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The relationship between attentional blink and psychometric intelligence: A fixed-links model approach

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Abstract

Attentional blink (AB) denotes the impairment in identifying a target when this target follows a preceding target after about 150 to 500 msec. Several models explain AB and some studies suggest that more processes than only one are involved in AB. Therefore, confounding effects of these underlying processes might be the reason why previous studies could not observe a relationship between AB and psychometric intelligence. In the present study, fixed-links models were used to disentangle the processes underlying the performance of 66 female and 52 male volunteers on an AB task. In accordance with theoretical explanations of AB, three latent variables with loadings describing a linearly increasing, a linearly decreasing and a u-shaped trend described the data well. Psychometric intelligence was related to the latent variables reflected by the u-shaped ($\beta = .30$; $p < .05$) and the linearly increasing trends ($\beta = .23$; $p < .05$) but not to the latent variable reflected by the linearly decreasing trend ($\beta = .10$; *n.s.*). These results support the assumptions that more processes than only one are involved in AB. Decomposition of the underlying processes seems to be promising to investigate intelligence-related individual differences on this early level of information processing.

Key words: attentional blink; intelligence; fixed-links models

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Introduction

The relationship between psychometric intelligence and attention has been widely investigated. Various types of attention were reported to predict psychometric intelligence. Rather consistent are the findings that sustained attention (Crawford, 1991; Schweizer, Zimmermann, & Koch, 2000; Stankov, Roberts, & Spilsbury, 1994) and attention control (see Kane & Engle, 2003; Unsworth, Spillers, & Brewer, this issue) are important mechanisms underlying intelligence. On the contrary, the association between intelligence and other aspects of attention, such as attentional switching (Rockstroh & Schweizer, 2001; Stankov, 1988a) or divided attention (Lansman & Hunt, 1982; Roberts, Beh, Spilsbury, & Stankov, 1991; Stankov, 1988b, 1989) is much more unclear. A more comprehensive overview of the relationships between different types of attention and psychometric intelligence is provided by Schweizer, Moosbrugger, and Goldhammer (2005).

An attentional process which has been hardly investigated regarding its relationship to psychometric intelligence is the attentional blink (AB). This phenomenon is normally investigated by means of the *rapid serial visual presentation* (RSVP) paradigm where a stream of about 14 to 20 stimuli is presented consisting of two targets and a number of distractor stimuli with a presentation rate of about 10 per second. AB refers to the impaired identification of the second target (T2) within the stream of stimuli, when the first target (T1) is correctly identified and T2 is presented about 150 to 500 msec after T1, i.e. on the second to fourth positions (*Lags* 2 to 4) after T1. It has been observed many times that T2 can be properly identified when it immediately follows T1 (that is, T2 is presented on Lag 1). This phenomenon is often referred to as *lag-1 sparing* (Visser, Bischof, & Di Lollo, 1999). Also when T2 is presented on Lag 5 or later, both targets can be correctly identified. Thus, performance on T2 identification can be described as a u-shaped curve with good performance when T2 is presented on Lags 1 or 5 or later, and impaired performance when T2 is presented on Lags 2, 3, or 4. Given the above mentioned studies on the relationships of different types of attentional processes and psychometric intelligence, it is rather surprising that previous studies on the relationship between AB and psychometric intelligence could not find a reliable association between the two constructs (Colzato, Spapé, Pannebakker, & Hommel, 2007; Martens & Johnson, 2009).

AB seems to reflect a fundamental limitation of information processing (Marois & Ivanoff, 2005). Individual differences in this limitation may lead to individual differences in the performance level also on higher-order cognitive tasks, such as tasks of intelligence tests so that, theoretically, a relationship between AB and psychometric intelligence should be expected. However, neither Colzato et al. (2007) nor Martens and Johnson (2009) found a relation between the magnitude of AB and psychometric intelligence. In both studies, individuals with high psychometric intelligence performed generally better on the AB task compared to individuals with low psychometric intelligence, irrespective of the lag on which T2 was presented. The magnitude of AB, however, did not differ between individuals with low and high psychometric intelligence. In the following paragraphs a detailed consideration of the theoretical accounts of AB may contribute to a better understanding of these findings reporting the absence of a relation between AB and psychometric intelligence.

