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Naming problems do not reflect a second independent core deficit in dyslexia: Double deficits explored

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ABSTRACT

The double deficit hypothesis states that naming speed problems represent a second core deficit in dyslexia independent from a phonological deficit. The current study investigated the main assumptions of this hypothesis in a large sample of well-diagnosed dyslexics. The three main findings were that (a) naming speed was consistently related only to reading speed; (b) phonological processing speed and naming speed loaded on the same factor, and this factor contributed strongly to reading speed; and (c) although general processing speed was involved in speeded naming of visual items, it did not explain the relationship between naming speed and reading speed. The results do not provide support for the existence of a second independent core naming deficit in dyslexia and indicate that speeded naming tasks are mainly phonological processing speed tasks with an important addition: fast cross-modal matching of visual symbols and phonological codes.

Introduction

Dyslexic children show severe difficulties with reading and spelling that are not a consequence of sensory impairments, low intelligence, or a lack of educational opportunities (Lyon, Shaywitz, & Shaywitz, 2003). It is widely accepted that the core deficit underlying dyslexia is a phonological deficit,

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and evidence in favor of such a deficit is substantial (for a review, see Vellutino, Fletcher, Snowling, & Scanlon, 2004).

However, impaired phonological processing does not seem to be the only problem in dyslexia; many dyslexics also show problems with speeded naming of visual items. The first demonstration of naming speed problems in dyslexics was given by Denckla and Rudel (1976a, 1976b). They found that dyslexic readers are slower in naming a restricted set of well-known visual items than are normal reading controls and nondyslexic poor readers. Since these first investigations, many researchers have reported that dyslexics were slower when asked to rapidly name visual items (for an overview, see Wolf, Bowers, & Biddle, 2000). To explain the persistent finding of naming speed problems in dyslexics, Wolf and Bowers developed the double deficit hypothesis (Bowers & Wolf, 1993; Wolf, 1997; Wolf & Bowers, 1999). The double deficit hypothesis acknowledges the existence of a phonological deficit but postulates that some dyslexics show a second independent naming speed deficit that is assumed to be equally important in causing reading problems. The claim that naming speed problems represent a second independent core deficit in dyslexia assumes that naming speed contributes uniquely to reading and spelling performance and that there should exist a subgroup of dyslexics showing naming speed problems in the absence of phonological problems. Moreover, it is assumed that dyslexics with a double deficit will show more severe literacy problems than will dyslexics with a single naming or single phonological deficit because the two problems are independent and additive. As the current study aims to test the main assumptions of the double deficit hypothesis in a large clinical sample of dyslexics, we summarize the evidence for each of these assumptions (for a review, see Bowers & Ishaik, 2003; Vukovic & Siegel, 2006).

Main assumptions of the double deficit hypothesis

The first main assumption claims the *unique contribution of naming speed skills to literacy performance.* Although several cross-sectional and longitudinal studies have reported that naming speed contributed uniquely to the variance in reading ability (Bowers & Swanson, 1991; Eleveld, 2005; Felton & Brown, 1990; Hulslander et al., 2004; Manis, Doi, & Bhadha, 2000; Van den Bos, 1998; Van den Bos, Zijlstra, & Van den Broeck, 2003; Wolf, 1986; Wolf, Bally, & Morris, 1986), other studies have found only a modest contribution of naming speed to literacy performance when compared with the contribution of phonological awareness (Cardoso-Martins & Pennington, 2004; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Plaza & Cohen, 2004). Some studies have even failed to find any unique contribution of naming speed to reading or spelling performance (Patel, Snowling, & De Jong, 2004; Torgesen, Wagner, & Rashotte, 1994). In reviewing the predictive value of naming speed, Allor (2002) concluded that although all studies have found a unique contribution of phonological awareness to literacy performance, the evidence for a unique contribution of naming speed is less convincing. In addition, naming speed seems to have a stronger and more consistent relationship with reading speed than with other literacy measures (e.g., Cornwall, 1992; Sunseth & Bowers, 2002; Vukovic, Wilson, & Nash, 2004; Wolf et al., 2000), although some studies have found unique contributions to spelling (Pennington et al., 2001; Savage, Pillay, & Melidona, 2008) or reading accuracy (Cornwall, 1992; Savage et al., 2008; Wolf et al., 1986).

The second assumption of the double deficit hypothesis states that *naming speed and phonological awareness deficits are independent and thus relatively unrelated.* The correlation between naming speed and phonological awareness indeed seems to be rather modest. Swanson, Trainin, Necoechea, and Hammil (2003) found a correlation of .38 in their meta-analysis of studies reporting correlations between naming speed and phonological awareness performance. In addition, Neuhaus and Swank (2002) showed that variance in rapid naming performance could not be accounted for entirely by variance in phonological processing, suggesting that naming speed cannot be interpreted as a purely phonological variable. However, some studies have suggested that the shared variance of phonological awareness and naming speed predicts at least as much of the variance in reading performance as does the unique variance of the separate variables (Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). Chiappe, Stringer, Siegel, and Stanovich (2002) showed that only 25% of the variance in reading that is explained by naming speed is unique, with the other 75% being shared with phonological awareness. In other words, although the modest correlation between phonological awareness and naming speed suggests that speeded naming tasks incorporate only a relatively small phonological component, it seems to be just this phonological component in speeded naming tasks that predicts reading performance the best.

The third main assumption of the double deficit hypothesis predicts the existence of a subgroup of dyslexics suffering from naming speed deficits in the absence of phonological deficits (single naming speed deficit). Wolf et al. (2000) reported several studies revealing a substantial percentage of dyslexics exhibiting such a single naming speed deficit. Moreover, Morris et al. (1998) identified one subtype that was characterized by only naming speed problems when using a cluster analysis method. It should be noted, however, that the naming speed problems in this subgroup were relatively mild. Other studies did not find strong evidence for the existence of a single naming deficit subtype. Pennington et al. (2001) included several phonological processing tasks to investigate the phonological performance of 71 dyslexics and found only one child who showed a naming deficit in the absence of phonological processing problems, suggesting that classification of subtypes depends greatly on the measures and cutoff points used for classification. Moreover, Spector (2005) showed that classification of subtypes is unstable because only half of the sample was reclassified to the same subtype a year after testing. In other words, the evidence for the existence of a single naming speed deficit subgroup is at least mixed.

The fourth assumption predicts that children with a double deficit *should be more impaired in reading and spelling than are children with a single deficit* because both deficits contribute independently to literacy problems and thus should be additive (Hulslander et al., 2004; Wolf et al., 2000). In addition, if naming speed and phonological awareness are related to different components of the reading process, the single naming speed deficit subtype should show a different performance pattern than the single phonological deficit subtype. Some studies (e.g., Lovett, Steinbach, & Frijters, 2000; Manis et al., 2000) have found support for the claim that double deficit children are more impaired than single deficit children. Others have not found any differences in reading and spelling between children with a double deficit and those with a single deficit (e.g., Ackerman, Holloway, Youngdahl, & Dykman, 2001). Wimmer, Mayringer, and Landerl (2000) showed that mainly reading speed, and not reading accuracy or spelling, was more impaired in children with a double deficit than in children with a single phonological deficit. However, because reading accuracy was high for all subtypes, results regarding word reading accuracy should be interpreted with caution. Schatschneider et al. (2002) and Vellutino et al. (2004) suggested that differences in reading ability between double deficit groups and single deficit groups may be a statistical artifact. Because naming speed and phonological processing are interrelated, children with a double deficit may have more pronounced phonological difficulties and thus more severe reading problems. On the other hand, Sunseth and Bowers (2002) and Wimmer et al. (2000) tested the severity of phonological processing problems in the double deficit subtypes and could not find evidence for the claim that double deficit children have more pronounced phonological difficulties.

