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Published in:
Journal of Experimental Child Psychology

DOI:
[10.1016/j.jecp.2015.05.003](https://doi.org/10.1016/j.jecp.2015.05.003)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2015

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

de Groot, B. J. A., van den Bos, K. P., van der Meulen, B. F., & Minnaert, A. E. M. G. (2015). The attentional blink in typically developing and reading-disabled children. *Journal of Experimental Child Psychology*, 139(November), 51-70. <https://doi.org/10.1016/j.jecp.2015.05.003>

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Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

The attentional blink in typically developing and reading-disabled children

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ARTICLE INFO

Article history:

Received 22 July 2014

Revised 5 May 2015

Available online 14 June 2015

Keywords:

Word reading

Fluency

Reading disabilities

Dyslexia

Phonological awareness

Rapid automatized naming

Visual attention

Attentional blink

ABSTRACT

This study's research question was whether selective visual attention, and specifically the attentional blink (AB) as operationalized by a dual target rapid serial visual presentation (RSVP) task, can explain individual differences in word reading (WR) and reading-related phonological performances in typically developing children and reading-disabled subgroups. A total of 407 Dutch school children (Grades 3–6) were classified either as typically developing ($n = 302$) or as belonging to one of three reading-disabled subgroups: reading disabilities only (RD-only, $n = 69$), both RD and attention problems (RD+ADHD, $n = 16$), or both RD and a specific language impairment (RD+SLI, $n = 20$). The RSVP task employed alphanumeric stimuli that were presented in two blocks. Standardized Dutch tests were used to measure WR, phonemic awareness (PA), and alphanumeric rapid naming (RAN). Results indicate that, controlling for PA and RAN performance, general RSVP task performance contributes significant unique variance to the prediction of WR. Specifically, consistent group main effects for the parameter of AB_{minimum} were found, whereas there were no AB-specific effects (i.e., AB_{width} and $AB_{\text{amplitude}}$) except for the RD+SLI group. Finally, there was a group by measurement interaction, indicating that the RD-only and comorbid groups are differentially sensitive for prolonged testing sessions. These results suggest that more general factors involved in RSVP processing may explain the group differences found.

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Introduction

There is strong scientific consensus that reading disabilities (RD) are linked to a deficit in phonological processing (Landerl et al., 2013; Lyon, Shaywitz, & Shaywitz, 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004). However, because reading is a visual–verbal process, nonphonological factors should be considered as well (Pennington et al., 2012). One such relatively new research domain concerns visual attention (Bosse, Tainturier, & Valdois, 2007; Franceschini et al., 2013; Lobier, Zoubrinetzky, & Valdois, 2012), for which two main aspects can be discerned: *spatial* and *temporal* attention. Examples of studies focusing on spatial aspects are those employing orienting or visual search paradigms (e.g., Casco & Prunetti, 1996; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti et al., 2006). Obviously, the serial quality of reading implies *temporal* shifts of attention as well (Farmer & Klein, 1995; Hari, Valta, & Uutela, 1999; Visser, Boden, & Giaschi, 2004). Temporal (selective) visual attention has frequently been studied in adults with the attentional blink (AB) paradigm (Raymond, Shapiro, & Arnell, 1992): “The AB is typically attributed to an inability to rapidly reallocate attentional resources from the first to the second target. Thus, it provides an ideal tool to investigate how visual attention is rapidly allocated to sequences of stimuli such as occurs when reading” (Visser et al., 2004, p. 2521). There are, however, relatively few studies that have linked the AB to reading and phonological processing in *children*. Before addressing specific research questions, brief descriptions of the AB and some background on its cognitive mechanisms, relations with phonological tasks, and the currently investigated subgroups are provided.

The attentional blink

The attentional blink refers to an interstimulus interval-related loss of accuracy in detecting the second of two targets (T1 and T2) within a stream of distractors in a rapid serial visual presentation (RSVP). If T2 is presented with a stimulus onset asynchrony (SOA) of approximately 200 to 500 ms, provided the correct identification of T1, participants tend to fail at identifying T2. This interval-bound loss of accuracy produces the characteristic conditional T2|T1 curve, which is interpreted as the AB (see Fig. 1). The SOA conditions are commonly referred to as Lag_1 , Lag_2 , ..., Lag_n , with the numerical affix corresponding to the number of stimuli separating T1 and T2 onset.

Although RSVPs frequently had been used to study visual perception (Broadbent & Broadbent, 1987), the interpretation of the AB being attentional rather than sensory was first proposed by Raymond and colleagues (1992). These authors based this on the observation that T2 performance

Fig. 1. The attentional blink.

improved significantly if T1 was ignored. Regarding the cognitive mechanisms of the AB, [Chun and Potter \(1995\)](#) proposed a *two-stage model* that assumes that processing of an RSVP requires two stages: an initial rapid detection stage of potential targets and a limited capacity storing stage in which identified targets are consolidated in working memory. These authors attributed the AB to a delay in the latter stage; that is, as long as the second stage is not complete for T1, processing of T2 is put on hold, rendering T2 vulnerable to decay. The two-stage model has seen several extensions, all of which describe a bottleneck in the second stage ([Dux & Marois, 2009](#)). In general, the research literature suggests that the AB is the consequence of the allocation of limited attentional resources to T1, leaving insufficient resources to adequately process T2 at short intervals. Slow temporal dynamics of attention processes are assumed to account for the observation that T2 identification is relatively unimpaired at short intervals, that is, Lag_1 -sparing (e.g., [Nieuwenstein, Chun, Van der Lubbe, & Hooge, 2005](#); [Wyble, Bowman, & Nieuwenstein, 2009](#)). One of the most recent methodological innovations in the study of the AB is the curve fitting method proposed by [Cousineau, Charbonneau, and Jolicoeur \(2006\)](#), which quantifies the AB with four parameters: AB_{width} , $AB_{minimum}$, $AB_{amplitude}$, and Lag_1 -sparing. According to the authors, this method offers the benefits of easier comparisons across experiments and statistically more powerful separate tests of the AB characteristics mentioned.