The first approach to explain AB was proposed by Raymond, Shapiro, and Arnell (1992). These authors assumed that features of T1, which indicate that the stimulus is a target, start an attentional process to fully identify the stimulus as a target. Since the stimulus immediately following T1 is presented before identification of T1 has been completed, the features of this stimulus are processed along with features of T1. When the stimulus following T1 is a distractor, the attentional process is confused by the fact that there are features concurrently indicating a target *and* a distractor requiring different responses. In order to cope with this confusion, a suppressive mechanism becomes activated which prevents processing of new stimuli for a certain period of time. Therefore, a second target cannot be identified when it is presented on one of the lags following Lag 1 while the suppressive mechanism is in operation.

An alternative account of AB is represented by the interference model (e.g., Isaak, Shapiro, & Martin, 1999; Shapiro, Raymond, & Arnell, 1994) which suggests that the stimuli of the RSVP stream are compared with internal templates of target features. Presentation of T1 leads to a match with its internal template so that its mental representation captures the limited resources for further processing for about the next 500 msec until the mental representation is consolidated in a more durable memory. In case that during this time interval T2 is presented, the mental representation of T2 competes for the limited processing resources with the mental representation of T1. Since T1 has already captured these resources, T2 cannot be processed properly and identification of T2 is impaired leading to the AB phenomenon. Furthermore, not only the two targets but also the distractor stimuli are assumed to compete with the target stimuli for the limited processing resources. In line with this assumption, Isaak et al. (1999) showed that AB is influenced by the number of competitive stimuli.

A further explanation of AB is the two-stage model by Chun and Potter (1995). According to this model, all stimuli of the stream are processed at a first stage so that potential targets can be detected by analyzing features which define the targets among the distractors, such as brightness, color, or even categorical identity. At this stage, stimulus representation is prone to rapid decay unless an attentional mechanism actively selects and enhances processing of a potential target. This attentional selection induces stimulus processing at a second stage where it is fully identified and consolidated in a more durable memory storage. Resources of the second stage are assumed to be limited so that the next stimulus can only be processed when processing of the preceding stimulus is completed. When T2 is presented before sufficient resources are available at Stage 2, T2 can only be processed at Stage 1 but not transferred to Stage 2. This results in an increased probability that the representation will decay before getting access to Stage 2 leading to the AB phenomenon.

More recently, Di Lollo, Kawahara, Ghorashi, and Enns (2005) reported that no AB was observed when T1 was followed by two further targets (three-target condition). In their paradigm, participants identified the third target with the same accuracy as the first target. In case, however, that the stimulus immediately following T1 was not a target but a distractor, performance of identifying T2 decreased substantially, although T2 was presented on the very same position as the third target in the three target condition. Proceeding from these findings, Di Lollo et al. (2005) put forward the idea that AB is caused by a temporary loss of control (TLC) of the central executive. More specifically, the TLC account suggests that an attentional set is endogenously established to accept targets and to reject distractors. The identification of a presented target requires resources of the central executive so that these resources are no longer available to maintain the attentional set. As long as a second (or even a third) target is presented after T1, the attenuated attentional set does not lead to problems because these targets will be correctly identified. If T1 is followed by a distractor, however, the attentional set is disrupted and changed exogenously so that further targets following the distractor cannot be identified correctly and, thus, become rejected. As soon as processing of T1 is completed, resources of the central executive are available to re-establish the attentional set so that targets can be properly identified again.

Similar to the TLC account, Olivers, van der Stigchel, and Hulleman (2007) proposed an attentional set to be responsible for AB. Unlike Di Lollo et al. (2005), Olivers et al. (2007) assume that the attentional set is not affected by the distractors. The attentional set leads to the acceptance of T1 as a target. This makes the attentional set more generous so that the next stimulus also has a high probability to be selected as a target. In case that the stimulus following T1 is a target, it can be identified correctly. However, if the stimulus following T1 is a distractor, it is also selected as a target but by mistake. As a consequence, the attentional set will be modified to select more strictly so that even following targets have a lower probability to be accepted. Thus, instead of a loss of control, Olivers et al. (2007) propose that the control is just temporarily tightened.

