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# A fixed-links modeling approach to assess individual differences in the attentional blink: Analysis of behavioral and psychophysiological data

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ABSTRACT

The attentional blink (AB) is a fundamental limitation of the ability to select relevant information from irrelevant information. It can be observed with the detection rate in an AB task as well as with the corresponding P300 amplitude of the event-related potential. In previous research, however, correlations between these two levels of observation were weak and rather inconsistent. A possible explanation of this finding might be that multiple processes underlie the AB and, thus, obscure a possible relationship between AB-related detection rate and the corresponding P300 amplitude. The present study investigated this assumption by applying a fixed-links modeling approach to represent behavioral individual differences in the AB as a latent variable. Concurrently, this approach enabled us to control for additional sources of variance in AB performance by deriving two additional latent variables. The correlation between the latent variable reflecting behavioral individual differences in AB magnitude and a corresponding latent variable derived from the P300 amplitude was high ($r = .70$). Furthermore, this correlation was considerably stronger than the correlations of other behavioral measures of the AB magnitude with their psychophysiological counterparts (all $rs < .40$). Our findings clearly indicate that the systematic disentangling of various sources of variance by utilizing the fixed-links modeling approach is a promising tool to investigate behavioral individual differences in the AB and possible psychophysiological correlates of these individual differences.



## 1. Introduction

The attentional blink (AB) phenomenon refers to the impaired detection of the second of two targets within a rapid serial visual presentation (RSVP) stream of stimuli (Raymond, Shapiro, & Arnell, 1992). In a typical AB task, the second target (T2) is presented at varying time lags (referred to as lag conditions) after the first target (T1). While individuals typically show high detection rates for T1 in all lag conditions, they often miss T2 when it is presented about 150 to 350 ms after T1. Given that each stimulus in the stream is presented for about 100 ms, impaired T2 detection is observed when T2 is presented at the second (Lag 2; i.e., 200 ms after T1) or third (Lag 3; i.e., 300 ms after T1) position after T1. However, if T2 is presented at later lags, it can be correctly identified. Also if T2 is presented directly after T1 (i.e., at Lag 1), unimpaired T2 detection has frequently been reported. This effect is known as Lag-1 sparing (Dell' Acqua, Jolicoeur, Pascali, & Pluchino, 2007). Thus, the AB phenomenon reflects a fundamental limitation in the cognitive selection of relevant information among irrelevant, distracting information for a certain period of time (Marois & Ivanoff, 2005).

In their review of the large body of AB theories and empirical findings, Dux and Marois (2009) concluded that the AB results from multiple processes and proposed an integral explanation for its occurrence. They assumed that all stimuli in the RSVP stream are processed perceptually and semantically. Based on an attentional set given by the task instructions, targets are detected and distractors are inhibited. When a target is detected in the stream, an attentional episode is triggered which leads to an enhancement of the target representation as well as the representation of the stimulus directly following the target. These stimuli compete for access to higher stages of processing. Because T1 is presented earlier and is more relevant for the task than the subsequently presented distractors, it will gather the attentional resources for consolidation in working memory (WM). As attentional resources are now bound to the WM consolidation of T1, stimuli presented during the AB period cannot be attentionally enhanced. Hence, if T2 is presented shortly after T1 (at Lag 2 or Lag 3), its mental representation is prone to rapid decay and backward masking so that its likelihood of being reported is lowered. If T2 directly follows T1, however, T1 and T2 enter the same attentional episode and both targets are processed simultaneously, allowing for both T1 and T2 to be identified which results in Lag-1 sparing. In the case that T2 is presented at a time at which T1 processing has been completed, its mental representation

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can gather the necessary attentional resources for WM consolidation and be processed successfully. Thus, the T2 detection rate is unimpaired in later lag conditions such as the Lag 4 or Lag 5 condition.

Converging evidence for Dux and Marois (2009) notion of more processes than only one to be involved in the AB was provided by Troche, Schweizer, and Rammsayer (2009). These authors used fixed-links modeling to disentangle the processes underlying the AB. Fixed-links models are a variant of structural equation models (SEM) for repeated-measures designs (Schweizer, 2008, 2009). They differ from standard SEM in that the factor loadings are not estimated but fixed according to theory-based assumptions, whereas the variances of the latent variables are freely estimated. If the variances of the latent variables are statistically significant and if the model fit is acceptable, these variables are meaningful for the task performance under investigation and the model represents the data adequately. Using the fixed-links modeling approach, Troche et al. (2009) identified a latent variable in an AB paradigm with a series of factor loadings following an inverted u-shaped course across the five lag conditions depicting individual differences in the typical time course of the AB effect. Thus, factor loadings for the Lag 1 and Lag 5 conditions were small, while factor loadings were larger for the Lag 2 and Lag 4 conditions and the largest factor loading characterized the Lag 3 condition. For brevity, this latent variable is henceforth referred to as *inverted u-shaped latent variable*. Because this latent variable was based on the T2 detection rate, large individual factor scores on this latent variable indicated a small AB magnitude, while low individual factor scores indicated a strong AB.