The AB and RD

In their seminal study on the relationship between the AB and RD, [Hari and colleagues \(1999\)](#) found that dyslexic adults consistently showed poorer T2|T1 performance relative to normal readers. Considering that both groups did show a significant AB, and that the difference between the two groups was only resolved for SOAs over 1 s, the authors concluded that stimulus identification takes dyslexics significantly longer. [Visser and colleagues \(2004\)](#) reported similar findings for children with dyslexia. A notable developmental difference between the results of these two studies is that the performance of children with dyslexia remains significantly poorer even for SOAs as long as 1.4 s. Visser and colleagues concluded that these children's poorer performances can be interpreted as a developmental delay in their ability to reallocate attentional resources. However, the finding of individuals with RD showing *AB-specific* deficits (i.e., a prolonged or deeper AB) is not supported by a recent study by [McLean, Castles, Coltheart, and Stuart \(2010\)](#). [McLean, Stuart, Visser, and Castles \(2009\)](#) also did not find *direct* evidence for a link between AB duration and reading in the general population of children. However, consistent with most previous studies, general RSVP task performance was found to be significantly poorer in poor readers. The authors interpreted these findings as reflecting more general factors influencing performance such as nonverbal reasoning, sustained attention, and short-term memory. Employing the previously mentioned curve fitting method ([Cousineau et al., 2006](#)), [Lallier, Donnadieu, and Valdois \(2010\)](#) reached similar conclusions. Specifically, these authors reported that $AB_{minimum}$ (i.e., the lowest T2|T1 performance encountered across conditions [Lags] and that could be considered to measure general AB task performance) is poorer in dyslexic individuals. In contrast, however, [Lacroix and colleagues \(2005\)](#) found a shallower AB, and significantly better general task performance for dyslexic adolescents, compared with normal readers. The authors speculated that these rather unexpected results could be explained by the notion of normal readers having extended episodic memory traces (cf. [Logan, 1988](#)) relative to dyslexics given that they continue to process better automatized, yet task-irrelevant, linguistic distractor stimuli. All available evidence considered, poor readers are generally expected to be less proficient at RSVP processing than typically developing peers.

The AB and reading-related tasks

Addressing the relationship between the AB and reading-related tasks, the current study focuses on (alphanumeric) rapid automatized naming (RAN) and phonemic awareness (PA). Numerous studies have made clear that both are important predictors of word reading (WR) and that many individuals with RD typically demonstrate impaired performances for such tasks (for a recent overview, see [Landerl et al., 2013](#)). Regarding possible associations between RAN and RSVP tasks, significant correlations are expected because both types of task involve serial processing of visual stimuli and rapid

temporal shifts of attention. Considering these common cognitive–attentional characteristics, RAN has indeed been implicated as a mediator for the AB–reading association (McLean et al., 2009; Visser et al., 2004). Regarding PA, a link with selective visual attention seems less obvious than with RAN. Whereas RAN tasks employ visual stimuli, typical PA tasks are vocal–auditory. However, based on their theory in which RD are seen as resulting from sluggish attentional shifting (SAS), and assuming that rapid stimulus sequencing is essentially amodal, Hari and Renvall (2001) predicted that difficulties with rapid serial processing tasks may be observed in all sensory modalities. This idea seems to be supported by several recent studies providing evidence for a modality-free link between AB tasks and phonological tasks (Laasonen et al., 2012; Lallier, Donnadieu, Berger, & Valdois, 2010; Lallier, Donnadieu, & Valdois, 2010). A second explanation could simply be that both tasks involve a high working memory load (see previous section for AB; see Landerl & Wimmer (2000) for PA).

Comorbidity

A characteristic of the current study is that, in addition to typically developing children and children with *specific* RD, children with comorbid specific language impairment (SLI) and attention deficit hyperactivity disorder (ADHD) are investigated. SLI has been defined as a failure of normal oral language development despite normal intelligence, an adequate learning environment, and no apparent hearing, physical, or emotional problems (Bishop, 1992). ADHD is a developmental disorder characterized by attentional dysfunction, impulsiveness, and hyperactivity (American Psychiatric Association, 2000). Estimates of the overlap with RD are substantial and at least suggestive of some common etiology (De Bree, Rispens, & Gerrits, 2007; McArthur, Hogben, Edwards, Heath, & Mengler, 2000; Vandewalle, Boets, Ghesquiere, & Zink, 2012; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). The question that applies in this context is which role is played by selective visual attention. As SLI is concerned, Lum, Conti-Ramsden, and Lindell (2007)—while following up on the suggestion by Hari and Renvall (2001) that sluggish attention shifting might account for generalized rapid sequencing difficulties in language-impaired individuals—found that adolescents with SLI showed a significantly *deeper* and *prolonged* AB relative to controls. The authors speculated that atypical performance for AB tasks in “dyslexics” might be specific to those with comorbid language impairments. If this were the case, there should be performance differences between RD-only and RD+SLI groups. With regard to ADHD, Mason, Humphreys, and Kent (2005) found no “major” group differences as to AB *duration* and *amplitude* in children with ADHD. However, general RSVP performance was poorer than that in controls. The authors interpreted these results as reflecting compromised working memory in children with ADHD. In addition, they suggested that children with ADHD are more distractible by nontarget stimuli, resulting in a form of distributed attention instead of focused attention.

Aims of the study

In summary, the current study investigated selective visual attention, and the possible link thereof with WR, alphanumeric RAN, and PA, in children attending schools of primary education. The main goals were to validate earlier findings of poorer, or atypical, RSVP processing in children with RD and comorbid conditions (RD-only, RD+SLI, and RD+ADHD) and to relate possible effects to phonological processing performances. The different RD subgroups are compared with each other and with a large control group of typically developing peers. An important innovation, which we want to follow up, is the curve fitting method developed by Cousineau and colleagues (2006). As described earlier, this method yields four AB parameters: AB_{width} , $AB_{minimum}$, $AB_{amplitude}$, and Lag_1 -sparing. In terms of these parameters, for RD-only children, the absence of a prolonged AB, but poorer overall RSVP performance, should demonstrate itself as a lowered $AB_{minimum}$, whereas the other parameters should appear relatively normal in this group. In addition, we wanted to investigate the effects of comorbidity of RD with SLI and ADHD. More specifically, we wanted to evaluate the claim articulated by Lum and colleagues (2007) that a deeper and prolonged AB may be specific to those children with dyslexia who have comorbid SLI. Also of interest was the observation of enhanced distractibility by salient task-irrelevant stimuli in children with ADHD (Mason et al., 2005). If this is a specific characteristic of ADHD, this should be seen as an additive effect, that is, as further attenuated general RSVP

performance or lower AB_{minimum} for the RD+ADHD group relative to the RD-only group. Moreover, the complication of a comorbid disorder possibly could produce negative cascading effects, which may affect specific aspects of the AB as well, resulting in an atypical AB. Finally, we evaluated the possible general effects of fatigue, or sustained attention, by comparing the group results for two consecutive measurement blocks.

Method

Participants, procedure, and group assignment

The current research initially concerned 417 Dutch children (214 girls and 203 boys) aged 7 to 13 years. The great majority of the children were recruited from intact classes of 13 regular elementary schools located in the northern region of the Netherlands. In addition, a relatively small number of children with clinical diagnoses of dyslexia, comorbid ADHD, or comorbid SLI were included. Labeling of these participants was based on independent formal diagnoses by certified educational psychologists in case of dyslexia, professional speech–language pathologists in case of SLI, or child psychiatrists in case of ADHD. Most clinically diagnosed participants were sampled from institutions specializing in care for these groups of children (i.e., care centers for dyslexia and/or ADHD or schools for special education in case of SLI). All of these institutions were located in the same geographic region as mentioned before. Only referrals with nonverbal IQ above 80 were recruited. For participants younger than 12 years, informed consent was required from their parents. Participants older than 12 were required to give consent on their own behalf as well. Data collection was carried out by the first author and 31 undergraduate students either at a university research facility or at the school of the participant.