To summarize, the results of studies investigating one or more double deficit assumptions are inconsistent and the evidence for the double deficit hypothesis is equivocal. The large variation in sample sizes, selection procedures for participants, and selected behavioral tasks may account at least partly for the inconsistent results (Vukovic & Siegel, 2006). An additional factor that might complicate the interpretation of the evidence for the double deficit hypothesis is the dynamic nature of the reading process and its related cognitive processes during literacy development. Therefore, the strength and nature of the relation between naming speed and literacy may depend on the age and reading expertise of the sample under study. Some studies have found evidence that the influence of naming speed and phonological awareness on reading performance changes with more reading experience, although not always in the same direction (e.g., Kirby, Parrila, & Pfeiffer, 2003; Landerl & Wimmer, 2008; Vaessen & Blomert, 2008, 2009; Van den Bos, Zijlstra, & lutje Spelberg, 2002; Wagner et al., 1997).

A final issue potentially complicating a straightforward interpretation of the evidence in the double deficit debate resides in the differences in orthographic transparency of the test language used in the different studies. In general, in opaque orthographies such as English, the evidence for the role of phonological awareness in reading development is strong if compared with the evidence for naming speed problems (e.g., Allor, 2002; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner, Torgesen, &

Rashotte, 1994). However, studies in relatively transparent orthographies have reported a rather modest, and over time decreasing, contribution of phonological awareness to reading, whereas naming speed contributions were strong and consistent (e.g., De Jong & Van der Leij, 1999; Landerl & Wimmer, 2008). Also in nonalphabetic languages such as Chinese, naming speed was consistently related with reading speed over time (Liao, Georgiou, & Parrila, 2008).

There might be several reasons for the observed differences between studies in opaque and more orthographically transparent languages. The orthographic structure of the language itself may influence the reading development of children and thus the cognitive processes involved in reading (see, e.g., the orthographic depth hypothesis [Katz & Frost, 1992] or the psycholinguistic grain size theory [Ziegler & Goswami, 2005]). In addition, methodological issues may have influenced the contrastive results reported for transparent and nontransparent languages. First, in transparent orthographies, performance on phonological awareness measures is often high and consequently the performance range is restricted, thereby potentially attenuating the estimated contributions of phonological awareness to reading in transparent languages. Including a sensitive measure for phonological awareness might help to avoid this problem, as does including a speeded measure for phonological awareness. For instance, Patel et al. (2004) showed that the contribution of phonological awareness to reading performance was strong in English as well as Dutch students when measured with a sensitive phonological measure including a speed component. A second methodological issue is that most English language studies have used reading accuracy to index reading ability, whereas most studies in transparent orthographies have used reading speed measures because word accuracy levels reach ceilings early in reading development (Wimmer & Hummer, 1990). A recent study suggested that the contrasting results between opaque and transparent languages regarding the contribution of phonological awareness and naming speed to reading may result because of a confound between the degree of transparency of a language and the habit of comparing accuracy measures in the one type of language with speed measures in the other type of language (Vaessen & Blomert, 2009). Therefore, accuracy and speed measures for both phonological awareness and reading were included in the current study.

Independent of the question as to whether naming speed problems represent a second core deficit, it is important to discuss what the nature of naming speed problems is. Some authors have claimed that naming speed problems reflect a general processing speed deficit (Kail & Hall, 1994), potentially causing a disruption of the temporal integration of visual and phonological information but also timing-related deficits outside of the language domain (Bowers, Sunseth, & Golden, 1999; Bowers & Wolf, 1993; Farmer & Klein, 1995; Wolf, 1991). However, several studies have failed to find any disruptions in general speed or timing for nonlanguage tasks (Chiappe et al., 2002; De Jong & Van der Leij, 2003), suggesting that the nature of the naming deficit is language specific. Several studies have reported that naming speed is most strongly related to literacy tasks that rely on the recognition of word-specific orthographic patterns such as the recognition of exception words (Bowers & Ishaik, 2003; Manis et al., 2000; Wile & Borowsky, 2004; Wolf, 1997; Wolf & Bowers, 1999), leading to the hypothesis that naming speed reflects a process that is involved in orthographic skill. However, the exact nature of this underlying process is still unclear; speeded naming has been associated with visual letter recognition speed (e.g., Bowers & Wolf, 1993), learning new orthographic patterns (e.g., Levy, Bourassa, & Horn, 1999), learning arbitrary associations (Manis et al., 2000), and the efficiency of integrating orthographic and phonological information (Berninger, Abbott, Billingsley, & Nagy, 2001; Bowers & Ishaik, 2003), among others.

Several opponents of the double deficit hypothesis have suggested that naming speed problems do not represent an independent core deficit but rather merely reflect problems in phonological processing; naming visual items is thought to depend on the fast retrieval of phonological codes, which in turn might be influenced by phonological problems in dyslexia (Chiappe et al., 2002; Clarke, Hulme, & Snowling, 2005; Katz & Shankweiler, 1985; Pennington et al., 2001; Torgesen et al., 1994, 1997; Vukovic & Siegel, 2006; Wagner & Torgesen, 1987; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). The fact that naming speed is not highly correlated with phonological awareness seems to contradict a purely phonological explanation of naming speed problems. However, since traditional phonological awareness tasks usually do not measure speed, potential relationships between speed of phonological decoding/processing and naming speed might be concealed. Therefore, in the current study, we included a speed measure in a traditional phonological awareness task.

In conclusion, the evidence for the double deficit hypothesis is mixed, and the nature of the naming deficit remains elusive. Therefore, Vukovic and Siegel (2006) recommended that the assumptions of the double deficit hypothesis be tested within participants in a large group of well-diagnosed dyslexics.

The current study

We investigated the four main assumptions of the double deficit hypothesis within the same group of well-diagnosed Dutch dyslexic children. We conducted an archive study using diagnostic data of 162 dyslexic children who were tested at specialized dyslexia institutes in The Netherlands. Nationally standardized measures for reading speed, reading accuracy, and spelling were available, making it possible to investigate the relationship between naming speed and different literacy measures. Furthermore, the phonological awareness task includes a measure for phonological processing speed. In addition, a visual matching speed measure was included to investigate whether naming speed problems in dyslexia are a result of more general processing speed problems. The dyslexic sample had a wide grade and age range (Grades 1–6, ages 80–153 months). This wide range created the opportunity to investigate whether the influence of naming speed and phonological awareness on literacy performance differs between younger and older dyslexics. In closing, it should be pointed out that Dutch is a language with a fairly transparent orthography, comparable to German (Borgwaldt, Hellwig, & De Groot, 2005), and is more consistent in the grapheme-to-phoneme direction than in the phoneme-to-grapheme direction.

Method

Participants and procedure

We used diagnostic data that were collected from the archives of a specialized dyslexia institute, the Regional Institute for Dyslexia, situated in four different regions in The Netherlands. We collected a sample of consecutive cases who had been diagnosed as dyslexic on the basis of a psychometric evaluation of their performance on a cognitive reading and spelling test battery. For all but one of the tests, Dutch national norms were available. These tests were standardized on large representative samples of the Dutch school population; this is possible because of the relatively homogeneous educational system for reading and spelling in The Netherlands. These normative data made it possible to compare the performance of the dyslexic sample with that of a large unselected school population.

At the institute, children are diagnosed as dyslexic when having severe reading and/or spelling problems in the absence of sensory, neurological, or attention problems. Children with clinically manifest comorbidity possibly related to the reading and spelling problems are not diagnosed as dyslexic and were not included in the study. Severe reading and/or spelling problems were defined as having a percentile score of 10 or less on a Dutch standardized word reading test (One-Minute Test [Brus & Voeten, 1973]) and/or having a percentile score of 10 or less on a standardized spelling to dictation test (PI-dictee [Geelhoed & Reitsma, 1999]). All included children at least had performance scores for reading and spelling, phoneme deletion, rapid naming speed, and an assessment of their IQ (Weschler Intelligence Scale for Children–Revised , 1986]).

