defining features of one target could be bound to a succeeding target and vice versa. In this condition, binding errors could manifest themselves as order reversals. Generally speaking, binding errors within an episode are compatible with the perceptual account of temporal episodes. Like order reversals, binding error could occur when targets are extracted from a selected snapshot (temporal episode) that maintains features of multiple targets and distractors (Snir and Yeshurun, 2017).

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1.3 T_1 COST

Ever since sparing effects were recorded, it has been known that they are accompanied by decrements in T_1 identification (e.g., Chun and Potter, 1995; Potter et al., 2002). However, this T_1 cost received more in-depth experimental consideration only in recent years (e.g., Dell'Acqua et al., 2009, 2012; Dux et al., 2008, 2014; Snir and Yeshurun, 2017). In most of those studies, the focus of interest is still the sparing effect rather than T_1 cost. For instance, Dell'Acqua et al. (2009) examined the interdependencies of sparing effects and the T_1 cost in an AB procedure that included three successive targets. The T_3 identification rate was systematically affected by the set of trials over which it was calculated. It was highest when all the trials are sampled, worse when only T_1-identified trials were sampled ($T_3|T_1$), and worst when only T_1- and T_2-identified trials were sampled ($T_3|T_1$ and T_2). The results suggest that some form of processing constraints limit the ability to identify all the targets concurrently. This T_1-cost effect is not easy to reconcile with an attentional account of temporal episodes. The effect suggests that the attentional episode that underlies T_1 identification is delayed or diminished when successive targets appear, but the cause of this delay remains vague. Some researchers argue that the T_1 cost should be regarded as a low-level perceptual phenomenon that is distinct from the attentional processes that modulate the AB (Olivers et al., 2009, 2011b; Wyble et al., 2009, 2011).

The perceptual account of temporal episodes associates the T_1 cost with the way in which successive targets modulate the timing of snapshot selection (Snir and Yeshurun, 2017). According to this account, in streams with successive targets, selection of a snapshot will be withheld in order to select a snapshot with multiple targets and maximize target identification. When selection is withheld, the representational quality of "aging" targets is diminished and, as a result, the probability that T_1 will be extracted from the selected snapshot diminishes as well.

2 PROACTIVE CONTROL: PREPARING FOR TARGETS

Virtually all AB theories agree that, once the instructions are comprehended, attentional mechanisms are modified to preferentially process upcoming targets (e.g., Di Lollo et al., 2005; Snir and Yeshurun, 2017). This modification could be thought of as a manifestation of proactive control in which an attentional set that maintains target-defining features is set up and used to monitor the stream. The relevance of proactive processes for AB phenomena is underscored by the finding that the degree of alpha event-related desynchronization (alpha ERD—a decrease in alpha power from baseline following an event) prior to the onset of the RSVP was associated with the magnitude of the AB (MacLean and Arnell, 2011). Similarly, Janson et al. (2014) included in their study a condition in which the presentation of T_1 was not preceded by a stream of distractors (i.e., ensuring their measurements are not contaminated by steady-state visual evoked potentials (ssVEPs) generated by the RSVP) and found that the amplitude of alpha oscillations before target presentation were related to

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the AB magnitude. Specifically, alpha power was lower in trials without AB (i.e., trials in which both T_1 and T_2 were correctly identified) compared with AB trials. They suggested that this endogenous alpha power relates to top-down processes, and therefore their study supports the notion that top-down proactive processes affect the AB. Still, the vast majority of AB theories associate the main results from the paradigm with perceptual and attentional processes that succeed target presentation rather than proactive control processes (e.g., Nieuwenhuis et al., 2005; Olivers and Meeter, 2008; Shih, 2008; Wyble et al., 2009). We are familiar with only two theories that associate proactive processes with AB phenomena (Di Lollo et al., 2005; Snir and Yeshurun, 2017).