The participants were first classified according to their WR performances as either children with RD (below the 10th percentile) or typically developing (TD) readers (above the 25th percentile). Children who fell in between were excluded ($n = 2$). In addition, because this study focused on RD and the comorbid groups of RD+SLI and RD+ADHD, normally reading children with a (single) diagnosis of SLI ($n = 4$) or ADHD ($n = 2$) were excluded. Children with threefold disabilities (SLI+ADHD+RD, $n = 2$) were excluded as well. The remaining 407 children were assigned to the four experimental groups according to Table 1.

Finally, with regard to the possibility of unnoticed cases of comorbidity in the RD-only group, it should be noted that, based on school records and parent information, this seems highly unlikely. Second, a number of children in the RD-only group were clinically diagnosed with dyslexia ($n = 20$). They formed a subgroup with the most severe RD. However, this does not deny the reading specificity of their learning disability given that this group showed normal IQs, oral language abilities, and general attention, as measured by standardized Dutch adaptations of the Wechsler Intelligence Scale for Children–Third Edition (Wechsler, 2005) ($M = 98.4$, $SD = 9.8$), Peabody Picture Vocabulary Test–Third Edition (Dunn & Dunn, 2005) ($M = 98.1$, $SD = 8.0$), and a Dutch ADHD Questionnaire (Scholte & Van der Ploeg, 1998, 2002, 2004) (median = 50th–60th percentile). Therefore, we had no indication of significant unnoticed comorbidities in our sample of RD-only children.

Table 1
Group frequencies and descriptive statistics of age in months.

Group	Frequencies			Age in months				
	<i>n</i>	Girls	Boys	<i>M</i>	<i>SD</i>	Median	Minimum	Maximum
RD-only	69	26	43	124.4	16.3	118	99	166
RD+ADHD	16	6	10	121.5	14.7	126	92	137
RD+SLI	20	13	7	130.1	18.5	133	99	165
Control	302	162	140	127.9	15.4	130	94	160
Total	407	207	200	127.1	15.7	128	92	166

Fig. 2. Experimental AB paradigm with examples of a Lag₃ trial (A) and Lag₅ trial (B).

Dual target RSVP paradigm

The visual attention (VA) task consisted of two counterbalanced dual target subtasks (letter–target and digit–target) to control for stimulus effects. Each subtask comprised 96 pseudorandomized test trials consisting of an RSVP applying to six conditions—referred to as Lag₁, ..., Lag₅ and Lag₇—which are explained shortly. This type of task has been frequently employed to investigate the AB, although the stimuli and the parameters change with the study being concerned. To maintain an ecologically sound link to reading, the current study employed alphanumeric stimuli, that is, digits and letters. Fig. 2 contains the schematic representations of a Lag₃ trial (A) and a Lag₅ trial (B) taken randomly from the letter–target subtask.

As indicated in Fig. 2, each trial started with a fixation cross, which remained visible for 1000 ms. The fixation cross was followed by 4 to 7 distractors (non-target-type stimuli), after which the first target stimulus (T1) was presented. Next, depending on the SOA of the condition, i.e., Lag, a number of distractors were presented, followed by the second target stimulus (T2). Finally, another four distractors were presented to avoid recency effects. Targets and distractors were presented with a duration of 50 ms and were separated by a blank interstimulus interval of 60 ms. As such, the Lag₁ condition corresponded to an SOA of 110 ms, and subsequent conditions corresponded to a multiple thereof. To limit the amount of trials, yet adequately fill each condition, the Lag₆ condition was omitted. The Lag₇ condition served as the lengthiest indicator of AB recovery. All stimuli were presented in white with a bold 14-point Arial font on a standard computer screen against a dark gray (RGB: 90, 90, 90) background. Psychology Software Tools E-Prime 2.0 was used for stimulus presentation and response recording.

Task procedure

At the start of the experiment, the child was seated in front the computer. Prior to task execution, it was explained to the child that he or she would be presented with a large number of rapid sequences of letters and digits and that the target stimuli (T1 and T2) needed to be identified while ignoring the distractor stimuli. Next, the child was instructed to focus on the already visible fixation cross and to start each trial with a key press (the spacebar on a standard computer keyboard). After each RSVP, the child was required to type on the keyboard, in the correct order, the letters or digits corresponding to the target stimuli. No feedback was provided as to the correctness of the responses given. The child practiced with 6 trials prior to the start of each block. The first measurement block (M1) was always preceded by the WR and RAN tasks and a short break. The second measurement block (M2) was always preceded by the PA task and another short break to avoid target confusion.

Performance measures

First, for each participant, mean T1 and T2 performances (accuracy) were taken as outcome variables of each measurement block. Second, a conditional variable, mean T2/T1 performance—that is,

T2 accuracy given that T1 was correctly identified—was computed. This conditional variable adheres to the traditional method of AB measurement.

AB parameterization

In addition to the raw T2|T1 performance measurements, a curve fitting method (Cousineau et al., 2006) was applied to the data to capture the AB with four parameters: Lag_1 -sparing, AB_{width} , $AB_{minimum}$, and $AB_{amplitude}$. These parameters can be defined as follows. Lag_1 -sparing refers to how quickly—in terms of SOA—T1 processing starts to negatively affect T2 performance. AB_{width} reflects the duration of the AB effect in terms of SOA and could be interpreted as indicating attentional dwell. That is, it indicates the T1–T2 interstimulus interval range for which T2 accuracy is affected by T1 processing. $AB_{minimum}$ equals the lowest T2 accuracy across all lags. $AB_{amplitude}$ reflects the difference between the asymptotic performance at long lags and $AB_{minimum}$. The latter parameter reflects the magnitude, severity, or deepness of the AB effect. Wolfram Mathematica 9 software was used to generate, for each participant, the optimized functions for T2|T1 performance. This method was employed in order to investigate AB-specific (interactive) effects. It was pointed out by Cousineau and colleagues (2006) that, as compared with traditional repeated measures analysis with the raw RSVP performance measurements, this set of variables, resulting from this parameterization method, allows for more robust statistical testing regarding the more intricate aspects of the AB. However, because analysis of variance (ANOVA) with raw RSVP performance data proved to be more reliable to evaluate (group) main effects (Cousineau et al., 2006), we revert to conventional testing where applicable. See also Lallier, Donnadieu, and Valdois (2010) for an application of this method with young reader groups.

Additional materials

Word reading fluency

To obtain a general index of WR fluency, we followed the international practice (Blomert & Vaessen, 2009; Torgesen, Wagner, & Rashotte, 2012) of combining scores on tests with real words and tests of pseudoword reading. For this purpose, scaled scores on three widely used Dutch timed, standardized WR tests for 7- to 14-year-old children—two tests with real words (Brus & Voeten, 1979; Van den Bos & Lutje Spelberg, 2010) and a pseudoword reading test (Van den Bos, Lutje Spelberg, Scheepstra, & De Vries, 1994)—were averaged, yielding an index of WR with the approximate distribution $\mathcal{N}(10, 3)$. The test manuals report test–retest reliabilities equal to or greater than .90 and intercorrelations of .90 for the real word reading tests and .75 to .78 for the current sample for pseudoword and real word reading associations. These high correlations certainly warrant the use of a composite score of general WR proficiency.