The final sample consisted of 162 primary school children who at the time of testing ranged between 80 and 153 months of age (*M* = 114.6 months, SD = 17.7).

Tasks

Speed and accuracy of reading. The standardized word reading task, the One-Minute Test (OMT) (Brus & Voeten, 1973), contains 116 words that vary from one to four syllables presented in four columns of 29 words. The list includes high-frequency words as well as low-frequency words. Reading speed was defined as the total amount of words read in 1 min, whereas reading accuracy was defined as the percentage of correctly read words (number of correctly read words/total number of words read in 1 min $*$ 100). Dutch norms are available for children from Grade 1 to the first class of secondary school (Van den Bos, lutje Spelberg, Scheepstra, & de Vries, 1994).

Speed and accuracy of pseudoword reading. In the standardized pseudoword reading task, the *Klepel* (Van den Bos et al., 1994), the syllabic structure and length of the pseudowords are similar to the words of the OMT. Most pseudowords differed in more than one letter from the words of the OMT. Reading speed was defined as the total amount of pseudowords read in 2 min, whereas reading accuracy was defined as the percentage of correctly read pseudowords (number of correctly read pseudowords/total number of pseudowords read in 2 min $*$ 100). Dutch norms are available for children from Grade 1 to the first class of secondary school.

Accuracy of spelling. The standardized word spelling to dictation task, PI-dictee (Geelhoed & Reitsma, 1999), consists of 135 words of increasing difficulty and syllabic complexity. The total amount of correctly spelled words was scored. Dutch norms are available for children from Grade 1 to Grade 6.

Speed and accuracy of phonological awareness. A phoneme deletion task developed by the Regional Institute for Dyslexia was used. Accuracy was defined as the total number of correct items. Mean response time was calculated by averaging the response latencies between the presentation of the word and the answer. Although the phoneme deletion task has no national norms, the data of 162 normal reading children from Grades 1 to 5 were used as the control norm group.

Naming speed. An adapted version of the Denckla and Rudel task was used to measure naming speed of letters, digits, and objects. The reaction time is time per 50 items. Dutch norms are available for children from kindergarten to secondary school (Van den Bos, 2003).

General intelligence. For verbal, nonverbal, and full-scale IQ scores (WISC-R, 1986), two subtasks, Coding and Digit Span, were used as measures for visual matching speed and verbal working memory, respectively. The Dutch version of the WISC-R has norms for children between 6 and 16 years of age.

Results

The assumptions of the double deficit hypothesis were tested using statistical procedures that assume normal distribution of the data and equal variances between groups. Not all tasks revealed a normal distribution. Therefore, we used log-transformed scores for phoneme deletion and naming speed tasks and square root-transformed scores for reading and spelling measures. The scores on WISC–digit span and WISC–coding were normally distributed and did not need transformation. After transformations, all scores were normally distributed except for word reading speed (scores showed a negative kurtosis value) and phoneme deletion accuracy (scores were somewhat positively skewed). Another methodological issue that should be taken into consideration is that a population of dyslexics might show a restricted performance range on reading and reading-related measures, especially when they are selected for low performance on a reading measure. A restricted range might attenuate the correlations and other analyses based on correlations within this population. However, a comparison of the variance in the dyslexic population and the variance in the normative samples of the tasks showed that the standard deviation (SD) in the dyslexic population was equal to or even larger than that in the normative samples, although mean scores were much lower than in the normative sample. The only exceptions were the word reading speed and pseudoword reading speed measures. For these tasks, the size of the correlations and amount of explained variance might be attenuated, and these values should be interpreted with caution.

Performance on literacy tasks, cognitive tasks, and IQ measures

Means and SDs on literacy tasks, IQ, and cognitive tasks are presented in Table 1. In addition, the mean standardized scores on the tasks (if available) are shown (all standardized scores are expressed in standard scores with a mean of 10 and an SD of 3), and the percentage of children showing a standardized score of 6 (percentile 10) or less is presented. In addition to poor performance on the reading and spelling tasks, the dyslexic sample showed poor performance on phoneme deletion, pseudoword

Table 1
Performance on literacy tasks, cognitive tasks, and IQ measures.

	Raw score		Standardized score (SS)[a]		% children with SS ⩽ 6 or IQ < 80
	Mean	SD	Mean	SD	
IQ full-scale (WISC)	n.a.	n.a.	102.6	11.0	1.9
IQ verbal (WISC)	n.a.	n.a.	102.9	12.2	1.9
IQ nonverbal (WISC)	n.a.	n.a.	101.8	12.3	3.9
RWR raw score (correct words/min)[b]	33.1	16.0	4.7	2.3	83.3
RWR speed (words/min)	36.5	15.3	n.a.	n.a.	n.a.
RWR accuracy (% correct)	87.7	12.8	5.8	4.0	58.1
PWR raw score (correct words/2 min)[b]	22.9	13.2	5.4	2.1	74.1
PWR speed (words/2 min)	38.7	15.5	n.a.	n.a.	n.a.
PWR accuracy (% correct)	57.5	17.0	6.4	2.9	56.1
Spelling (score, maximum = 135)	49.8	27.6	3.1	2.4	86.4
PA speed (s/item)	5.0	2.4	n.a.	n.a.	n.a.
PA accuracy (score, maximum = 28)	19.3	6.7	4.1	4.0	72.2
RAN letters (s/50 items)	38.1	11.3	6.1	3.6	50.6
RAN digits (s/50 items)	34.3	9.9	7.0	3.8	45.7
RAN objects (s/50 items)	59.1	16.2	7.3	3.4	40.7
WISC–digit span (score, maximum = 30)	9.7	2.6	9.0	2.8	19.2
WISC–coding (score, maximum = 93)	39.5	9.5	9.7	2.7	9.0

Note. WISC, Wechsler Intelligence Scale for Children; RWR, real word reading; PWR, pseudoword reading; PA, phonological awareness; RAN, rapid automatized naming. n.a., not available.

[a] Standardized scores: IQ expressed in IQ scores (mean = 100, SD = 15); performance on other tasks expressed in standardized scores (mean = 10, SD = 3). Standardized *z* scores for naming tasks and reading accuracy tasks were transformed into standardized scores to improve comparability of performance levels between tasks.

[b] Raw scores on the reading tasks embody both reading speed and reading accuracy. In further analyses, we use only reading speed and reading accuracy scores.

reading speed, and naming speed. Working memory seemed to be less affected; only 19% scored below the 10th percentile. The mean score on WISC–coding fell within the normal range, and only 9% of the sample performed below the 10th percentile, showing that the dyslexic sample did not exhibit major visual matching speed problems.

Naming speed and phonological awareness in relation to literacy measures

To get a first insight into the overall relationship between tasks, partial correlations (controlled for age) were calculated (Table 2). The results showed that phoneme deletion scores (accuracy and speed) were related to reading accuracy as well as reading speed. In contrast, naming speed was substantially correlated only with real word and pseudoword reading speed and not with reading accuracy. Furthermore, verbal and full-scale IQ scores were correlated with real word reading accuracy and speed, spelling, and phoneme deletion accuracy but not with naming speed or phonological processing speed. WISC–digit span was modestly but significantly correlated with all reading and spelling measures except pseudoword reading speed. Also, digit span scores were related to performance on the phoneme deletion task (accuracy and speed). Performance on WISC–coding, was correlated only with naming speed and not with phonological awareness accuracy or speed, reading speed, reading accuracy, or spelling performance.

Testing the assumptions of the double deficit hypothesis

Unique contributions of naming speed to reading and spelling performance

To investigate whether naming speed contributed uniquely to reading and spelling performance, hierarchical regression analyses were performed. WISC–coding was not included in analyses because this task was not correlated with any of the reading or spelling measures. In the initial analyses, WISC–digit span was entered in the model directly after verbal IQ. However, WISC–digit span did not

Table 2
Relations between cognitive and literacy skills (partial correlations controlled for age).