The above mentioned theoretical models emphasize different aspects of the RSVP paradigm to be responsible for AB. On one hand, in the models of Raymond et al. (1992), the TLC model as well as its modification by Olivers et al. (2007), the distractor stimuli lead to a change in the mode of processing which, in turn, leads to AB. Chun and Potter (1995), on the other hand, point to the significance of T1 processing and limited resources to explain the impaired processing of T2. Finally, the interference model (e.g., Isaak et al., 1999) emphasizes the number of stimuli – rather independent of whether the stimuli are distractors or targets. Because empirical evidence exists for all these models, it is not surprising that several researchers conclude that probably more processes than only one underlie AB. For example, Vogel, Luck, and Shapiro (1998) suggested a hybrid model that incorporates both the interference model and the two-stage model. The results of Kawahara, Enns, and Di Lollo (2006) give evidence for the notion that primarily TLC and bottleneck models (as for example the two-stage model) account for AB. Eventually, Visser et al. (1999) found no relationship between magnitude of lag-1 sparing and magnitude of AB. This, again, indicates that different mechanisms may be involved in the AB phenomenon.

To sum up, there is no decisive evidence against one of these models so far. Rather, there is increasing evidence for the notion that more processes than only one are involved in AB so that it would be highly interesting to disentangle these processes. Most recently, Schweizer (2008, 2009) proposed fixed-links models as a method to decompose several processes underlying the performance in a repeated measures design. Fixed-links models belong to the family of structural equation models. The main difference between standard structural equation models and fixed-links models is that the matrix of factor loadings is not estimated but fixed in fixed-links models, whereas the variances of the latent variables are free. Due to the fixing of loadings, the model needs theory driven constraints to define the loadings. For a typical AB task, for example, it could be assumed that a latent variable has the strongest impact on the identification of T2 on Lag 3 where AB is most strongly pronounced. When T2 is presented on earlier or later lags the impact of this latent variable is smaller. Under these conditions, the factor loadings reflecting performance on T2 could be described by a u-shaped function. The assumption of such a latent variable would be most consistent with the TLC model or its modification by Olivers et al. (2007) as here an attentional set is assumed, which is initially well established, but then disturbed or modified for a certain time before it is re-established at a later point in time.

The theoretical outcome predicted by the two-stage model (Chun & Potter, 1995) should rather be a linearly increasing function. That is, at the beginning of T1 processing, more resources are required which are not available for T2 processing. However, the better T1 is consolidated in the more durable storage the more available are resources of Stage 2 to process T2. According to the two-stage model, this process could be better described as a linearly increasing rather than a u-shaped function (for a similar idea see Visser et al., 1999). Finally, the interference model (Isaak et al., 1999; Shapiro et al., 1994) assumes that the interference effect becomes more pronounced with an increasing number of stimuli competing for processing resources. Also distractor stimuli compete for processing resources so that performance of T2 identification on the five lags is described by a linearly decreasing rather than by a u-shaped function.

Proceeding from these considerations, a first goal of the present study was to further elucidate the processes underlying the AB phenomenon by means of fixed-links models. Since this is the first study using fixed-links models to investigate AB and it is widely unknown how many and what kind of processes underlie the AB phenomenon, seven potential models will be introduced and tested against each other. A first model proceeded from the assumption that performance on T2 identification can be described by a u-shaped function of the factor loadings. Models 2 and 3 assume a linearly increasing or a linearly decreasing function of factor loadings, respectively. Models 4 and 5 combine the u-shaped function with a linearly increasing or decreasing function, respectively. Model 6 represents a combination of the linearly decreasing and the linearly increasing functions, whereas Model 7 proceeds from the assumption that all three functions of factor loadings explain the pattern of results.

If more processes than only one are involved in AB, it is conceivable that these processes could have been confounded in previous studies. This might have attenuated the relation to psychometric intelligence. To test this hypothesis, a second goal of the present study was to investigate whether psychometric intelligence is related to latent variables identified by utilizing the fixed-links model approach.

Methods

Participants

Participants were 52 males and 66 females (112 undergraduate students enrolled in introductory psychology courses at the University of Göttingen and 6 vocational school students). They ranged in age from 19 to 32 years (mean ± standard deviation: 22.3 ± 2.7 years). All participants had normal or corrected-to-normal vision. For taking part in the study, they received course credits or were paid.

Measurement of psychometric intelligence

Psychometric intelligence was assessed by the short version of the Berliner Intelligenz-Struktur (BIS) test (Jäger, Süß, & Beauducel, 1997). BIS is based on a hierarchical model classifying cognitive abilities with regard to type of mental operation as well as type of content. Four operations (Capacity, Speed, Memory, Creativity) and three contents (Verbal, Numerical, Figural) are differentiated within the BIS model. The combinations of four operations and three contents result in twelve abilities (e.g., Numerical Capacity, Verbal Speed, etc.). At the top of the hierarchy, operation- and content-related abilities are subsumed to a general factor of intelligence. More detailed information about the BIS model is provided by Bucik and Neubauer (1996) or Süß, Oberauer, Wittmann, Wilhelm, and Schulze (2002).