Rapid automatized naming

RAN was assessed by the two alphanumeric subtests of a frequently used Dutch standardized testing battery (Van den Bos & Lutje Spelberg, 2010), which are adaptations of those used by Denckla and Rudel (1976). Participants were required to sequentially state, as quickly and accurately as possible, the names of 50 letters or digits that were presented to them in columns (5×10) on a standard sheet of paper. The times to complete each subtest were converted to scaled scores, which were combined in a composite score (i.e., RAN_{an}), distributed $\mathcal{N}(10, 3)$. The reported reliabilities for the subtests are .84 and .86, respectively.

Phonemic awareness

PA was assessed by a Dutch standardized computer-assisted auditory test measuring phonemic analysis skills (De Groot, Van den Bos, & Van der Meulen, 2014). The test consisted of a phoneme elision task and a phoneme substitution task spanning 2×12 trials (e.g., “Say STREEK without the /R/” and “Substitute the first letters [i.e., phonemes] of the first and surnames KEES BOS and state the result,” respectively). Response times and accuracies were recorded and combined by means of a standardized scoring rule that imposes an age-dependent time penalty when an erroneous answer is given by the participant. This results in separate standardized scores for the subtests and a composite index of PA, all distributed $\mathcal{N}(50, 10)$. The reliabilities are .82, .91, and .92, respectively.

Statistical analyses

Analysis of variance

Testing for group differences on general RSVP performance was executed with a repeated measures ANOVA, with lag and measurement (block) inserted as within-participants factors and Group as the between-participants factor. To investigate the possible effects of unequal sample sizes, a secondary series of these analyses was conducted. For these analyses, first a stratified random (re)sampling with replacement (1000 iterations) was performed with the experimental group as the stratification variable. The sampling procedure was designed to match the sample sizes of the RD-only, RD+SLI, and control groups of each iteration to that of the smallest group (RD+ADHD, $n = 16$). Next, each instance was subjected to a separate analysis, and all relevant parameters were averaged afterward to obtain unbiased estimators.

As far as the investigation of the main and interactive effects of specific aspects of the AB is concerned, the Lag_1 -sparing, AB_{width} , $\text{AB}_{\text{minimum}}$, and $\text{AB}_{\text{amplitude}}$ parameters were employed as the dependent variables in a multivariate analysis of variance (MANOVA), with group (primary) and measurement (secondary) as between-participants factors. As mentioned in the Introduction, age effects are expected. Because the current study investigated a fairly broad age range of young developing readers, age in months was included as a covariate to accommodate for such effects. Furthermore, an important aim of the current study was to investigate the interrelations among the AB, WR, and phonological processing. As indicated in the Introduction, the AB and phonological processing are expected to be related to one another as well as to reading. Therefore, similar to the regression analyses (see below), to establish the *unique* relation between the AB and reading, RAN_{an} and PA were also included as covariates in subsequent reruns of the analyses.

Discriminant function analysis

Discriminant function analysis was used to investigate the predictive values of the age-corrected RSVP measurements for group membership. A secondary goal of this procedure was to investigate whether RSVP performance could be described with a limited number of latent functions, yielding a manageable predictor set for subsequent regression analysis.

Regression analysis

Having uncovered existing latent RSVP functions, hierarchical regression analysis was employed to consider, in concert with RAN_{an} and PA, the RSVP-based group membership probabilities as predictors for WR performance. The goal of these analyses was to investigate the unique and common contributions to the prediction of WR.

Results

Before presenting the results of the RVSP task, Table 2 provides a descriptive overview of the experimental groups' results for WR and the phonological variables, that is, RAN_{an} and PA. For each of the three variables, the three RD groups were compared in a univariate ANOVA. These analyses yielded a significant main effect only for PA, $F(2, 104) = 9.23$, $p = .001$. Post hoc analysis (Tukey HSD) indicated that the children with RD+SLI performed significantly lower ($p \leq .041$) than the other two groups, which did not significantly differ from each other.

T1 and T2

In this section, group comparisons on raw RSVP performance are presented. T1 and T2 were considered as the dependent variables in separate repeated measures ANOVAs, with lag and measurement (block) as within-participants factors and group as the between-participants factor. Age in months was inserted as a covariate to accommodate for assumed age effects. In a second run of the analyses, RAN_{an} and PA were added as covariates to investigate the interactive effects of the RSVP performance measurements with phonological processing and WR.

Table 2Standardized means (z-scores) and standard deviations for WR, RAN_{an}, and PA and number of participants per group.

Variable	RD-only (<i>n</i> = 69)		RD+SLI (<i>n</i> = 20)		RD+ADHD (<i>n</i> = 16)		TD (<i>n</i> = 302)		Total (<i>n</i> = 407)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
WR	−1.94	0.48	−2.15	0.55	−2.08	0.48	0.43	0.69	0.17	1.22
RAN _{an}	−1.55	0.81	−1.79	0.76	−1.54	0.94	0.12	1.00	−0.31	1.20
PA	−1.62	1.20	−2.98	0.63	−2.00	1.15	−0.05	1.24	−0.51	1.46

Fig. 3. Age-corrected T1 (top) and T2 (bottom) performances by SOA condition curves for RD-only, RD+SLI, and RD+ADHD groups and controls on the first (left) and second (right) measurements (M1 and M2, respectively).

Regarding raw T1 performance, there were substantial main effects of age, $F(1,382) = 107.45$, $p < .0001$, $\eta_p^2 = .22$, and group, $F(3,382) = 30.31$, $p < .0001$, $\eta_p^2 = .19$ (for age-corrected means, see the top half of Fig. 3). In addition, a significant Group $\times$ Measurement interaction was found, $F(3,382) = 8.65$, $p < .0001$, $\eta_p^2 = .07$. As to the first measurement (M1), post hoc (Tukey HSD) analysis indicated that all three RD groups performed significantly poorer than the TD group ($p \leq .005$), with the comorbid groups showing the poorest performances. Remarkably, analysis of the data of the second measurement (M2) revealed an even stronger differential pattern of poorer performance for all three RD groups as compared with controls ($p < .0001$). Although the RD subgroups did not differ significantly from each other on T1 performance, and seem to form a cluster for M2, the RD+SLI group does seem more severely impaired compared with the other RD groups, particularly from Lag₃ on up for M1. As a

consequence of adding RAN_{an} and PA as covariates, the main effect for group—although remaining significant—was attenuated significantly, $F(3,371) = 3.91$, $p = .009$, $\eta_p^2 = .03$. This attenuation particularly seemed to operate on M1, dissolving the contrast between the RD-only group and the control group, whereas this contrast remained considerable for M2. However, when collapsing over measurements, only the contrast between the RD+ADHD subgroup and the TD group remained ($p = .014$).