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. RWR speed														
2. RWR accuracy	**.40**													
3. PWR speed	**.78**	**.31**												
4. PWR accuracy	.17	**.49**	.03											
5. Spelling	**.56**	**.43**	**.35**	**.32**										
6. PA accuracy	**.28**	**.30**	**.20**	**.22**	**.21**									
7. PA speed	−**.37**	−**.32**	−**.35**	−**.35**	−**.29**	−.08								
8. RAN letters	−**.45**	−.06	−**.55**	−.04	−**.21**	−.10	**.30**							
9. RAN digits	−**.40**	−**.19**	−**.61**	−.06	−.15	−.17	**.32**	**.69**						
10. RAN objects	−**.25**	−.02	−**.36**	.16	−.14	−.14	**.23**	**.40**	**.51**					
11. IQ full-scale	**.26**	**.20**	.07	.12	**.30**	**.23**	−.15	−.04	−.03	−.17				
12. IQ verbal	**.26**	**.24**	.08	.14	**.33**	**.23**	−.13	−.06	.03	−.06	**.83**			
13. IQ nonverbal	.15	.07	.05	.05	.15	.15	−.09	.01	−.09	−.22	**.77**	**.30**		
14. Digit span	**.21**	.22	.07	**.26**	.22	**.32**	−**.22**	−.12	.10	−.05	**.31**	**.46**	.03	
15. Coding	.17	.02	.14	.11	.13	.12	−**.18**	−**.33**	−**.24**	−**.44**	**.23**	.04	**.34**	.06

Note. Significant correlations ($p < .05$) are printed in bold. RWR, real word reading; PWR, pseudoword reading; PA, phonological awareness; RAN, rapid automatized naming.

contribute to any of the literacy measures after controlling for verbal IQ. Therefore, new analyses were performed without WISC–digit span.

Age was entered in the first step in the regression equation, and verbal IQ was entered in the second step. In the first model, phonological awareness (PA) accuracy and speed were entered in the third and fourth steps, respectively, and a combined measure of rapid automatized naming (RAN) letters and digits was entered last. In the second model, RAN was entered before PA accuracy and speed.

The results of the hierarchical regressions (R^2 and R^2 change of each subsequent model) are presented in Table 3. The composite score of naming speed of RAN letters and digits predicted a significant amount of variance of word and pseudoword reading speed (5 and 17%, respectively) even after controlling for phonological awareness speed and accuracy. In contrast, naming speed did not predict any variance in reading accuracy and spelling.

Phonological awareness accuracy contributed modestly to all aspects of literacy (2–4%) when entered into the equation before RAN. After controlling for RAN, this variable contributed significantly to word and pseudoword reading accuracy and to real word reading speed (1–3%). Phonological awareness speed contributed significantly to all aspects of literacy (2–9%) even after controlling for RAN performance.

Table 3
Contributions of naming speed and phonological awareness to reading and spelling performance (hierarchical regression analyses).

Step	RWR speed		RWR accuracy		PWR speed		PWR accuracy		Spelling	
	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
1. Age	.52	.52**	.20	.20**	.32	.32**	.21	.21**	.49	.49**
2. IQ verbal	.56	.04**	.26	.05**	.33	.01	.24	.03*	.57	.08**
3. PA accuracy	.59	.03**	.30	.04**	.35	.02*	.27	.04*	.59	.02*
4. PA speed	.66	.06**	.35	.05**	.43	.08**	.35	.08**	.63	.04**
5. RAN letters and digits	.71	.05**	.35	.00	.60	.17**	.36	.01	.63	.00
3. RAN letters and digits	.67	.11**	.27	.01	.58	.25**	.24	.00	.59	.02*
4. PA accuracy	.69	.01*	.30	.04**	.58	.00	.27	.03*	.60	.01
5. PA speed	.71	.02*	.35	.05**	.60	.02*	.36	.09**	.63	.03**
Adjusted R^2	.70**		.32**		.58**		.34**		.62**	

Note. RWR, real word reading; PWR, pseudoword reading; PA, phonological awareness. RAN letters and digits is a composite score of rapid automatized naming letters and digits.
* $p < .05$.
** $p < .01$.

Validity of subtypes

The double deficit hypothesis assumes that a subgroup of dyslexics shows naming speed problems in the absence of phonological problems. To test this assumption, the sample was divided in four groups: children with a single phonological deficit, children with a single naming speed deficit, children with a double deficit and children with no deficit in phonological awareness or naming speed. Definitions for a naming deficit and a phonological deficit were as follows: performing at least 1 SD below the average of the relevant norm group on a composite score on RAN letters and digits and performing at least 1 SD below the average on phoneme deletion accuracy, respectively. In our sample, 17 children (10.5%) showed a single naming deficit (ND), 66 children (40.7%) showed a double deficit (DD), 51 children (31.5%) showed a single phonological deficit (PD), and 28 children (17.3%) did not show problems on phoneme deletion or RAN.

To check whether the single naming speed subtype indeed did not show phonological problems of any type, we investigated performance on verbal working memory and phonological awareness speed. Within the sample of 17 children with a single ND subtype, 5 performed below the normal range (standardized score < 8) on verbal working memory (digit span), and, 3 ND children showed very slow response times on the phoneme deletion task (mean reaction time > 7 s, which is more than 1 SD above the mean of all dyslexics). In other words, only 9 children in our sample of 162 children (5.5%) showed a single naming deficit in the absence of phonological problems of any kind.

Independence of phonological processing and naming speed

The third assumption that was tested concerns the independence of naming speed and phonological processing. Correlations (presented in Table 2) showed that naming speed and phoneme deletion performance were not significantly related (correlation coefficients with RAN letters, digits, and objects varied between .10 and .17, $p > .05$) and that the correlation between naming speed and digit span performance was not reliable (rs between .05 and .12, $p > .05$). However, naming speed and phoneme deletion speed were significantly correlated (RAN letters $r = .30$, RAN digits $r = -.32$, RAN objects $r = .23$, all ps < .05).

Severity of reading and spelling problems in DD subtype

The double deficit hypothesis assumes that the DD subtype is more impaired in reading and/or spelling than the single ND subtype because both deficits contribute independently to their reading and spelling problems. In addition, the single ND subtype is assumed to show a literacy performance pattern different from that of the single PD subtype.

Analyses of covariance (ANCOVAs), controlled for age, were used to investigate the effect of deficit subtype on literacy performance. Post hoc analyses (with Bonferroni correction) were used to compare the three double deficit subtypes (the no-deficit subgroup was excluded from analysis). Reading and spelling abilities of the three subtypes are presented in Fig. 1.

A significant main effect of deficit subtype was found for pseudoword reading speed, $F(2, 128) = 9.153$, $p < .0001$, $r = .35$, but not for real word reading speed, $F(2, 128) = 2.275$, $p > .05$, $r = .18$. Post hoc comparisons revealed that the DD subtype was slower than the PD subtype on pseudoword reading ($p < .001$). The single ND subtype did not differ from the DD subtype or the PD subtype ($p > .05$).

Furthermore, a significant main effect of deficit subtype was found for real word reading accuracy, $F(2, 128) = 3.004$, $p < .05$, $r = .22$. Children with an ND made significantly fewer errors than did children with a PD ($p < .05$). The DD subtype did not differ from the single deficit subtypes ($p > .05$).