According to the *temporary loss-of-control* account of Di Lollo et al. (2005), prominent experimental findings could be understood by postulating a cognitive control mechanism that either maintains the configurations of the attentional set (proactive control) or consolidates a detected target (reactive control). Crucially, this mechanism cannot execute both functions in parallel. As a result, after T_1 is detected, the configurations of the attentional set could not be maintained and it is subject to exogenous interference. Thus, distractors that follow T_1 can distort the contents of the attentional set and hinder the identification of trailing targets. When T_1 is followed by successive targets, the attentional set is not distorted and sparing effects ensue. This notion of temporary loss of control was employed in a recent electrophysiological study (EEG) to account for the observed pattern of alpha synchronization (Glennon et al., 2016). Specifically, on AB trials (i.e., trials in which T_2 was not identified), prior to the onset of T_1, a transient increase in synchronization of a predominantly right frontoparietal alpha network emerged. Following T_1 presentation a rapid desynchronization of this alpha network was observed, and it was followed by a resynchronization during presentation of the intervening distractor. The authors suggested that the initial increase in synchronization reflects the establishment of an endogenous attentional set that is tuned to target-defining characteristics and help the participant to detect and report T_1. They further suggested that the synchronization pattern of this network that followed T_1 offset may be due to a failure to maintain this endogenous tuning to the target-defining features and instead reflects exogenous tuning to distractor features.

As explained earlier, the *limited snapshots theory*, proposed by Snir and Yeshurun (2017), adheres to the perceptual account of temporal episodes. Accordingly, it suggests that the attentional set is configured to accommodate the episodic representations that are formed during an RSVP. Importantly, this set maintains not only target-defining feature but also structural information regarding the upcoming streams such as the number of targets, their expected temporal distributions (e.g., sparse, successive), and their probable serial positions. This information is used to devise a selection strategy that would maximize target identification. For instance, if the streams contain three targets that tend to appear close to one another, an efficient selection strategy would conduct selection only after a considerable amount of target features are represented in the monitored stream. Essentially, selection is withheld until multiple targets can be selected.

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Even though most theories pay little attention to proactive control processes, a diverse array of experimental finding suggests that those processes may play a central role in the formation of AB phenomena. Those processes could influence performance through their interaction with reactive control mechanisms or on their own. Two types of manipulations that modulate the size of the AB substantiate the importance of proactive control. First, prior knowledge regarding the upcoming targets, which could be incorporated into the attentional set, has been shown to alter participants' performance (e.g., Dux et al., 2008; Martens and Johnson, 2005; Visser, 2015; Visser et al., 2014). Second, when the similarity between targets and distractors is increased, the magnitude of the AB is usually enlarged (Folk et al., 2002, 2008; Olivers and Watson, 2006). Arguably, the attentional set, whose contents differentiate between targets and distractors, is less efficient when similarity is high.

2.1 PRIOR KNOWLEDGE

When the design of the streams increases the relative importance of certain upcoming targets their identification is facilitated (Dux et al., 2008; Visser, 2015). For instance, Dux et al. (2008) differentially emphasized the report of T_1 and T_3 in three-target streams with consecutive targets. Within each block of trials, the participants were asked to report all three targets on 50% of the trials. In the remaining 50%, one group of participants was asked to report only the identity of T_1 and another group was asked to report only the identity of T_3. T_1 identification was higher than T_3 identification in the T_1-emphasized group and vice versa in the T_3-emphasized group. In a similar study, Visser (2015) manipulated the proportion of two-target and three-target streams in a block of trials. Three-target streams appeared on 33% of the trials for one group and on 66% of the trials for another group. As expected, the identification of T_3 was higher in the high-probability group. The results of Dux et al. (2008) and Visser (2015) suggest that proactive mechanisms accommodate the likely structure of upcoming streams. This could be accomplished by prolonging the attentional episode (Visser, 2015) or by delaying the selection of an episodic representation (Snir and Yeshurun, 2017).