A similar pattern emerged for raw T2 performance (see bottom half of Fig. 3). Accommodating for the substantial effect of age, $F(1,382) = 124.80$, $p = .0001$, $\eta_p^2 = .25$, a substantial main effect of group was found, $F(3,382) = 35.37$, $p < .0001$, $\eta_p^2 = .22$. The Group $\times$ Measurement interaction effect also proved to be significant, $F(3,382) = 5.22$, $p = .002$, $\eta_p^2 = .04$. Post hoc analysis (Tukey HSD) indicated that all three RD subgroups differed from the TD group ($p < .0001$). Moreover, a significant difference between the RD-only and RD+SLI subgroups was established ($p = .037$).

As was the case for T1, the addition of RAN_{an} and PA as covariates considerably attenuated the main effect of group on T2 performance, $F(3,371) = 5.79$, $p = .001$, $\eta_p^2 = .05$. Similarly, the attenuation was particularly effectuated for M1, where the difference between the RD-only and control groups disappeared, whereas the group main effect remained considerable at M2. However, when collapsing over measurements, only the contrasts between the comorbid groups and the TD group remained (RD+SLI $p = .005$; RD+ADHD $p = .018$).

Attentional blink variables

This section specifies the results of the ANOVAs for the (derivative) AB-specific variables. First, similar to the previously applied procedure for T1 and T2, the main and interaction effects of group membership, measurement block, and lag were investigated for the “raw” conditional variable T2|T1. This is followed by a subsection in which the results of the MANOVAs on the AB parameters are presented and two subsections in which the interactive effects of PA and RAN_{an} are controlled for. Finally, the effects of measurement block for the AB parameters are evaluated.

T2|T1

As expected, conventional repeated measures ANOVA of the raw T2|T1 data revealed substantial main effects for age, $F(1,382) = 67.99$, $p = .0001$, $\eta_p^2 = .15$, group, $F(3,382) = 28.81$, $p < .0001$, $\eta_p^2 = .19$, measurement, $F(1,382) = 55.79$, $p < .0001$, $\eta_p^2 = .13$, and lag, $F(5,382) = 2.57$, $p = .025$, $\eta_p^2 = .01$. In addition, a significant Group $\times$ Measurement interaction was found, $F(3,382) = 7.80$, $p < .0001$, $\eta_p^2 = .06$, as well as a significant Group $\times$ Lag interaction, $F(5,382) = 3.14$, $p < .0001$, $\eta_p^2 = .02$. Post hoc (Tukey HSD) analysis indicated that all three RD groups differed from the control group ($p < .0001$). The difference between the RD-only and RD+SLI groups found for T2 performance was also visible for T2|T1 performance ($p = .061$). T2|T1 performance of the RD-only group seems to be particularly affected, relative to TD children, at M2. Notably, as a consequence of adding RAN and PA as covariates, the main effect of group, although remaining significant, was attenuated significantly, $F(3,371) = 5.97$, $p = .001$, $\eta_p^2 = .05$. However, the attenuation was particularly present for M1, where the difference between the RD-only and TD groups had disappeared, whereas the main group effect remained considerable for M2. Overall, only the contrasts between the comorbid groups and the control group remained significant (RD+SLI, $p = .006$; RD+ADHD, $p = .010$).¹

AB parameters

In Fig. 4, the averaged fitted curves for the separate measurement blocks are presented. See Appendix A for an overview of the age corrected group averages of the AB function parameters (cf. Cousineau et al., 2006). All of the depicted curves resemble the shape that was presented in the Introduction (Fig. 1) quite well. That is, after a relatively good performance in the Lag₁ condition, the AB reaches its maximum effect at around Lag₂, and task performance is gradually restored for conditions with larger SOAs in all groups.

¹ Note that to accommodate for unequal sample sizes, all of the above analyses were also performed according to the resampling procedure mentioned in Method. However, because the results did not differ from those reported in this section, they were omitted for reasons of parsimony.

Fig. 4. Fitted accuracy curves for T2/T1 M1 (left) and M2 (right) for RD-only, RD+SLI, and RD+ADHD groups and controls.

Table 3

Pairwise AB parameter group comparisons for two measurement blocks (M1 and M2) with *t*- and *p*-values and effect sizes.

Parameter		RD-only vs. control	RD+SLI vs. control	RD+ADHD vs. control	RD-only vs. RD+SLI	RD-only vs. RD+ADHD	RD+SLI vs. RD+ADHD
Lag ₁ -sparing	M1	$t(369) = 1.96$ $p = .051$ $\eta_p^2 = .01$	<i>ns</i>	$t(316) = -2.10$ $p = .036$ $\eta_p^2 = .01$	<i>ns</i>	$t(83) = 2.77$ $p = .007$ $\eta_p^2 = .09$	$t(33) = 2.15$ $p = .039$ $\eta_p^2 = .13$
	M2	$t(356^a) = 2.46$ $p = .014$ $\eta_p^2 = .02$	$t(309) = 2.76$ $p = .006$ $\eta_p^2 = .02$	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{width}	M1	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{minimum}	M1	$t(369) = -2.44$ $p = .015$ $\eta_p^2 = .02$	$t(319) = -5.14$ $p < .001$ $\eta_p^2 = .08$	$t(316) = -2.98$ $p = .003$ $\eta_p^2 = .03$	$t(86) = 2.99$ $p = .004$ $\eta_p^2 = .10$	<i>ns</i>	<i>ns</i>
	M2	$t(356) = -5.43$ $p < .001$ $\eta_p^2 = .08$	$t(309) = -4.57$ $p < .001$ $\eta_p^2 = .06$	$t(305) = -3.89$ $p < .001$ $\eta_p^2 = .05$	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{amplitude}	M1	<i>ns</i>	$t(319) = 4.13$ $p < .001$ $\eta_p^2 = .05$	<i>ns</i>	$t(86) = -2.68$ $p = .009$ $\eta_p^2 = .08$	<i>ns</i>	<i>ns</i>
	M2	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>

Note: *p*-values greater than .10 are displayed as nonsignificant (*ns*).

^a Due to some attrition, the degrees of freedom are smaller for the second measurement block.

Separate series of MANOVAs were performed on the four T2/T1-based AB parameters (Cousineau et al., 2006) for each measurement block. Table 3 provides an overview of the resulting group contrasts. With regard to Lag₁-sparing, small significant effects were found for the RD-only, RD+SLI, and RD+ADHD (M1) groups as compared with controls. These effects indicate that the RD-only (M1 and M2) and RD+SLI (M2) groups did not show fully recovered performance levels at Lag₁. However, the RD+ADHD (M1) group showed significantly better performance at Lag₁ relative to controls. The latter also applies to the contrasts—with significantly larger effect sizes—with the RD-only ($\eta_p^2 = .09$) and RD+SLI ($\eta_p^2 = .13$) groups at M1. Remarkably, these effects disappeared at M2, where Lag₁-sparing in the RD+ADHD group dropped to the level of the other RD groups. Regarding AB_{width},

Table 4

RAN_{an} controlled pairwise AB parameter group comparisons for two measurement blocks (M1 and M2) with *t*- and *p*-values and effect sizes.