The short version of BIS is composed of six subscales which measure capacity with two verbal, two numerical, and two figural subtests. Speed, memory, and creativity were measured with one verbal, one numerical, and one figural test, each. To obtain a measure of general psychometric intelligence, individual subtest scores were normalized and averaged across the 15 subtests.

Attentional Blink (AB) task

Apparatus and stimuli. The AB task was programmed with E-prime 1.1 software. For recording the participants′ responses, a response panel with five response keys was connected to a computer. Stimuli were the letters of the alphabet except for F, I, K, Q, and Z. They were presented in Arial font and were 3 cm high and about 2 cm wide. They were presented in the center of a 19" monitor screen (ViewSonic VX924) at a viewing distance of approximately 1 m. The stimuli were white on a black background. Only the first target (T1) was presented in yellow (RGB as preset by E-prime).

Procedure. The task included one experimental and one control condition. Both conditions consisted of 80 trials each. Each trial began with a fixation cross presented for 1,000 ms in the center of the monitor screen. Then the RSVP stream started comprising 15 stimuli which were presented for 100 ms each without interstimulus interval. No letter was used more than once within a stream. T1 was presented on the third or eighth positions in half of the trials, respectively. T2 was the letter X which was presented on 60 out of the 80 trials. If T2 was presented, it could occur on Lag 1, Lag 2, Lag 3, Lag 4, or Lag 5. Thus, T2 occurred 12 times on each of the five lags. Positions of T1 and T2 were randomized across trials.

In the experimental condition, at the end of the RSVP stream, participants were required to indicate whether the yellow letter (i.e., T1) was a vowel or a consonant and to press one of two designated keys on the response panel. Immediately after the response to this first question, participants were asked whether an "X" was presented or not. If they had seen an "X", participants should press the outer left button, otherwise the outer right button. In the control condition, the same set of RSVP streams was presented but participants were just asked to decide whether an "X" was presented or not. After the response on T2, a black display was presented for 1,000 or 1,250 ms, randomly chosen, before the next trial was started.

Written and verbal instructions which described the upcoming task as well as ten practice trials preceded the control and experimental conditions. The order of the two conditions was counterbalanced across participants. It took about 20 minutes to complete both conditions. Participants were tested with the AB task one week after the assessment of psychometric intelligence. Immediately before the AB task, participants worked on another task of about 15 minutes duration which is not reported here. For fixed-links modeling, Muthén and Muthén′s (2005) Mplus software was used, and the maximum likelihood method was selected for parameter estimation.

Results

Percentages of correct responses on T2 are given in Table 1. Note that for the experimental condition, percentages of correct responses on T2 are reported under the condition that T1 was correctly identified to rule out that strategic differences had been applied on the task. As can be seen from Figure 1, a marked AB was observed with the present task.

Results of correlational analyses of performance on the five lags in the two conditions of the AB task as well as intelligence scores can be seen from Table 2. Within each condition performance on the five lags was significantly correlated. Also between the conditions, performance on all lags was significantly correlated with the exception of performances on Lag 1 in the experimental condition and performance on Lags 2 and 5 in the control condition. Psychometric intelligence was positively related to performances on all lags in the experimental but also in the control condition. Only performance on Lag 1 in the experimental condition was not significantly related to psychometric intelligence. In both conditions, the correlation between performances on Lag 3 and psychometric intelligence was significantly larger than the correlation between performance on Lag 1 and psychometric intelligence (both *p*s $< .05$). Furthermore, in the control condition, the correlation between performance on Lag 3 and psychometric intelligence was larger than the correlation between performance on Lag 2 and psychometric intelligence ($p < .05$). These correlational analyses give weak evidence that the individual differences in psychometric intelligence have the strongest impact on the performance on Lag 3 where AB was most strongly pronounced.

For statistical tests of fixed-links Models 1 to 7, only performance on the five lags of the experimental condition was analyzed. Model fit statistics for the seven models are presented in Table 3. As can be seen, none of the Models 1 to 3, considering AB a unitary phenomenon, fitted the empirical data appropriately. The same held true for Models 4 to 6 which

Table 1:
Mean and standard errors of means (S.E.M.) for percentage of correct T2 identification in the experimental and the control condition of the AB task

	Lag	Mean	S.E.M.
Experimental condition			
	1	.53	.03
	2	.34	.03
	3	.38	.03
	4	.59	.03
	5	.64	.03
Control condition			
	1	.89	.02
	2	.92	.01
	3	.89	.01
	4	.89	.01
	5	.87	.01

Note. For the experimental condition, a T2 response was only included when T1 was correctly identified.