Importantly, the inverted u-shaped latent variable was not sufficient to describe the experimental data reported by Troche et al. (2009) completely. Rather, two further latent variables were necessary for a full description. The factor loadings of one of these two additional latent variables increased, whereas the factor loadings of the other latent variable decreased from the Lag 1 to the Lag 5 condition. Therefore, these latent variables were referred to as *increasing* and *decreasing latent variables*, respectively. As a preliminary explanation, Troche et al. (2009) suggested that availability of processing resources accounted for the increasing process and interference effects for the decreasing process. More specifically, with ongoing processing of T1, attentional resources should become more and more available for the processing of T2. This should result in a monotonously increasing improvement of T2 detection rate. At the same time, however, the increasing number of distractors proceeding T2 may enhance interference and, thus, decrease the T2 detection rate from the Lag 1 to the Lag 5 condition. Although the very meaning of the two additional latent variables requires further investigation, their existence underlines that the AB is not a unitary process but composed of different and quite independent processes. In sum, fixed-links modeling facilitates the measurement of the AB magnitude as a latent variable with an inverted u-shaped course of factor loadings. Individual differences in the magnitude of the specific performance decrement during the critical AB period are described by this latent variable. Concurrently, additional processes can be distinguished from this inverted u-shaped latent variable in terms of two additional latent variables and statistically controlled for.

For studies on the correlational relationship between the AB and any other variable of interest, such a compound of processes underlying the AB can lead to severe problems of interpretation. If, for instance, no significant correlation is observed, it may be concluded that the variable of interest is not related to the processes underlying the AB. The same result, however, could also mean that the variable of interest is functionally related to one AB process, but that this relation is masked or diminished by the effect of another process that is not associated with the variable of interest but involved in the AB. On the contrary, when a significant correlation between the AB and a given variable of interest could be established, it is not clear which of the underlying AB-related processes accounts for this relationship. Hence, the involved processes have to be disentangled to enable an unambiguous interpretation of correlational results.

Common measures of the AB used in correlational studies are the mean T2 detection rate across all lag conditions (e.g., Klein, Arend, Beauducel, & Shapiro, 2011) or difference scores between the minimal T2 detection rate (usually at Lag 2 or Lag 3) and the T2 detection rate in a late lag condition (e.g., Lag 5 or later; Colzato, Spapé, Pannebakker, & Hommel, 2007). Both these measures do not separate the different processes underlying the AB hampering the interpretation of correlational results. This might also be the reason why previous research could not establish a reliable correlational relationship between the behavioral AB as measured by the T2 detection rate and the AB at the psychophysiological level as measured by the T2-related P300 amplitude in the event-related potential (ERP; Vogel, Luck, & Shapiro, 1998).

The P300 component is a pronounced wave with its amplitude between 300 and 600 ms after the presentation of an attended stimulus (Polich, 2007) and is considered a major index of working memory consolidation (e.g., Donchin & Coles, 1988; Polich, 2012). Vogel et al. (1998) observed a distinct P300 amplitude when T2 was presented immediately or about 600 ms after T1, but a markedly smaller P300 amplitude when T2 was presented about 250 ms after T1 (i.e., during the time window of the AB). These authors, therefore, concluded that the absence of the P300 component indicated a failure to consolidate T2 in WM during the AB period which, in turn, led to the inability to report T2 properly. The finding that impaired T2 detection at the behavioral level is accompanied by a decreased P300 amplitude at the psychophysiological level shows the robustness of the AB across different levels of observation and has been confirmed by several subsequent studies (e.g., Dell' Acqua, Jolicoeur, Pesciarelli, Job, & Palomba, 2003; Kranczioch, Debener, & Engel, 2003; McArthur, Budd, & Michie, 1999). Thus, the AB is not only reflected by a decrease in the T2-related hit rate but also by a decrease in the T2-related P300 amplitude during the time window of the AB.

Nevertheless, despite the well-established parallelism of the T2 detection rate and T2-related P300 amplitude across the lag conditions of an AB task, correlational analyses by McArthur et al. (1999) showed a rather weak and inconsistent association between T2 detection rate and T2-related P300 amplitude. McArthur et al. (1999) presented the AB task twice: In one condition, participants had to identify T1 and to detect T2 while, in the second condition, participants should ignore T1 but detect T2. An AB was observed when both targets were attended to, but not when the first target should be ignored. As a measure of the AB magnitude, for each participant the detection rate of T2 following T1 at Lags 2, 3, and 4 was averaged in both conditions. In a next step, the mean T2 detection rate in the condition with two targets to be identified was subtracted from the mean T2 detection rate in the condition where only T2 had to be attended to. Analogous difference scores were computed for the P300 amplitude. In the first experiment, the correlation between T2 detection rate and P300 amplitude was $r = -.59$, but only $r = .04$ and $r = -.33$ in a second experiment. Therefore, the authors concluded, that "it seems unlikely that there is any consistent relationship between the magnitude of the AB and P300 at the individual level" (McArthur et al., 1999, p. 3694).

Given that the T2-related P300 amplitude represents the consolidation of T2 in WM, the parallel time course of T2 detection rate and T2-related P300 amplitude might suggest that the consolidation of T2 in WM is a necessary but not sufficient condition to correctly report T2. For example, processes associated with interference in WM might lead to a failure to correctly report T2 although its mental representation has been successfully consolidated in WM. In this case, McArthur et al.'s (1999) conclusion might be correct that there is no consistent (correlational) relationship between AB measures obtained at the behavioral and at the psychophysiological level, respectively. It should be noted, however, that difference scores as computed by McArthur et al. (1999) do not separate the multiple processes apparently underlying the AB (Dux & Marois, 2009; Troche et al., 2009). Thus, it is possible that an existing relationship between the behavioral and the psychophysiological AB measures is masked and cannot be identified. From