No significant main effect of subtype was found for pseudoword reading accuracy, $F(2, 128) = 1.150$, $p > .05$, $r = .13$, or spelling, $F(2, 128) = 0.735$, $p > .05$, $r = .10$. Because some children who were classified as having a single naming deficit actually showed problems with verbal working memory or phoneme deletion speed, it is possible that the results of the single ND subtype are influenced by these phonological problems. Therefore, the performance of the 9 "pure" ND children was investigated (see Table 4). The performance of this pure ND group was somewhat better than that of the original ND group on all reading and spelling measures. However, the difference between the pure ND group and the single PD group was significant only for real word reading accuracy, main effect of subtype, $F(2, 123) = 4.064$, $p < .05$, $r = .25$, post hoc comparisons between PD and pure ND,

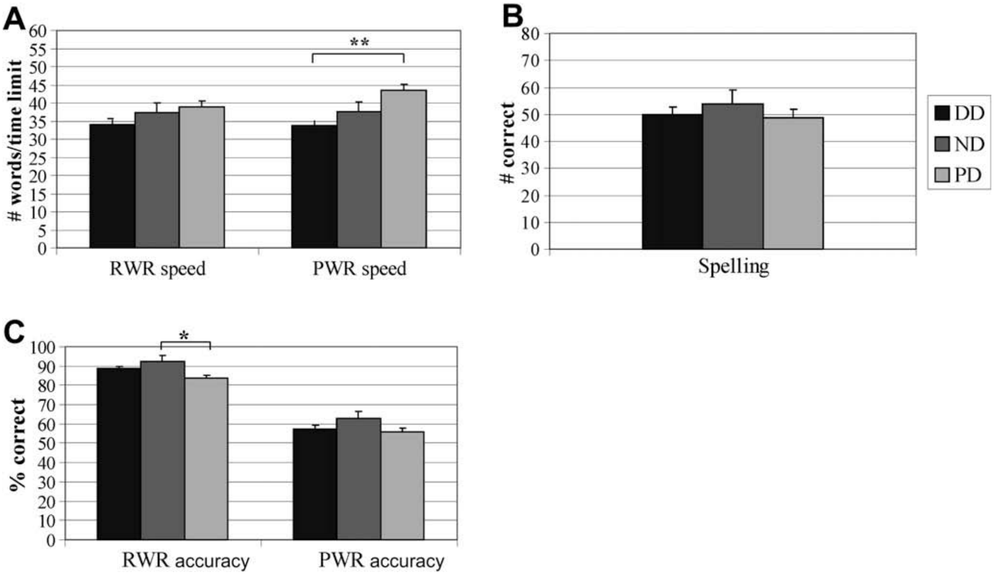

Fig. 1. Reading and spelling performance of single and double deficit subtypes: (A) reading speed; (B) spelling; (C) reading accuracy. DD, double deficit; ND, naming deficit; PD, phonological deficit; RWR, real word reading; PWR, pseudoword reading.

Table 4
Means and standard deviations on the literacy tasks for the double deficit subtypes (ND children with verbal working memory problems or phonological processing speed problems excluded).

	DD		Pure ND		PD	
	Mean	SD	Mean	SD	Mean	SD
RWR speed (words/min)	34.6	14.5	38.9	18.2	39.1	17.1
RWR accuracy (% correct)	88.9	10.2	49.9	4.6	83.4	16.0
PWR speed (words/2 min)	34.5	12.1	35.1	14.8	43.7	17.0
PWR accuracy (% correct)	57.7	15.8	68.6	8.3	55.7	19.1
Spelling (# correct, maximum 135)	51.0	26.1	57.1	36.2	49.1	30.0

Note. DD, double deficit group; pure ND, pure single naming deficit group; PD, single phonological deficit group; RWR, real word reading; PWR, pseudoword reading.

$p < .05$. Thus, the exclusion of children with verbal working memory or phonological processing speed problems from the ND group led to a generally less severely affected group of children but did not lead to different outcome patterns.

Development of relationship among naming speed, phonological awareness, and literacy performance

The relationship among phonological awareness, naming speed, and literacy performance may change when children grow older and have more reading experience. To investigate the effect of age, the sample was divided into two age groups based on the median age of the sample (113 months). There were several children whose age was 113 months; therefore, the sizes of the two subsamples were not completely equal (see Table 5). Hierarchical regression analyses were performed for each age group (young dyslexics $n = 79$, older dyslexics $n = 83$) with (pseudo)word reading speed, reading accuracy, and spelling as independent variables. Age was entered first in the regression equation, followed by verbal IQ. In the first model, phoneme deletion accuracy and phoneme deletion speed were entered as the third and fourth steps, respectively, followed by a composite score of RAN letters and

Table 5
Means and standard deviations on literacy tasks, IQ, and cognitive tasks for the two age groups.

	Young dyslexics (age < 113 months, n = 79)		Old dyslexics (age ⩾ 113 months, n = 83)	
	Mean	SD	Mean	SD
IQ full-scale (WISC)	104.5	11.3	100.7	10.5
IQ verbal (WISC)	104.6	11.6	101.3	12.6
IQ nonverbal (WISC)	103.5	13.3	100.1	11.0
RWR speed (words/min)	27.0	11.0	45.6	13.3
RWR accuracy (% correct)	84.2	14.4	91.0	10.1
PWR speed (words/2 min)	31.5	12.3	45.5	15.1
PWR accuracy (% correct)	52.2	14.8	62.4	17.5
Spelling (# correct, maximum = 135)	34.8	17.4	64.2	28.0
PA speed (s/item)	5.7	2.3	4.3	2.3
PA accuracy (# correct, maximum = 28)	16.7	6.6	21.8	5.9
RAN letters (s/15 items)	43.5	11.2	33.0	8.8
RAN digits (s/50 items)	37.8	9.5	31.0	9.1
RAN objects (s/50 items)	65.3	16.5	53.2	13.7
WISC–digit span (score, maximum = 30)	9.0	1.9	10.4	2.9
WISC–coding (score, maximum = 93)	37.7	10.2	41.3	8.5

Note. WISC, Wechsler Intelligence Scale for Children; RWR, real word reading; PWR, pseudoword reading; PA, phonological awareness; RAN, rapid automatized naming.

digits. In the second model, RAN letters and digits was entered as the third step, followed by phoneme deletion accuracy and phoneme deletion speed as the fourth and fifth steps, respectively.

Means and standard deviations on the cognitive and literacy tasks of the two age groups are shown in Table 5. In Table 6, the results of the regression analyses are presented. In general, the results show

Table 6
Contributions of naming speed and phonological awareness to reading and spelling performance (hierarchical regression analyses) for the two age groups.

Age < 113 months	RWR speed		RWR accuracy		PWR speed		PWR accuracy		Spelling	
Step	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
1. Age	.37	.37**	.34	.34**	.27	.27**	.05	.05*	.25	.25**
2. IQ verbal	.38	.02	.40	.06**	.27	.00	.05	.00	.33	.08**
3. PA accuracy	.38	.00	.41	.01	.27	.00	.06	.01	.33	.00
4. PA speed	.42	.03	.44	.03	.31	.05*	.15	.09**	.38	.05*
5. RAN letters and digits	.57	.15**	.47	.03	.59	.28**	.19	.04	.40	.02
3. RAN letters and digits	.56	.17**	.42	.02	.57	.31**	.07	.02	.36	.03
4. PA accuracy	.56	.00	.43	.01	.58	.00	.08	.01	.36	.00
5. PA speed	.57	.01	.47	.04*	.59	.02	.19	.11**	.40	.04*
Adjusted R^2	.54**		.43**		.56**		.13**		.36**	
Age < 113 months	RWR speed		RWR accuracy		PWR speed		PWR accuracy		Spelling	
Step	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
1. Age	.16	.16**	.10	.10**	.07	.07**	.21	.21	.28	.28**
2. IQ verbal	.30	.15**	.18	.09**	.10	.03	.29	.08	.44	.16**
3. PA accuracy	.48	.18**	.27	.08**	.19	.10**	.37	.07	.51	.07**
4. PA speed	.59	.11**	.37	.10**	.35	.16**	.44	.07	.55	.04*
5. RAN letters and digits	.64	.06**	.37	.01	.54	.20**	.44	.00	.55	.00
3. RAN letters and digits	.53	.23**	.27	.09**	.51	.42**	.32	.03	.46	.02
4. PA accuracy	.61	.07**	.31	.04*	.52	.01	.37	.05*	.51	.05*
5. PA speed	.64	.03*	.37	.06**	.54	.02	.44	.07**	.55	.04*
Adjusted R^2	.61**		.33**		.51**		.40**		.51**	

Note. RWR, real word reading; PWR, pseudoword reading; PA, phonological awareness; RAN, rapid automatized naming.
* $p < .05$.
** $p < .01$.

that the influence of naming speed and phonological awareness was stronger in older dyslexics than in younger dyslexics. Phonological awareness showed an unexpectedly low contribution in the youngest group. It is possible that correlations between phonological awareness and literacy are somewhat attenuated because the scores are not entirely normally distributed even after transformation. Moreover, the youngest group showed less variance on pseudo word reading speed and spelling, which might also have attenuated correlations between the performance on these tasks and performance on the cognitive tasks. However, the most important finding in the light of this study is that in both age groups naming speed contributed significantly only to reading speed and not to reading accuracy or spelling. Although naming speed did account for a small amount of the variance in real word reading accuracy in the older dyslexics when entered first in the regression equation, this effect disappeared when analyses were controlled for phonological awareness.