Another manner in which prior knowledge can affect performance is through temporal expectancy. When participants are presented with cues that point to probable temporal positions of upcoming targets, the identification rate of the cued targets tends to increase (e.g., Choi et al., 2012; Martens and Johnson, 2005; Tang et al., 2014; Visser et al., 2014). Other temporal regularities could also facilitate performance. Using two-target streams, Visser et al. (2014) examined whether fixing the lag between T_1 and T_2 would ameliorate the AB. In their study, one group of participants viewed only lag-3 trials and a second group was administered a standard variable-lag condition. Participants in the fixed lag group were notified regarding the temporal regularity and they were encouraged to use it in order to enhance their performance. Indeed, lag-3 identification of T_2 was higher in this group compared with the variable-lag group. Martens and Johnson (2005) used a very similar procedure,

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but they did not inform participants in the fixed-lag condition of the temporal regularity embedded in their streams. In this case, there were no differences between the fixed-lag and the variable-lag groups. Taken together, temporal expectancy studies suggest that proactive mechanisms can adjust the attentional set in a manner that accommodates temporal regularities. The temporal position of a target may be regarded as a target-defining feature that is maintained in the attentional set and used to monitor the stream. Alternatively, knowledge regarding temporal regularities may be used to delay, prolong, or, accelerate the deployment of attention.

2.2 TARGET–DISTRACTOR SIMILARITY

Arguably, the most direct evidence for the involvement of proactive control mechanisms in the AB procedure comes from studies, demonstrating that the AB magnitude varies with target–distractor similarity (e.g., Chun and Potter, 1995; Folk et al., 2008; Maki et al., 1997; Olivers and Watson, 2006). For instance, Folk et al. (2008) employed a modified version of the AB paradigm that included only a single target that differed from the other RSVP items by its color. Critically, the stream's items were presented in the center of a squared frame, and on some of the trails the frame briefly changed its color before target presentation (with varying lag between the color change and target presentation). The authors found that an AB emerged when the frame changed its color to that of the target but not when it changed to a different color. They suggested that an AB emerged because when the frame acquired the target's color, it matched the features held in the attentional set, and this resulted in attentional capture to the frame and the item it surrounded. Hence, in effect, this item functioned as T_1. The fact that this attentional capture only happened with the color that matched the target-defining features supports the notion of a proactive control mechanism that governs the selection of items that match task-relevant features. Olivers and Watson (2006) also provided evidence in support of an attentional set that maintains target-defining features. In their AB procedure, T_1 was a color-defined target and T_2 was a group of dots that had to be enumerated. They found that when the dots had the same color as T_1 the magnitude of the AB was smaller than when the dots had a different color. Interestingly, when the color of the dots matched the color of the distractors, the AB was larger than when they had a "neutral" color, even when the last distractor in the stream appeared before T_1. Thus, these findings suggest that in addition to target-defining features, the attentional set holds distractor-defining features that are used to inhibit irrelevant RSVP items.

3 REACTIVE CONTROL: IDENTIFYING (AND MISSING) TARGETS

In the standard AB procedure, a stream of distractors precedes the first target (e.g., Chun and Potter, 1995; cf. Duncan et al., 1994). Clearly, in order to ensure adequate performance in the task, those distractors must be recognized as nontargets. It is generally believed that the processes through which distractors are differentiated from

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targets, whatever they may be, do not lead to a blink-like effect on T_1 identification. Accordingly, most theories suggest that the processes that follow the appearance of T_1 underlie the main findings of the AB literature. Those processes include attentional amplification (e.g., Nieuwenhuis et al., 2005; Shih, 2008), target consolidation (e.g., Chun and Potter, 1995; Wyble et al., 2009), and distractor suppression (Olivers and Meeter, 2008; Raymond et al., 1992). Together, they could all be described as manifestations of reactive cognitive control.