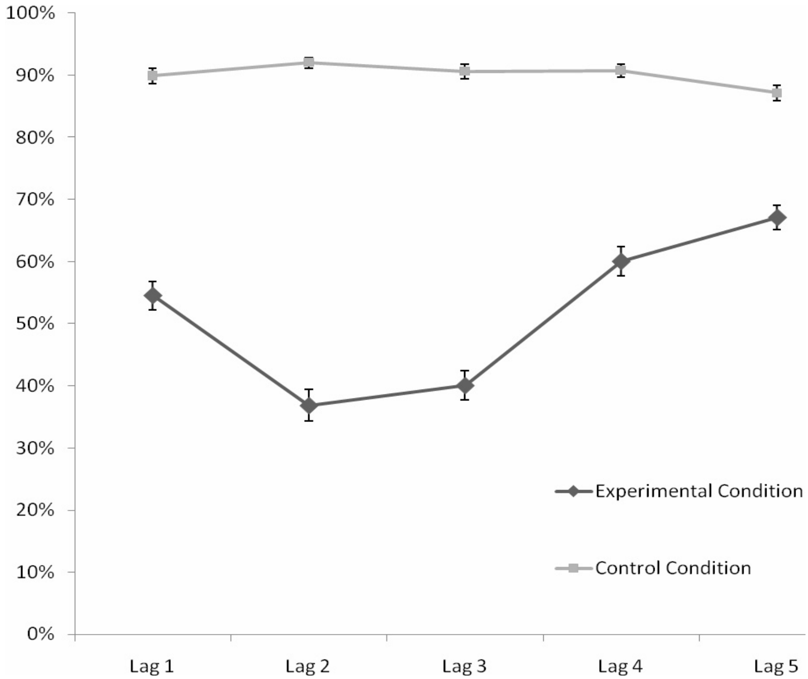

Figure 1:

Percentages of correct identifications of the second target in the experimental condition (when T1 was correctly identified) and in the control condition on the five lags after the first target

assumed two processes to underlie AB, whereas the fit of Model 7 was fairly good. The χ^2-value was statistically insignificant, Comparative Fit Index (CFI) and Tucker-Lewis-Index (TLI) were close to 1. The root mean square error of approximation (RMSEA) was .03, the standardized root mean square residual (SRMR) was .06, and the 90% confidence interval (C. I.) of the RMSEA included zero. Furthermore, the three latent variables showed substantial variances (latent variable of increasing process: 0.002, $t = 5.15$, $p < .001$; latent variable of decreasing process: 0.002, $t = 5.23$, $p < .001$; latent variable of u-shaped process: 0.014, $t = 3.59$, $p < .001$). Thus, it is reasonable to assume that three independent mechanisms may be involved in AB.

For the interpretation of the latent variables, it should be noted that *correct* T2 identification (under the condition that T1 was correctly identified) was measured so that high scores on the latent variables do not reflect the impairment of information processing but the *complement* of this impairment. For example, a high factor score on the latent variable, which is based on the u-shaped function, indicates a *low* AB because T2 was more often correctly identified.

In a next step, the relationships between the three latent variables underlying AB and psychometric intelligence were investigated. For this investigation the corresponding fixed-links model (Model 7) was transformed into a structural equation model by adding intelli-

Table 2:
Intercorrelations between performances on the five lags of the experimental and control condition of the AB task as well as psychometric intelligence in 118 participants

	Experimental condition					Control condition				
	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
Experimental condition										
Lag 1										
Lag 2	.65***									
Lag 3	.50***	.73***								
Lag 4	.39***	.57***	.62***							
Lag 5	.27**	.46***	.53***	.69***						
Control condition										
Lag 1	.20*	.26**	.23*	.30**	.20*					
Lag 2	.13	.30**	.26**	.18*	.24**	.45***				
Lag 3	.21*	.37***	.38***	.18*	.29**	.41***	.59***			
Lag 4	.23*	.32***	.22*	.28**	.29**	.52***	.37***	.48***		
Lag 5	.13	.36***	.37***	.31**	.29**	.43***	.41***	.47***	.56***	
General intelligence	.15	.27**	.33***	.27**	.28**	.19*	.22*	.42***	.32***	.31***

* $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed)

Table 3:
Summary of fit statistics for the seven structural equation models investigating the mechanisms underlying the AB in 118 participants.