Nature of naming speed problems

It has been hypothesized that the general processing speed underlies the relationship between reading speed and naming speed. If naming speed reflects general processing speed, performance on naming speed tasks should be related to other tasks that measure speed such as a task that measures visual matching speed. Indeed, the correlation between speed of matching two visual symbols (measured by performance on WISC–coding) and naming speed was significant ($r = -.33$ with RAN letters, $r = -.24$ with RAN digits, and $r = -.44$ with RAN objects, $p < .05$ [see Table 2]), although the correlation between WISC–coding and phonological processing speed was not significant ($r = -.18$) However, the fact that naming speed tasks seems to have a general speed component does not necessarily imply that this general speed component is the main connection between naming speed and reading speed.

To get more insight into the nature of the naming speed deficit and its relation to visual matching speed and phonological processing, we performed an exploratory factor analysis on phoneme deletion accuracy, phoneme deletion speed, RAN letters and digits naming speed, object naming speed, WISC–coding, and WISC–digit span. In the initial analysis, only factors that had an eigenvalue $\geqslant 1$ were extracted (Kaiser's, 1960 criterion). Two factors were extracted (eigenvalues of 2.714 and 1.071). However, the communalities of PA speed, RAN objects, and WISC–coding were rather low (<.60). This suggests that the two-factor solution is not optimal. Therefore, we decided to use Jolliffe's (1972, 1986) criterion, which accepts all factors with eigenvalues $\geqslant .70$. Three factors were extracted (see Table 7). In this three-factor solution, all communalities were above .70, and the eigenvalue of the third factor was .716 (the proportion of explained variance was 75.8%). Factor loadings, communalities, and component correlations are presented in Table 7. RAN objects and WISC–coding loaded most strongly on the first factor. The factor loadings are in the expected direction; RAN objects loaded pos-

Table 7
Relation among phonological awareness, naming, digit span, and coding (principal components analysis with oblimin rotation: factor loadings, communalities, and component correlations).

	Factor			Communality (h^2)
	1	2	3	
PA accuracy		.79		.72
PA speed			.94	.86
RAN objects	.66			.72
RAN letters and digits	.43		.60	.74
WISC–digit span		.87		.77
WISC–coding	−.88			.74
Component correlations				
Factor 1				
Factor 2	−.21			
Factor 3	.31	−.31		

Note. Factor loadings <.40 are not presented. PA, phonological awareness; RAN, rapid automatized naming; WISC, Wechsler Intelligence Scale for Children.

Table 8
Contributions of extracted factors to literacy performance (hierarchical regression analyses).

	RWR speed		RWR accuracy		PWR speed		PWR accuracy		Spelling	
	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2	R^2	ΔR^2
1. Age	.53	.53**	.24	.24**	.34	.34**	.21	.21**	.50	.50**
2. IQ verbal	.57	.04**	.29	.04**	.34	.01	.23	.02	.56	.07**
3. Phonological accuracy factor	.59	.02*	.33	.05**	.36	.01	.28	.05**	.58	.02*
4. Phonological decoding speed factor	.68	.09**	.38	.05**	.55	.19**	.32	.04**	.62	.04**
5. Nonalphabetic processing speed	.69	.01	.39	.01	.59	.04**	.32	.00	.63	.01
Adjusted R^2	.68**		.36**		.57**		.29**			.61**

Note. RWR, real word reading; PWR, pseudoword reading.
* $p < .05$.
** $p < .01$.

itively and WISC–coding loaded negatively due to the fact that RAN objects is expressed in response time (a longer response time is associated with lower performance), whereas WISC–coding is expressed in number of items within a time limit (a higher score is associated with better performance). Phoneme deletion accuracy and WISC–digit span loaded on the second factor. Phoneme deletion speed loaded most strongly on the third factor, and RAN letters and digits loaded on both the first and third factors. Although interpretation of the three factors is never fully unbiased, for the purposes of this study, we refer to the three factors as a *nonalphabetic processing speed* factor, a *phonological accuracy* factor, and a *phonological decoding speed* factor.

The fact that the naming speed tasks loaded on two different factors underlines the common assumption that speeded naming tasks involve multiple cognitive processes. Not all of these cognitive components will be equally predictive for reading; therefore, investigating which components account for variance in reading performance may help to get more insight into the specific nature of the relationship between naming speed and reading. To examine which of the naming components is most predictive for reading, hierarchical regression analyses were performed with the three extracted factors as predictors and reading and spelling performance as dependent variables. If both the phonological decoding speed factor and the nonalphabetic processing speed factor explain a reasonable amount of variance in reading or spelling, this would indicate that both components of naming play a role in reading and/or spelling performance and would support the claim that naming speed tasks capture a nonphonological cognitive process that is associated with reading performance. However, if only the phonological decoding speed factor is a significant predictor, it seems more likely that the phonological component of the speeded naming tasks accounts for most of the variance in reading.

The order of entry into the regression equation was as follows: age, verbal IQ, phonological accuracy factor, phonological decoding speed factor, and nonalphabetic processing speed factor. Using this order of entry, we were able to investigate whether the nonalphabetic processing speed factor contributed significantly to reading when controlling for all of the other factors.

Results are shown in Table 8. The phonological decoding speed factor was a significant predictor for all literacy measures, but especially for pseudoword reading speed, even after accounting for phonological accuracy (17% of the variance of pseudoword reading speed was explained uniquely by the phonological decoding speed factor). The nonalphabetic processing speed factor contributed uniquely to pseudoword reading speed (4% of the variance was explained), but this contribution was weak compared with the contribution of phonological decoding speed.

Discussion

The current archive study tested four main assumptions of the double deficit hypothesis (Bowers & Wolf, 1993; Wolf & Bowers, 1999) within participants in a large clinical sample of well-diagnosed dyslexics and found a unique but highly specific contribution of naming speed to literacy performance, a significant relation between naming speed performance and phonological awareness speed, and no convincing evidence for a single naming deficit subtype, and that double deficit children did not differ in severity from single deficit children on most literacy measures. Therefore, we could not confirm the four main assumptions of the double deficit hypothesis.

More particular, the central assumption of the double deficit hypothesis postulates the independence of speeded naming and phonological deficits in dyslexia. In younger dyslexics as well as older dyslexics, we found a unique contribution of naming speed to reading speed but not to reading accuracy or spelling. Second, although we did not find a significant relation between naming speed performance and phonological awareness if expressed in accuracy of performance, we did find a relation if expressed in speed of phonological processing. In addition, the double deficit hypothesis predicts that if naming speed problems constitute a second core deficit, a substantial subgroup of dyslexics should have naming deficit problems in the absence of phonological problems. In our sample, only 5% of the participants showed naming speed problems in the absence of any phonological problems. Finally, on the basis of the assumed independence and additivity of the deficits, the double deficit hypothesis also predicts that the different subtypes will show differentiating literacy performance patterns and that the double deficit subtype shows more severe reading problems than does the single deficit subtype. However, the double deficit children did not differ from single deficit children in real word reading speed, reading accuracy, or spelling, and they revealed poorer performance only on pseudoword reading speed, whereas the two single deficit subtypes differed only in real word reading accuracy. In other words, the main assumptions of the double deficit hypothesis could not be confirmed.