Parameter		RD-only vs. control	RD+SLI vs. control	RD+ADHD vs. control	RD-only vs. RD+SLI	RD-only vs. RD+ADHD	RD+SLI vs. RD+ADHD
Lag ₁ -sparing	M1	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	$t(356) = -1.93$ $p = .054$ $\eta_p^2 = .01$	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{width}	M1	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{minimum}	M1	$t(369) = 2.66$ $p = .008$ $\eta_p^2 = .02$	$t(319) = 1.86$ $p = .063$ $\eta_p^2 = .01$	$t(316) = 2.07$ $p = .004$ $\eta_p^2 = .01$	$t(86) = 1.09$ $p = .061$ $\eta_p^2 = .04$	$t(83) = -2.26$ $p = .026$ $\eta_p^2 = .06$	<i>ns</i>
	M2	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{amplitude}	M1	$t(369) = -2.34$ $p = .020$ $\eta_p^2 = .02$	$t(319) = -1.88$ $p = .061$ $\eta_p^2 = .01$	$t(316) = -2.19$ $p = .030$ $\eta_p^2 = .02$	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>

Note: *p*-values greater than .10 are displayed as nonsignificant (*ns*).

no significant group differences were found. With regard to AB_{minimum}, as predicted, all RD groups performed poorly relative to controls. In addition, there was the predicted (large) difference between the RD-only group and the RD+SLI group (M1), with the latter group performing more poorly. However, this difference had disappeared at M2, apparently due primarily to a significantly poorer performance of the RD-only group relative to M1 ($\eta_p^2 = .02$ to $\eta_p^2 = .08$, respectively). As for AB_{amplitude}, there were medium-sized significant effects for the RD+SLI group at M1 when compared with controls ($\eta_p^2 = .05$) and the RD-only group ($\eta_p^2 = .08$), indicating a predicted *deeper* AB for the comorbid RD+SLI group. However, at M2 these effects had dissipated because all groups showed a significantly deeper AB at M2.

To investigate whether the AB parameter group effects are modified by interactive effects of RAN_{an} and PA, these variables were added as additional covariates in two consecutive series of MANOVAs.

AB × RAN

Regarding RAN_{an}, the results are summarized in Table 4. As for Lag₁-sparing, there were no sizable effects for RAN_{an} except for a marginally significant effect when contrasting the RD-only group with controls at M2, which rendered the earlier found group contrast (see Table 3) insignificant. Apparently, controlling for RAN_{an} attenuated the Lag₁-sparing group difference. A similar trend was visible for M1 except that the effect of RAN_{an} did not reach significant levels. There were no apparent interactions with RAN_{an} for any of the group comparisons for AB_{width}. Quite to the contrary, an attenuating effect on AB_{minimum} of RAN_{an} was found for most group differences at M1 with the exception of a nonsignificant effect for the contrast between the comorbid groups. However, RAN_{an} was not a significant interactive factor for AB_{minimum} at M2. Similarly, RAN_{an} significantly mediated some of the effects for AB_{amplitude} for the contrasts involving the control group at M1 as well as M2.

AB × PA

Regarding PA, the results are summarized in Table 5. As for Lag₁-sparing, PA did not produce any significant effects at M1. For M2, there were significant main effects of PA for the contrasts between the RD-only group and the other three groups, particularly the two comorbid subgroups. However, despite considerable effect sizes of PA for the within-RD contrasts, there was no Group × PA interaction effect. Thus, with the exception of the contrast between the RD-only and control groups, where a previously found main effect (Table 3) of group was rendered insignificant, controlling for PA does not modify the previously found group main effects on Lag₁-sparing. Regarding AB_{width}, similar to the interactions with RAN_{an} (Table 4), PA does not modify group main effects. With regard to

Table 5

PA controlled pairwise AB parameter group comparisons for two measurement blocks (M1 and M2) with *t*- and *p*-values and effect sizes.

Parameter		RD-only vs. control	RD+SLI vs. control	RD+ADHD vs. control	RD-only vs. RD+SLI	RD-only vs. RD+ADHD	RD+SLI vs. RD+ADHD
Lag ₁ -sparing	M1	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	$t(347) = -2.00$ $p = .047$ $\eta_p^2 = .01$	<i>ns</i>	<i>ns</i>	$t(75) = -2.84$ $p = .006$ $\eta_p^2 = .10$	$t(70) = 3.05$ $p = .003$ $\eta_p^2 = .12$	<i>ns</i>
AB _{width}	M1	<i>ns</i>	$t(315) = -1.89$ $p = .060$ $\eta_p^2 = .01$	$t(310) = -2.12$ $p = .035$ $\eta_p^2 = .01$	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	<i>ns</i>	$t(304^a) = -1.89$ $p = .060$ $\eta_p^2 = .01$	<i>ns</i>	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{minimum}	M1	$t(360) = 3.70$ $p < .001$ $\eta_p^2 = .04$	$t(315) = 3.86$ $p < .001$ $\eta_p^2 = .05$	$t(310) = 3.63$ $p < .001$ $\eta_p^2 = .04$	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	$t(347) = 3.04$ $p = .003$ $\eta_p^2 = .03$	$t(304) = 2.50$ $p = .013$ $\eta_p^2 = .02$	$t(299) = 2.18$ $p = .030$ $\eta_p^2 = .02$	<i>ns</i>	<i>ns</i>	<i>ns</i>
AB _{amplitude}	M1	$t(347) = -2.38$ $p = .001$ $\eta_p^2 = .03$	$t(315) = -3.72$ $p < .001$ $\eta_p^2 = .04$	$t(310) = -3.66$ $p < .001$ $\eta_p^2 = .04$	<i>ns</i>	<i>ns</i>	<i>ns</i>
	M2	$t(347) = -1.91$ $p = .057$ $\eta_p^2 = .01$	$t(304) = -1.97$ $p = .050$ $\eta_p^2 = .01$	$t(299) = -1.91$ $p = .057$ $\eta_p^2 = .01$	<i>ns</i>	<i>ns</i>	<i>ns</i>

Note: *p*-values greater than .10 are displayed as nonsignificant (*ns*).

^a Due to some attrition, the degrees of freedom are smaller for the second measurement block.

AB_{minimum}, if controlling for PA performance, the negative group main effects for the RD subgroups are attenuated significantly for both measurements. Finally, an effect of PA significantly modified the group main effect of the AB_{amplitude} parameter for the RD+SLI group when compared with the control group at M1 only.

Measurement effects

To investigate the effects of measurement block, MANOVAs were performed with measurement as a within-participants factor. Fig. 5 shows the parameter estimates for the four groups according to measurements M1 and M2. Regarding Lag₁-sparing, there is a clear crossover interaction, indicating that the comorbid groups show atypical performance decreases at M2 (RD+SLI: $F(1,308) = 10.27$, $p = .001$; RD+ADHD: $F(1,304) = 4.55$, $p = .034$) relative to controls. The RD-only group shows a slope similar to controls. With regard to AB_{width}, as compared with controls, the RD-only group again shows a similar slope, indicating a wider AB, whereas the comorbid groups show a less widened (RD+ADHD) or relatively normalized (RD+SLI) AB at M2. Regarding AB_{minimum}, all four groups show poorer performances at M2. The Group $\times$ Measurement interaction was also significant, $F(1,383) = 2.59$, $p = .053$. However, a further inspection of underlying contrasts indicated that this effect can primarily be attributed to the contrast between controls and the RD-only group, $F(1,355) = 6.93$, $p = .009$. Finally, regarding AB_{amplitude}, there was only one significant contrast found—controls versus RD+SLI, $F(1,308) = 5.78$, $p = .017$ —indicating that the RD+SLI group showed a relatively normalized AB_{amplitude} at M2, whereas this group had performed significantly poorer than controls at M1.