Many AB theories postulate an attentional gate that opens after T_1 is detected (e.g., Olivers and Meeter, 2008; Raymond et al., 1992; Reeves and Sperling, 1986). While the gate is open, processing of stimuli from the stream is amplified. This amplification enables the identification of T_1 and, if they appear before the gate is closed, of trailing targets as well. Some theories suggest that the gate closes passively after a short while (Reeves and Sperling, 1986), while others suggest that the gate is actively inhibited and closed when a distractor appears (Olivers and Meeter, 2008; Raymond et al., 1992). According to the latter, the processing of a distractor that follows T_1 interferes with the identification of T_1, prompting control mechanisms to shut the attentional gate.

The *episodic simultaneous-type serial-token* (eSTST) computational model adheres to the notion of an attentional episode, but it suggests that the processing of targets, rather than the processing of distractors, prompts the termination of attentional episodes (Wyble et al., 2009, 2011). This theory suggests that for a target to be identified, it must go through two stages of processing (cf. Chun and Potter, 1995), conceptualized using the type/token differentiation proposed by Kanwisher (1987). In the first stage, the long-term representation of the target's identity is activated (i.e., type activation), and in the second stage, a representation of its actual appearance is formed (i.e., token formation). The theory asserts that the activity of a central attentional mechanism is amplified when a target is processed in the first stage and actively suppressed when a target is processed in the second stage. Thus, T_1 will both increase and decrease attentional processing of other RSVP targets, depending on the temporal distance of these targets from T_1. At short temporal distances, T_1 is mainly processed in the first stage of processing and thus increased attentional processing will ensue. At longer temporal distances, attentional processing of trialing targets will be suppressed because T_1 will occupy the second stage of processing. Recently, Dell'Acqua et al. (2015) reported an AB effect on two electrophysiological components: frontal P3a and posterior P3b. For both components, a short lag between the targets resulted in amplitude suppression, but with the P3b postponed latency was also observed. The authors suggested that the suppressed P3a amplitude may reflect reactive inhibitory processes like those suggested by the eSTST model, and that these processes then lead to the delayed and reduced Pb3.

The *overinvestment hypothesis* of Olivers and Nieuwenhuis (2006) is unique in that it does not contain a mechanism that terminates attentional episodes. Instead, this hypothesis suggests that attentional amplification, on its own, has detrimental effects on target identification. According to this theory, when T_1 is detected,

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attentional mechanisms enhance the processing of any trailing stimuli, both targets and distractors. This introduces a substantial amount of competition among different stimuli. Notably, the facilitated processing of distractors interferes with the identification of trailing targets, resulting in an AB.

The notion that the AB is brought about by overinvestment of resources is in line with several electrophysiological studies (e.g., Keil and Heim, 2009; MacLean and Arnell, 2011; Petro and Keil, 2015; Wierda et al., 2010). For instance, Petro and Keil (2015) examined the neural correlates of the AB by comparing pretarget amplitude and phase measures of alpha oscillations as well as the ssVEP evoked by the RSVP stream of trials in which T_2 was correctly identified (no AB) to trials in which T_2 was not identified (AB trials). They found that on trials with incorrect T_2 report intertrial ssVEP phase locking was heightened immediately prior to T_1 onset. Given that a more consistent ssVEP phase across trials was linked to increased selective attention (Ding et al., 2006; Porcu et al., 2013), this is in line with the idea of overinvestment of attentional resources. Additionally, Petro and Keil found reduced alpha activity prior to T_1 on T_2-incorrect trials. The authors suggested that high alpha is related to lower levels of external attention control, and therefore the observed reduced alpha activity on AB trials is also consistent with the overinvestment account of the AB.