How far do the current results resonate with other studies in transparent languages? In line with the current results, RAN has been found to be a consistent predictor of reading speed in younger children as well as older children (Aarnoutse, Van Leeuwe, & Verhoeven, 2005; De Jong & Van der Leij, 1999; Landerl & Wimmer, 2008; Van den Bos et al., 2002). However, in contrast to the present study three of these studies reported the absence of phonological contributions to reading after Grade 1 (Van den Bos et al., 2002 did not measure phonological awareness). One explanation for this difference might be that we tested dyslexic children, whereas the other studies focused on normal reading children. Another explanation might be that these studies investigated the predictive value of kindergarten phonological awareness to later reading performance, whereas we tested the influence of phonological awareness performance on concurrent reading performance. De Jong and Van der Leij (1999) showed that Grade 1 phonological abilities are a better predictor for reading than are kindergarten phonological abilities, possibly indicating that kindergarten measures of phonological processing skills might not be a good predictor for phonological awareness performance in later grades (Kirby et al., 2003). In addition, predicting reading performance from tests that were administered several years earlier might attenuate potential correlations (Vaessen & Blomert, 2009).

Another difference between the current study and some other studies with poor readers in transparent orthographies (Landerl, Wimmer, & Frith, 1997; Wimmer, 1996; Wimmer et al., 2000; Yap & Van der Leij, 1993) is that these studies found relatively high accuracy levels on reading tasks. Wimmer et al. (2000) stated, "In consistent orthographies, the typical dyslexic child exhibits accurate word decoding skills but poor reading fluency" (p. 669). In contrast, in the current study, error percentages on pseudoword reading exceeded 30% in younger dyslexics as well as older dyslexics even though they were selected on reading speed. This finding is not unique; another Dutch study (Van den Bos, 1998) found even higher error percentages in its sample of poor readers. Because reading accuracy levels are measured using timed reading tasks, some errors may be made in attempting to "save time and effort" (Wimmer et al., 2000, p. 668). However, there is no evidence for a speed–accuracy trade-off in the correlation pattern between reading speed and accuracy (in this case, a positive correlation between percentage of errors and number of words read would be expected). Therefore, our results indicate that dyslexic children in transparent orthographies do show problems with word decoding next to problems with reading fluency.

One could argue that the current study provides some support for the double deficit hypothesis. First, naming speed did predict a unique proportion of the variance in reading speed in dyslexic participants. The finding that reading accuracy and spelling were not predicted by naming speed does not necessarily contradict the double deficit hypothesis given that speeded naming might reflect a deficit that is affecting mainly reading speed. Moreover, the rather modest relationship between naming speed and phonological processing speed might suggest that the performance on those tasks is at least partly independent. In addition, we did find a small group of children with single naming speed deficits.

However, the fact that we found a rather small group with single naming speed problems loses impact when one considers the fact that the large majority of the children with naming speed problems (90%) did show phonological problems. How can such a large overlap be explained if naming speed problems and phonological problems represent two largely independent deficits? In addition, the small differences in literacy performance among the three deficit subtypes do not provide sufficient evidence for the claim that the two presumably independent deficits are additive or that children with a single naming speed deficit show a performance pattern different from that of children with a phonological deficit. Moreover, the creation of deficit subtypes based on cutoffs defined on continuous variables may create statistical problems (Compton, DeFries, & Olson, 2001). Adjusting cutoff criteria and tasks may substantially influence the group size of the deficit subtypes. In addition, creating subtypes based on two measures that are correlated to reading and spelling results in less regression toward the mean in the double deficit subtype, and this might cause differences between single and double deficit subtypes that are due to a statistical artifact. Therefore, even if differences can be found among subtypes, these should be interpreted carefully. Finally, although the modest correlation between naming speed and phonological processing speed seems to be an indication of relative independence, a modest correlation does not necessarily imply that naming speed problems reflect an independent deficit. The process of speeded visual naming recruits cognitive processes over and above phonological processing that very likely differ from the extra cognitive processes recruited in traditional phonological awareness tasks over and above phonological processes. Therefore, high correlations between performance on naming tasks and traditional phonological awareness tasks cannot, and should not, be expected. The more relevant question is which characteristic of the naming task accounts for the variance in reading speed and whether this characteristic can be seen as independent from phonological processing. The fact that phonological processing speed and alphanumeric naming speed loaded on the same factor, which was highly predictive for reading performance, suggests that it is the phonological part of the naming process that makes the task particularly predictive for reading speed. Savage, Pillay, and Melidona (2007) came to similar conclusions; they extracted three naming components—a phonological decoding factor, an additional alphanumeric naming factor, and a more general naming factor—but only the phonological decoding component (which included naming speed of digits and letters and phonological decoding) was a substantial predictor of literacy. Altogether, the most parsimonious interpretation of the results leads inevitably to the conclusion that there is no evidence for the existence of a second core nonphonological naming deficit.

The only consistent finding is that naming speed contributes uniquely to reading speed. However, this unique contribution of naming speed to reading speed does not necessarily indicate that naming represents a second core deficit in dyslexia; it may simply imply that speeded naming tasks tap an aspect of phonological processing that is not captured by traditional phonological awareness tasks. This leads to the question: What exactly defines the relationship between naming speed and reading speed?

The finding that naming speed contributed only to reading speed, together with the finding that naming speed correlated with phonological processing speed, could point to a general speed interpretation of the naming speed deficit given that speed of processing clearly poses as the shared central element in the deficit pattern (phonological awareness, naming, and reading). General processing speed has indeed been suggested as the common basis for naming and reading speed deficits (Catts, Gillispie, Leonard, Kail, & Miller, 2002; Kail & Hall, 1994). However, our results do not confirm this hypothesis. First, there is no indication that visual matching speed was impaired in our dyslexic sample (the mean standardized score was approximately 10, and only 9% of the sample performed below the 10th percentile on WISC–coding). Furthermore, although rapid naming speed loaded on a nonalphabetic processing speed factor as well as on a phonological decoding speed factor, the phonological decoding speed factor is the one that was highly predictive of reading speed, whereas the nonalphabetic processing speed factor accounted for only a small proportion of the variance in reading speed. In agreement with Wimmer and Mayringer (2001), our results do not support a general speed deficit that causes reading speed problems as well as naming speed problems in dyslexia. A recent literature review on general processing speed deficits in dyslexia advanced a similar conclusion (Savage, 2004).

To explain the finding that naming speed contributes uniquely to reading speed, even when controlling for phonological awareness speed, we suggest taking a closer look at the task used to measure rapid naming. There is an essential difference between phonological awareness tasks and speeded naming tasks phonological awareness tasks are essentially unimodal in nature and are confined to the domain of spoken language, whereas naming tasks are always cross-modal in nature. Fast cross-modal matching of visual/orthographic units to phonological codes is an important aspect of fluent reading. Wimmer and Mayringer (2002) proposed that in regular orthographies the main problem in dyslexics is the progress from slow sequential grapheme–phoneme decoding into fast parallel phonological/orthographic processing. The fact that speeded naming tasks also require fast matching of visual units to phonological codes may explain why reading speed and naming speed share a part of the variance and why naming problems are associated with slow reading in dyslexics. It might also explain why naming speed and speed on phonological awareness tasks are related. Several studies have suggested that orthographic information is automatically activated during the phonological process (Perre & Ziegler, 2008; Ziegler & Muneaux, 2007) and that this orthographic information may influence performance on phonological awareness tasks (Landerl, Frith, & Wimmer, 1996). Therefore, speed on phonological awareness tasks might also partly reflect the efficiency of the integration of phonological and orthographic information, as do speeded naming tasks.