Modell	χ^2	df	*p*	CFI	TLI	AIC	RMSEA	90% C.I. of RMSEA	SRMR
1. U-shaped function only	92.63	9	< .001	.71	.68	74.63	.28	.23 – .33	.21
2. Linearly increasing function only	137.51	9	< .001	.56	.51	119.51	.35	.30 – .40	.27
3. Linearly decreasing function only	119.62	9	< .001	.62	.58	101.62	.32	.27 – .38	.32
4. U-shaped and linearly increasing functions	53.88	8	< .001	.84	.80	37.88	.22	.17 – .28	.15
5. U-shaped and linearly decreasing functions	49.69	8	< .001	.86	.82	33.69	.21	.16 – .27	.14
6. Linearly increasing and decreasing functions	28.71	8	< .001	.93	.91	12.71	.15	.09 – .21	.12
7. All three functions	7.78	7	.35	1.00	1.00	-6.22	.03	.00 – .12	.06

Note. CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; AIC = Akaike Information Criterion (AIC = χ^2 – 2df); RMSEA = Root Mean Square Error of Approximation; SRMR = Standardized Root Mean Square Residual.

gence as criterion variable. Also the extended model showed a good model fit [χ^2 (9) = 8.01; p = .53; CFI = 1.00; TLI = 1.00; RMSEA = .00; 90% C. I. of RMSEA ranging from .00 to .10; SRMR = .06]. This model is presented in Figure 2. Psychometric intelligence was positively related to the latent variables reflecting the linearly increasing (completely standardized regression weight β = .25; t = 2.58; p < .05) and u-shaped trends (completely standardized regression weight β = .30; t = 2.33; p < .05) but not to the linearly decreasing trend (completely standardized regression weight β = .10; t = 0.92; *n.s.*). The multiple correlation of the latent variables representing the various processes and psychometric intelligence was .40.

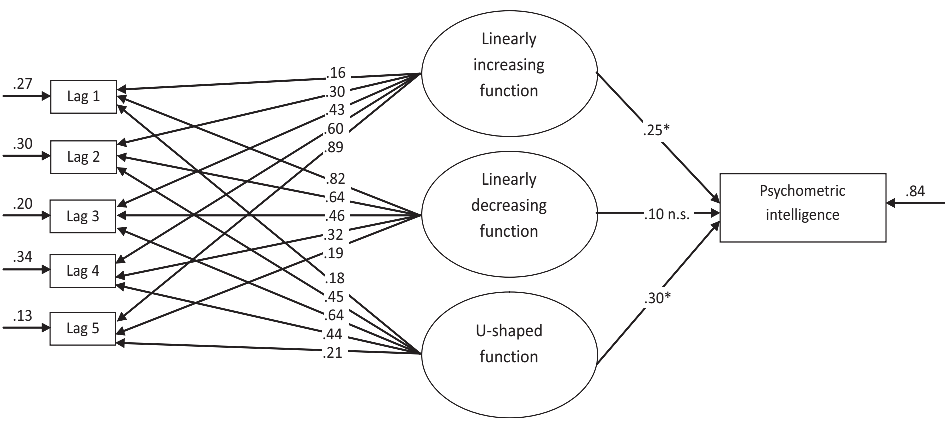

Figure 2:
Fixed-links model with three latent variables and their relations to psychometric intelligence (completely standardized regression weight β, raw constraints, completely standardized error variances) (* p < .05 (two-tailed))

Discussion

In the present study, we examined the assumption that more than a single hypothetical process is involved in the AB phenomenon. To further elucidate the nature of these processes, fixed-links models were used to investigate specific latent variables. The results suggest the existence of three processes represented by u-shaped, linearly increasing, and linearly decreasing functions. Furthermore, the decomposition of the processes underlying AB revealed that two of these processes, reflected by the u-shaped and linearly increasing functions, were related to psychometric intelligence.

The finding that the empirical data can be properly described in terms of three latent variables is in line with the assumption that one process cannot sufficiently explain the outcome of experimental findings (e.g., Kawahara et al., 2006; Visser et al., 1999). In contrast to these previous studies, fixed-links modeling enables a systematic decomposition and investigation of the specific processes underlying AB.