Evidently, there is much more agreement regarding the mechanisms that initiate attentional episodes than there is regarding the mechanisms that underlie termination of those episodes. The extant theories assign different roles to the processing of distractors. Distractors contribute to the AB by virtue of their inhibition (Olivers and Meeter, 2008; Raymond et al., 1992), enhancement (Olivers and Nieuwenhuis, 2005, 2006), or simply because they provide temporal separation between T_1 and trailing targets (Wyble et al., 2009, 2011). Studies that employ manipulations that alter the processing of distractors are instrumental in distinguishing between those different accounts. In dual-task studies, attentional amplification of distractors (and targets) is attenuated by the introduction of a concurrent, attention-demanding, task (e.g., Olivers and Nieuwenhuis, 2005, 2006; Wierda et al., 2010). In addition, procedures that omit distractors from the RSVP could be used to examine the involvement of distractor processing in AB phenomena (Nieuwenstein et al., 2009a,b).

3.1 DUAL TASK

Many AB accounts suggest that targets are missed when they are deprived of attentional resources (e.g., Chun and Potter, 1995; Wyble et al., 2009). This widespread belief is challenged by findings from dual-task studies, in which target identification was enhanced when a concurrent task accompanied the standard AB procedure (e.g., Arend et al., 2006; Olivers and Nieuwenhuis, 2005, 2006). For example, the usual lag-dependent deficits in target identification were substantially reduced when participants were administered a free association task or when they were asked to listen to music while they completed the AB procedure (Olivers and Nieuwenhuis, 2005).

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Similar findings emerged when a working memory task was administered alongside the AB streams (Olivers and Nieuwenhuis, 2006). Assuming that the concurrent tasks tax attentional mechanisms, the dual-task results seem to refute the notion that targets are missed due to diminished attentional resources. Indeed, the overinvestment hypothesis, which associates AB phenomena with attentional amplification of distractors rather than diminished amplification of targets, was formulated in light of those results (Olivers and Nieuwenhuis, 2006). According to this account, the employed secondary tasks decrease the attentional reaction that T_1 prompts. As a result, the processing of subsequent distractors is not amplified considerably, attenuating the interference to T_2 processing.

This account was substantiated in a dual-task study that measured EEG concurrently with standard behavioral measurements (Wierda et al., 2010). On the single-task condition the participants had to perform a typical AB task and ignore an irrelevant dot that moved in the periphery, whereas on the dual-task condition they also had to detect brief color changes of the moving dot. As expected, the behavioral AB was smaller on the dual-task than on the single-task condition. As for the electrophysiological measurements, distractor related activity measured at occipital regions was significantly lower in the dual-task than in the single-task condition, supporting the overinvestment hypothesis. Interestingly, the amplitude of the P3 component, elicited by T_2, was reduced in the dual-task condition. A possible interpretation of this reduction suggests that the magnitude of inhibitory reactions that accompany amplified processing of distractors was attenuated in the dual-task condition (Wierda et al., 2010).

3.2 OMITTED DISTRACTORS

Experiments in which the distractor that succeeds T_1 was omitted from the streams led to divergent results and conclusions. Early studies observed a marked reduction in the magnitude of the AB (Chun and Potter, 1995; Raymond et al., 1992). Those results motivated theoretical accounts, suggesting that the appearance of this distractor interferes with the processing of T_1 and elicits an inhibitory reaction (e.g., Olivers and Meeter, 2008; Raymond et al., 1992). However, if the AB is primarily elicited by this inhibitory response, then it should be completely eliminated when all the distractors that separate T_1 and T_2 are omitted. Recent studies refute this possibility (Nieuwenstein et al., 2009a,b). For instance, when Nieuwenstein et al. (2009a) limited the presentation duration of T_2 to 58 ms, a typical AB emerged even when the distractors that intervene between T_1 and T_2 were replaced with a blank screen. These results suggest that the processing of distractors and related inhibitory reactions are not necessary for an AB to occur (inhibitory reactions may still contribute to the magnitude of the AB). The results are compatible with theoretical accounts that associate the termination of attentional episodes with the processing of targets (e.g., Wyble et al., 2009, 2011).