Discriminant function analysis

To determine the optimal functions underlying RSVP performance, discriminant function analysis was performed on all age-corrected RSVP data. The analysis resulted in three functions with respective

Fig. 5. Parameter estimates according to two measurement blocks (M1 and M2).

Fig. 6. Canonical discriminant function scatterplot with group centroids.

canonical correlations of .61, .44, and .32. The first two had significant and marginally significant values of Wilks' λ ($\chi^2 = 286.61$, $df = 144$, $p < .001$ and $\chi^2 = 116.78$, $df = 94$, $p = .056$, respectively), indicating that those functions yielded clear group differences. The first function correlated significantly with nearly all RSVP measurements, with correlations ranging from .19 to .65, but least of all with T2/T1 performances at M1. Therefore, this function seems to be guided by general RSVP performance. The second function primarily loaded on AB-specific RSVP measurements that involved T2 and T2/T1 processing at M1, with more modest correlations ranging from .18 to .33. Fig. 6 depicts the scatterplots and group centroids for the first two (salient) discriminant functions.

Table 6

Results of discriminant function analysis.

Group membership		Predicted group membership				
		RD-only	RD+SLI	RD+ADHD	Control	Total
Count	RD-only	27	5	1	31	64
	RD+SLI	3	11	1	2	17
	RD+ADHD	2	0	5	6	13
	Control	9	5	2	278	294
Percentage	RD-only	42.2	7.8	1.6	48.4	100
	RD+SLI	17.6	64.7	5.9	11.8	100
	RD+ADHD	15.4	0	38.5	46.2	100
	Control	3.1	1.7	0.7	94.6	100

Table 7WR predictive values for RSVP, RAN_{an}, and PA.

	Block	Predictors	ΔR^2	R^2	sr^2	Common variance ($R^2 - \sum sr^2$)
Model 1	1	RSVP _{RD-only}	.368	.368	.230	0
		RSVP _{RD+SLI}			.105	
		RSVP _{RD+ADHD}			.051	
Model 2a	1	RSVP _{RD-only}	.368	.664	.049	.276
		RSVP _{RD+SLI}			.036	
		RSVP _{RD+ADHD}			.008	
	2	RAN _{an}	.296		.296	
Model 2b	1	RSVP _{RD-only}	.368	.523	.098	.217
		RSVP _{RD+SLI}			.039	
		RSVP _{RD+ADHD}			.015	
	2	PA	.154		.154	
Model 3a	1	RSVP _{RD-only}	.368	.705	.031	.428
		RSVP _{RD+SLI}			.020	
		RSVP _{RD+ADHD}			.003	
	2	RAN _{an}	.336		.182	
		PA			.040	
Model 3b (reversed)	1	RAN _{an}	.661	.705	.182	.428
		PA			.040	
	2	RSVP _{RD-only}	.044	.031		
		RSVP _{RD+SLI}		.020		
		RSVP _{RD+ADHD}		.003		

The group centroids in Fig. 6 show that Function 1 separates the RD subgroups from controls. Function 2 seems to further dissociate the RD-only participants from comorbid participants. Application of the discriminant functions resulted in an overall group classification accuracy rate of 82.7% (RD-only: 42.2%; RD+SLI: 64.7%; RD+ADHD: 38.5%; control: 94.6%). The classification results of the discriminant function analysis are presented in Table 6.

The presented accuracy rates indicate that the RSVP task does the best job of detecting controls. Second to controls, it seems to quite adequately single out the children with RD and comorbid SLI. The prediction of the RD-only and RD+ADHD groups seems to be most precarious.

Regression analysis

Finally, and most generally, we wanted to evaluate the predictive value of the RSVP task for WR both exclusively and in concert with RAN_{an} and PA. For this purpose, the extracted group membership probabilities, as resulting from the application of the previously described discriminant functions, were considered together with RAN_{an} and PA as predictors in a series of hierarchical regression analyses, with the WR index as the dependent variable. The results of these analyses are presented in Table 7.

A first run of the analyses (Model 1) showed that RSVP performance alone predicted a significant proportion ($R^2 = .376$) of total WR variance, with the RD-only, RD+SLI, and RD+ADHD groups' probability scores accounting for 23.0%, 10.5%, and 5.1%, respectively. In a second run, Model 2a shows an increase of .296 for the multiple correlation coefficient on account of RAN_{an} . However, inspection of the unique contributions, as indicated by the squared semipartial correlations (sr^2), revealed that these predictors share a significant proportion of WR variance ($R^2 = .276$). Alternatively, including PA (Model 2b) led to a somewhat smaller increase of explained variance (15.4%), with a common component of 21.7%, suggesting that PA, relative to RAN_{an} , explains less unique WR variance and shares less common WR variance with RSVP processing. A third run of the analyses (Models 3a and 3b), which included both RAN_{an} and PA as predictors, indicated a total explained variance of 70.5%. Further inspection of Models 3a and 3b revealed unique contributions of RSVP ($sr^2 = .054$), PA ($sr^2 = .040$), and RAN_{an} ($sr^2 = .182$), indicating RAN_{an} as the strongest predictor of WR performance and RSVP processing and PA explaining a smaller but significant proportion of WR variance each. The results of a reevaluation of the same predictor set, while employing a reversed order of insertion, demonstrate a modest but significant contribution for the RSVP performance measurements above and beyond RAN_{an} and PA and a quite substantial overlap between RSVP processing and RAN_{an} and PA.

Discussion

The goal of this study was to validate earlier findings of poorer or atypical dual target RSVP processing in children with specific or comorbid RD and relate possible effects to phonological processing measurements.

T1 and T2

We began the analyses with the evaluation of the raw RSVP measurements, that is, first target (T1) and second target (T2) correct identification rates. Results indicated significant group differences for both T1 and T2 performances, with the RD-only group performing poorer than controls and comorbid groups performing poorer than the RD-only group. The finding of subnormal T1 and T2 performances in children with RD is consistent with previous studies (McLean et al., 2010; Visser et al., 2004). This can generally be interpreted as reflecting a less accurate and slower system response of reading-disabled children in speeded task situations. With regard to the comorbid groups, the even more depressed performances relative to the RD-only group may be due to additive effects induced by the presence of the comorbid condition. The fact that the differences between the comorbid groups and the RD-only group seem to be more pronounced for T2 than for T1 is suggestive of additional impairments related to dual task requirements.