The u-shaped function seems to be primarily related to the typical time course of AB with quite good probabilities to identify T2 when presented immediately or about 500 msec after T1 but with impaired performance when T2 is presented within a time window of approximately 150 to 450 msec after T1. From a theoretical point of view, this process may be explained by a temporary loss of control as suggested by the TLC hypothesis (Di Lollo et al., 2005). According to this account, an attentional set, relying on the resources of the central executive, is implemented to identify targets and to reject distractors. The processing of a first target also requires resources of the central executive so that these resources are no longer available for maintaining the attentional set. This results in an impairment of T2 identification as long as the resources of the central executive are bound to T1 processing. After T1 processing is completed, resources are available again to re-establish the attentional set and, thus, enable proper identification of T2 and rejection of distractors. An alternative explanation of this latent variable is the modification of the TLC account by Olivers et al. (2007). The dynamic process proposed by these authors would also lead to a u-shaped trend of performance on the five lags. The attentional set is suggested to be dynamically modulated depending on whether a distractor or a target stimulus followed T1. When T1 is correctly identified as a target, the attentional set tends to accept also the next stimulus as a target leading to the lag-1 sparing. When the stimulus following T1, however, is a distractor, the selection mode of the attentional set becomes stricter in order to avoid that further stimuli are selected erroneously as a target. The higher strictness of the attentional set leads to a failure to select further targets so that it has to be re-modulated and becomes less strictly again.

The linearly decreasing function indicates a mechanism responsible for decreasing T2 identification from Lags 1 through 5. This effect might be explained in terms of the interference model (Isaak et al., 1999; Shapiro et al., 1994) suggesting that each distractor competes with T2 for the limited available processing resources. Thus, with an increasing number of distractors, T2 identification should become more and more difficult leading to a decrease of performance on T2 identification from Lag 1 to Lag 5.

Eventually, the latent variable which is based on the linearly increasing function indicates that T2 processing improves linearly from Lag 1 to Lag 5. This latent variable may be explained by the two-stage model proposed by Chun and Potter (1995). The limited resources of Stage 2 are occupied by processing of T1 so that they are no longer available for the processing of T2. While the mental representation of T2 is waiting for processing, it is prone to rapid decay on Stage 1 so that the impairment of T2 identification is highest when T2 is presented shortly after T1. However, the more T1 is consolidated in a more durable storage the more resources are available to process T2 so that performance of T2 identification increases from Lag 1 through Lag 5.

The meaning of the trends associated with the latent variables is highly tentative in nature. The possibility to decompose the mechanisms underlying AB, however, should encourage future research to validate the meaning of the latent variables identified in the present study. For example, it could be investigated whether performance on typical interference tasks such as the Stroop task (Stroop, 1935) are correlated with the latent variable associated with the linearly decreasing trend. Another approach to validate the processes underlying the three latent variables is represented by the experimental manipulation of the AB task. If one of the processes can be prevented from becoming effective by appropriate experimental manipulation of the task, the fixed-links model should reveal only two of the three processes identified in the present study. For example, the presentation of three targets, that is two targets immediately following T1, should avoid the disturbance of the attentional set (see Di Lollo et al., 2005) so that the u-shaped trend would not be identified by a fixed-links model.

A common finding is that some participants do not show AB. These participants are referred to as "non-blinkers". In the present study, 26 non-blinkers were identified. Visual inspection of their data revealed that 10 non-blinkers showed almost no change in T2 identification (when T1 was correctly reported) from Lag 1 to Lag 5, while in 13 non-blinkers the means of T2 identification described a monotonic increase, in 2 non-blinkers a monotonic decrease and in one participant an inverted u-shape. In contrast to a previous report (Martens, Johnson, Bolle, & Borst, 2009) blinkers and non-blinkers did not differ in overall performance on the task (and not in psychometric intelligence). Furthermore, the three latent variables could also be identified when non-blinkers had been removed from the data. Therefore, it can be ruled out that our finding of linearly increasing and decreasing trends is based on non-blinkers in the present sample. It might be assumed that the mechanism reflected by the u-shaped trend is the most dominant mechanism out of the three mechanisms in the majority of participants (i.e. in blinkers) so that the means of T2 identification on the lags 1 to 5 describe a u-shaped trend. The pattern of results in non-blinkers, however, indicates that in some participants the processes reflected by the linearly increasing or decreasing trends are more pronounced than the mechanism reflected by the u-shaped trend. In this case, the means of correct T2 identification do not describe a u-shaped trend but another trend which is probably influenced by the most dominant underlying process. Thus, it seems as if also in non-blinkers all three mechanisms underlying AB are effective but with another balance of dominance compared to blinkers.