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4 SUMMARY AND CONCLUSIONS

The AB paradigm is extensively employed in order to study the mechanisms that guide and constrain the deployment of attention to different points in time (e.g., Chun and Potter, 1995; Olivers and Meeter, 2008; Raymond et al., 1992; Wyble et al., 2009). The efficiency of temporal attention mechanisms is determined by the temporal structure of upcoming stimuli, the ability to prepare for this structure beforehand, and the capacity to react in a timely and accurate manner as those stimuli appear. The AB procedure allows one to examine each of those aspects on its own as well as their possible interactions.

4.1 TEMPORAL EPISODES AND THE AB

A wide range of experimental findings from the AB literature substantiate an episodic account of performance in this task (e.g., Snir and Yeshurun, 2017; Wyble et al., 2009). According to this account, targets are identified when attention is deployed to a temporal episode that includes them. Within an episode, features of different stimuli are processed in parallel, inducing a high degree of competition and interference. As a result, temporal episodes enable the combined identification of multiple target features, but they also hinder the individuation of distinct stimuli. Empirically, this state of affairs is expressed in binding errors, order reversals, and the T_1 deficits that accompany sparing effects. The vast majority of AB studies adopt an attentional account of these episodes (e.g., Olivers and Meeter, 2008; Shih, 2008; Wyble et al., 2009). According to this position, attentional mechanisms amplify the processing of several stimuli that appear within a limited interval. An alternative account, proposed by Snir and Yeshurun (2017), suggests that temporal episodes could be construed as perceptual, rather than attentional. This position claims that the rapid presentation rates that characterize RSVPs induce the formation of grouped representations regardless of attentional amplification (cf. Akyürek and Hommel, 2005). Attentional mechanisms can select one of those grouped episodes for more thorough processing that enables individuation of separate stimuli.

Evidently, the attentional and perceptual accounts describe the contribution of attentional deployment to the grouping and individuation of stimuli in almost opposite terms. The attentional account argues that attention intensifies combined processing and diminishes individuation, whereas the perceptual account argues that attention intensifies individuation of otherwise grouped representations. Thus, the most natural way to contrast and compare these accounts involves experimental procedures that examine grouping and individuation under different levels of attentional engagement. To this end, procedures that enable meaningful report of both discrete and configural information would be very instrumental. In the commonly employed AB procedures, the combined processing of several stimuli is expressed either in invalid reports (e.g., binding errors, order reversals, etc.) or in reports of discrete information from temporally adjacent stimuli (i.e., sparing effects). We are not familiar with procedures that enable valid reports of configural information. Such a procedure may require, for instance, identification of an oddball target whose distinctiveness stems from its neighboring targets.

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Regardless of the specific manner in which temporal episodes are construed, most theories assume, implicitly or explicitly, that the deployment of attention in a goal-directed manner to pertinent temporal episodes is guided by cognitive control mechanisms (e.g., Shih, 2008; Taatgen et al., 2009). Two distinct forms of control should be considered when performance in the AB is examined: proactive and reactive (Braver, 2012; Braver et al., 2009). Proactive control refers to the maintenance of goal-relevant information that precedes stimulus presentation and biases perception and attention in accordance with behavioral goals. Those goals are also pursued using reactive control processes, which regulate the perceptual and attentional reactions to presented stimuli. Together, cognitive control mechanisms regulate the initiation, duration, and termination of temporal episodes. However, it is plausible to assume that proactive and reactive mechanisms are differentially involved in different facets of temporal episodes. Proactive processes, which guide the differentiation of targets from distractors, have a large influence on the detection of T_1 and the initiation of episodes. In contrast, the termination of episodes is strongly influenced by the stimuli that succeed T_1 and the controlled reactions that they prompt (cf. Snir and Yeshurun, 2017 assign an important role in episode termination to proactive control). Even though proactive control mechanisms were addressed in a few AB theories (Di Lollo et al., 2005; Snir and Yeshurun, 2017), most theories pay little attention to these processes (e.g., Olivers and Meeter, 2008; Shih, 2008; Wyble et al., 2009). Arguably, this theoretical asymmetry explains why there is relatively little debate regarding the mechanisms that initiate temporal episodes and little agreement regarding the mechanisms that terminate those episodes.