T2|T1 and AB parameters

Turning specifically to the AB, we found substantial effects of group, indicating that all three RD groups performed significantly poorer than controls, with the RD+SLI group showing the poorest performances. Going beyond the level of general RSVP performance, and consistent with Lallier, Donnadieu, and Valdois (2010) and McLean and colleagues (2010), our results indicate that the RD-only group is primarily differentiated from controls by a lower AB_{minimum} , indicating generally depressed RSVP performances. Because AB_{width} (i.e., duration) and $AB_{\text{amplitude}}$ (i.e., magnitude) are preserved in this group, there is no indication of a prolonged (cf. Visser et al., 2004), deeper (cf. La Rocque & Visser, 2009), or shallower (cf. Lacroix et al., 2005) AB for the current RD-only group. Finally, the RD-only group was slightly impaired on the Lag_1 -sparing parameter, indicating that T1 processing interferes with T2 processing throughout the RSVP task. This result suggests that these children are more vulnerable for stimulus interference when information is presented to them at short temporal proximities (Potter, Staub, & O'Connor, 2002). Alternatively, they may experience problems in maintaining attentional control over the target set template, or their target set template (letters or digits) itself may be deficient. This template can be thought of as a filter that passes stimuli matching the

target set prescription. If this filter is functioning adequately, targets may pass the filter and the occurrence of Lag₁-sparing is probable (Visser, Bischof, & Di Lollo, 1999). However, if it is flawed, this could lead to a suppressed Lag₁-sparing effect. Intriguingly, the group effect for Lag₁-sparing was neutralized by controlling for (alphanumeric) RAN. We speculate that the Lag₁-sparing effect for the RD-only group might be due to the use of alphanumeric stimuli, which are less automatized in children with RD.

With regard to the RD+SLI group, we evaluated the proposal of Lum and colleagues (2007) that a deeper and more prolonged AB may be specific to this subgroup. Contrasting the RD+SLI with the RD-only group revealed substantial group differences for AB_{minimum} and AB_{amplitude}. Besides an overall poorer RSVP task performance, this indicates that the RD+SLI group indeed shows a considerably deeper AB. However, because there were no group differences for AB_{width}, the hypothesized more *prolonged* AB was not there. Thus, as far as SLI is concerned, there appear to be additive effects that could possibly be attributed to known working memory difficulties in children with SLI (e.g., Edwards & Lahey, 1998; Gathercole & Baddeley, 1990; Kamhi & Catts, 1986). As for the comorbid group of RD+ADHD, we hypothesized that enhanced distractibility for salient, task-irrelevant stimuli (Mason et al., 2005) may exert additional negative effects on RSVP performance. Indeed, for this group, a lower AB_{minimum} was found relative to the RD-only group. The other parameters were not affected. Note, however, that it is possible that testing failed to produce further significant results due to the relatively small sample size of this group ($n = 16$). Notwithstanding, and consistent with previous research findings (Bental & Tirosh, 2007; Bolden, Rapport, Raiker, Sarver, & Kofler, 2012; Kibby & Cohen, 2008; Tiffin-Richards, Hasselhorn, Woerner, Rothenberger, & Banaschewski, 2008; Van De Voorde, Roeyers, Verté, & Wiersema, 2011), these results suggest that the mechanisms for high-level processing in working memory are essentially intact in this group and that the explanation of their depressed RSVP performances for dual target conditions with longer temporal proximities may lie in additional impairments in executive functioning. In sum, it appears that the AB_{minimum} parameter most consistently indicates group differences and that the finding of the comorbid groups showing the lowest AB_{minimum} values may be interpreted as reflecting additive effects of ADHD and SLI.

Endurance

Evaluating the effect of fatigue on RSVP performance by comparing the results for two measurement blocks, all groups showed significantly poorer performances at the second measurement. However, compared with the first measurement, the RD groups showed even more depressed RSVP performances relative to controls. Moreover, whereas the RD-only group initially outperformed the comorbid groups, the difference between the RD groups had disappeared at the second measurement. Apparently, the presumed negative effects of sustained attention requirements and/or fatigue were relatively more costly to the RD-only group, although this clustering may also simply be due to floor effects having affected the performances of the comorbid groups. However, the reasoning is consistent with previous findings of children with RD experiencing difficulties with sustained attention (Kupietz, 1990). Of course, this interpretation is necessarily tentative because the concept of sustained attention was not independently operationalized in the current study. Nevertheless, taken at face value, these results present an intriguing, possibly reading-related effect of endurance that would be worthwhile to follow up in future investigations.

Links with RAN and PA

A major aim of this study was to investigate the interactive links of RSVP processing with RAN and PA. In the following subsections, this aim is discussed in the context of group comparisons, and the predictive values of RSVP processing, RAN, and PA, for continuous WR performance.

Group comparisons

Consistent with McLean and colleagues (2009), we found that RAN_{an} mediated some of the negative effects of RD on RSVP processing. A possible explanation is provided by Visser and Ohan (2012),

who suggested that, given a high target–distractor resemblance, high RAN speed might be related to a “larger” AB. These authors suggested that faster RAN leaves extra resources available to be “mis-employed” to process subsequent distractors. Regarding PA, despite larger main effects for AB_{minimum}, group contrasts were very similar to those for RAN_{an}. However, as hypothesized earlier, this similarity might very well be based on different mechanisms. With regard to RAN, the serial aspect seems to be a likely candidate for commonality, whereas the stronger link between PA and AB tasks might be explained by shared working memory involvement. Finally, the finding of the largest and most consistent reading-related effects for AB_{minimum} is in line with Lallier, Donnadieu, and Valdois (2010), suggesting that these effects primarily concern generic (i.e., non-AB-specific) cognitive processes.

Predictive patterns

Investigating the unique and common WR contributions of RSVP processing, RAN_{an}, and PA, regression analysis indicated that the employed RSVP task explains a quite substantial proportion of total WR variance (36%). However, the analyses also indicated significant overlap with RAN and PA. After having accounted for shared variance, there remained a small but significant unique contribution to the prediction of WR by RSVP task performances (5%). In line with McLean and colleagues (2009), the current research yields corroborative evidence for the link between general RSVP task performance and WR performance for a larger sample of typically developing children from a broader age range. Moreover, the current study extends these results to RD subgroups. Also largely consistent with McLean and colleagues (2009, 2010), we found no evidence that AB duration is linked to WR performance, perhaps with the exception of the RD+SLI group. However, it seems that a prolonged AB is associated with concomitant impairments given that the RD-only group showed no such prolongation.

Finally, our results demonstrate stronger associations of RAN with WR than those reported in the study by McLean and colleagues (2010). These findings can safely be attributed to our use of alphanumeric stimuli (Van den Bos & Lutje Spelberg, 2010; Van den Bos, Zijlstra, & Lutje Spelberg, 2002; Wagner, Torgesen, Rashotte, & Pearson, 2013). However, controlling for RAN_{an} (and PA as well) still left significant room for the RSVP task in predicting WR. Although the unique link between RSVP task performances and WR proved to be less strong than that for RAN_{an}, it was still substantial for this age range, with a size similar to that of phonemic awareness. In sum, these findings strongly suggest that, next to phonological processes, the basic capacity to simultaneously process serially presented visual information is essential to reading proficiency.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jecp.2015.05.003>.

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