In the present study three independent processes influence T2 processing. The effects of these processes on the performances in T2 identification develop differently on the different lags and are confounded when only overall variance is analyzed. This confounding effect may be the reason why previous studies did not observe a significant relationship between AB and psychometric intelligence (Colzato et al., 2007; Martens & Johnson, 2009). When variance is decomposed with regard to the different sources, as it is done with fixed-links models, the latent variables reflected by the u-shaped function and the linearly increasing function, explained significant portions of variance of psychometric intelligence.

If one assumes that the latent variable associated with a u-shaped trend reflects the mechanisms proposed by the TLC model, its relationship to psychometric intelligence indicates that individuals with higher psychometric intelligence are less vulnerable to a disturbance of the attentional set compared to those with lower psychometric intelligence. Due to less limited resources of the central executive, individuals with higher psychometric intelligence have more resources available to process T1 and, concurrently, to maintain the attentional set. This conclusion would be in line with the common finding of a functional relationship between psychometric intelligence and working memory capacity (e.g., Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Kyllonen & Christal, 1990). Nevertheless, for such a conclusion the meaning of the latent variable has to be validated. As long as the meaning is not clear, one can alternatively conclude that individuals with higher psychometric intelligence adjust the attentional set more appropriately to the requirements of the task compared to individuals with lower intelligence. This conclusion would be in accordance with Olivers et al.′s (2007) model.

If the linearly increasing function virtually reflects the progress in processing T1 (Chun & Potter, 1995), higher factor scores on this latent variable should indicate faster consolidation of T1 in a more durable storage. Higher speed of information processing, however, is well known to be positively related to psychometric intelligence (for reviews see Jensen, 2006; Sheppard & Vernon, 2008; Vernon, 1987). Thus, in individuals with higher psychometric intelligence T1 is processed faster and, therefore, resources are earlier available for T2 processing. If the increasing function really reflects speed of T1 consolidation in a more durable storage, the present results provide the opportunity to dissociate bottlenecks of information processing, as maybe reflected by the u-shaped function, from speed of information processing. This seems of particular interest since some studies reported that the relationship between limited resources of information processing and psychometric intelligence may primarily rely on the relationship between speed of information processing and psychometric intelligence (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kieras, Meyer, Mueller, & Seymour, 1999; Salthouse, 1996). In the present study, the linearly increasing function was unrelated to the u-shaped function since the three latent variables were modeled to be independent of each other. Therefore, it appears highly unlikely that speed of information processing affected more than only one latent variable.

Finally, the linearly decreasing function was not associated with psychometric intelligence and may reflect the interference resulting from the processing of the increasing number of distractors. At first sight, the lack of a relationship between interference and psychometric intelligence is surprising as there is some evidence that individuals with higher psychometric intelligence are less susceptible to interference compared to individuals with lower psychometric intelligence (Brewin & Beaton, 2002; Dempster & Corkill, 1999). It should be noted, however, that due to the other two latent variables introduced in the present study, the influence of limited resources and speed of information processing on the relationship between interference and psychometric intelligence may have been statistically partialed out. This controlling of limited resources and/or speed of information processing may be the reason that no relation between the latent variable represented by the linearly decreasing function and psychometric intelligence could be observed. This view is supported by the results reported by Borella, Carretti, and Mammarella (2006). In their study, the relationship between psychometric intelligence and a measure of susceptibility to interference was almost completely mediated by working memory capacity.

To sum up, the present results support the notion that more processes than only one are involved in the AB phenomenon. Fixed-links models indicated three latent variables underlying performance on the AB task. The latent variable reflected by the linearly increasing function might be well explained by the two-stage model (Chun & Potter, 1995) while the latent variable reflected by the u-shaped curve might be explained by the TLC model (Di Lollo et al., 2005) or the assumption of a dynamical modulation of an attentional set (Olivers et al., 2007). The latent variable reflected by a linearly decreasing trend, finally, might represent interference effects of distractor stimuli on T2 identification. The interpretation of these latent variables is speculative and has to be confirmed by future studies. The decomposition of the processes underlying AB, however, revealed that two out of the three processes were related to psychometric intelligence while the third process was not. Thus, a confounding effect of these three processes might be the reason why a relation between AB and psychometric intelligence could not be observed in previous studies. Fixed-links models seem to be an appropriate method to disentangle the processes underlying AB and to investigate individual differences in AB in more detail.

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