The involvement of proactive control mechanisms in participants' performance could be examined using manipulations of the presented stimuli (e.g., target–distractor similarity). However, these manipulations could also affect reactive mechanisms and processes that follow the attentional amplification of targets. Plausibly, the clearest manifestation of proactive mechanisms is implicated in contextual manipulations that alter the probable characteristics of targets in an experimental block (e.g., the proportion of three-target vs two-target streams; Visser, 2015). Using those procedures, performance in the exact same streams, but with different proactive expectations, could be compared. For instance, manipulations of the target set size may alter the initiation of temporal episodes. Suppose that a participant is asked to identify letters from the target set {A, S, D, F} in one block and from the target set {A, S, D, F, G, H, J, K} in another block. In the latter block, the proactive task is much more difficult and relatively late initiations of temporal episodes could be expected in this condition. As a result, sparing effects may be prolonged in this condition (according to some theoretical accounts, e.g., Wyble et al., 2009).

4.2 TEMPORAL EPISODES BEYOND THE AB

Construing the temporal episode that is evident in the AB procedure as perceptual rather than attentional (Snir and Yeshurun, 2017) may facilitate future synthesis between AB accounts and other phenomena that are typically associated with temporally extended perceptual processes. Specifically, the idea of an extended perceptual episode that encompasses several items is consistent with various findings, demonstrating

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perceptual effects that last for a relatively long duration (~400 ms). For example, the phenomenon of temporal crowding, much like the AB paradigm, involves a presentation of a stream of items at the same location. However, the participants are asked to identify only a single target (Bonneh et al., 2007; Tkacz-Domb and Yeshurun, 2017; Yeshurun et al., 2015). The magnitude of crowding is determined by the interitem intervals, whereby shorter intervals lead to stronger crowding. Akin to AB phenomena, evidence of temporal crowding was found with relatively long intervals (at least 400 ms; Tkacz-Domb and Yeshurun, 2017). Feature fusion is another relevant perceptual phenomenon. In one demonstration of feature fusion a Vernier stimulus (i.e., a pair of vertical bars separated by a horizontal offset to the left or right) and an anti-Vernier stimulus (a Vernier with an opposite offset) are presented in rapid succession at the same location. Due to the rapid presentation, the two Verniers are not perceived individually. Instead, one fused Vernier whose offset is influenced by the two presented offsets is experienced (e.g., Herzog et al., 2003). Interestingly, Scharnowski et al. (2009) have shown that applying transcranial magnetic stimulation over the occipital cortex up to 400 ms after the presentation of the Verniers can determine the perceived offset direction of the fused Vernier. This finding suggests that the processes responsible for stimuli integration were not completed beforehand, and that conscious percept of the fused stimulus occurred 400 ms after stimulus presentation. Another relevant perceptual phenomenon is implicated in the sequential metacontrast paradigm (e.g., Otto et al., 2006). This procedure starts with a central Vernier with a horizontal offset, followed by two flanking streams of aligned Verniers (Verniers without a horizontal offset). Under these conditions, the participants do not consciously perceive the central Vernier but they manage to perceive its offset direction. When another offset is introduced in one of the flanking streams, and attention is directed to that stream, the two offsets are integrated, even when they are presented 400 ms apart (Otto et al., 2009), suggesting that the window of temporal integration could be extended considerably.

Taken together, these different procedures reveal perceptual processes that extend over a relatively long duration. Similar processes may also take part in the AB procedure, and it may prove helpful to consider a combined account of all different phenomena—those that were traditionally viewed as perceptual and those that were traditionally viewed as attentional.

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