The concept of naming speed reflecting the ability to quickly and automatically recode visual/orthographic information was advanced by the authors of the double deficit hypothesis themselves (see Bowers & Wolf, 1993). Initially, they interpreted this as a visual problem and not a phonological problem, possibly related to deficits in the magnocellular system (e.g., Wolf & Bowers, 1999), although an extensive previous review already had indicated that nonlanguage auditory–visual transfer deficits in dyslexia are unlikely (Vellutino, 1979). However, our results revealed that phonological processing speed and naming speed did load on the same factor that turned out to be the strongest predictor for reading speed, suggesting that the problem is very likely more phonological in nature. Wimmer et al. (2000) also proposed that the deficit is not purely visual but that the formation of grapheme–phoneme associations or the association of written words with their phonological presentation probably forms the basis of the reading deficit and is consequently reflected by the naming problems. In a more recent article, Bowers and Ishaik (2003) hypothesized that "RAN reflects the efficient integration of verbal and visual information" (p. 153). This is in agreement with the claim of Berninger et al. (2001) that RAN is a measure for the efficiency and automaticity of integration of orthographic and phonological information. According to Wimmer, Mayringer, and Landerl (1998), the crucial problem in learning to read is the difficulty in forming memory representations of letter sequences. They assumed that the critical step in the formation of new orthographic representations is the formation of the corresponding phonological forms, suggesting that phonological processing is deeply involved in orthographic processing.

In summary, we suggest that the reason why a speeded naming task is uniquely predictive for reading speed resides in the finding that it is a phonological processing speed task with an important addition that is absent in traditional phonological awareness tasks; naming tasks require fast matching or integration of visual to phonological codes. The underlying mechanisms of this integration process are not yet understood at this time, but we speculate that phonological processing contributes heavily to this cross-modal integration and that impaired performance on phonological awareness and naming tasks likely reflect phonological processing problems as well as less automatic integration of visual and phonological codes.

When interpreting the results of the current study, it is important to keep in mind that the research sample included only dyslexic children. The correlation pattern in a normal reading population might be different (McBride-Chang & Manis, 1996). Moreover, the scores on the reading speed measures suffered from a restricted range compared with the scores in a population with a full range of reading abilities. As a consequence, correlations between reading speed measures and cognitive skills might be attenuated, and so the amount of explained variance might be lower than that found in a normal population. Therefore, the strength of the contributions should be interpreted with caution. However, the relative weights of the different cognitive contributions to reading performance, and thus the interpretation of the results, would not be different if correlations between reading speed and the cognitive measures were stronger. Yet it remains important to investigate the cognitive contributions to literacy performance in an unselected school sample with a large range of reading abilities to examine how far the results of the current study with dyslexics can be generalized to other populations. In a recent study investigating the unique effects of naming speed and phonological awareness on reading and spelling performance in a large unselected school sample, we found a pattern similar to that in the current study; naming speed was related only to reading speed, whereas phonological awareness showed a consistent and unique relation to reading speed, reading accuracy, and spelling (Vaessen & Blomert, 2008, 2009). The contributions of phonological awareness performance to reading and spelling were even higher in the unselected school sample than in the current dyslexic sample, strengthening our conclusions about the importance of phonological awareness in reading.

Another point that should be kept in mind is that the current study was conducted in a rather transparent orthography. The results should be replicated in other languages with varying orthographic transparencies to investigate whether the results can be generalized.

Although the current work is an archive evaluation study, limiting the choice of cognitive tasks to those available, we believe that the selected measures represent the measures used in the relevant literature fairly well. Furthermore, we believe that this potential weakness of the study was well compensated by the strengths over previous studies; we tested all assumptions within participants in a large set of well-diagnosed dyslexics (in reference to Vukovic & Siegel, 2006), included several measures of literacy (in reference to Wolf et al., 2000), and (most important) included a phonological processing speed factor that enabled us to reveal the intricate relation between phonological speed and naming speed.

Conclusions

The current study tested the main assumptions of the double deficit hypothesis in a large group of well-diagnosed dyslexics. The results do not support that naming speed problems represent a second independent core deficit in dyslexia. Naming speed and phonological processing speed show an intricate relation that is probably reflective of a common underlying factor for which general speed does not account. The unique contribution of naming speed to reading speed is probably attributable to the fact that speeded naming tasks, like speeded reading tasks but unlike standard phonological awareness tasks, require the fast cross-modal matching of visual/orthographic units to phonological codes. Therefore, the intricate relation between deficits in naming and phonological processing speed may reflect two sides of the same coin: the processes involved in establishing integrated written and spoken speech associations (for similar suggestions, see Bowers & Ishaik, 2003; Wimmer et al., 1998, 2000). Recent brain imaging evidence shows that the detection of congruency between letters and speech sounds is predicted by the activation for isolated speech sounds (Blau, Atteveldt, Ekkebus, Goebel, & Blomert, in press), directly supporting the role of phonological processes in the cross-modal basis of reading.

The results of the current study indicate that the search for independent naming deficits might not easily result in theoretical advances. The findings suggest that a direct investigation of the cross-modal nature of the reading process in deviant and normal readers may present better chances to reveal why naming essentially reflects the speed aspects of the manifold relations between phonological processing and reading, thereby opening new theoretical perspectives on the cognitive dynamics of reading development.

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References

Aarnoutse, C., Van Leeuwe, J., & Verhoeven, L. (2005). Early literacy from a longitudinal perspective. *Educational Research and Evaluation, 11*, 253–275.

Ackerman, P. T., Holloway, C. A., Youngdahl, P. L., & Dykman, R. A. (2001). The double-deficit theory of reading disability does not fit all. *Learning Disabilities Research & Practice, 16*, 152–160.

Allor, J. H. (2002). The relationships of phonemic awareness and rapid naming to reading development. *Learning Disability Quarterly, 25*, 47–57.

Berninger, V. W., Abbott, R. D., Billingsley, F., & Nagy, W. (2001). Processes underlying timing and fluency: Efficiency, automaticity, coordination, and morphological awareness. In M. Wolf (Ed.), *Dyslexia, fluency, and the brain* (pp. 383–414). Timonium, MD: York.

Blau, V., Attenveldt, N., Ekkebus, M., Goebel, R., & Blowert, L. (in press). Reduced neural integration of letters and speech sounds links phonological and reading deficits in adult dyslexia. *Current Biology*.

Borgwaldt, S. R., Hellwig, F. M., & De Groot, A. M. B. (2005). Onset entropy matters: Letter-to-phoneme mappings in seven languages. *Reading and Writing: An Interdisciplinary Journal, 18*, 211–229.

Bowers, P. G., & Ishaik, G. (2003). RAN's contribution to understanding reading disabilities. In S. Graham, H. Swanson, & K. R. Lee Harris (Eds.), *Handbook of learning disabilities* (pp. 140–157). New York: Guilford.

Bowers, P. G., Sunseth, K., & Golden, J. (1999). The route between rapid naming and reading progress. *Scientific Studies of Reading, 3*, 31–53.

Bowers, P. G., & Swanson, L. B. (1991). Naming speed deficits in reading disability: Multiple measures of a singular process. *Journal of Experimental Child Psychology, 51*, 195–219.

Bowers, P. G., & Wolf, M. (1993). Theoretical links among naming speed, precise timing mechanisms, and orthographic skill in dyslexia. *Reading and Writing: An Interdisciplinary Journal, 5*, 69–85.

Brus, B. T., & Voeten, M. J. M. (1973). *Een-minuut test, vorm A en B [One-Minute Test, Versions A and B]*. Nijmegen, The Netherlands: Berkhout.

Cardoso-Martins, C., & Pennington, B. F. (2004). The relationship between phoneme awareness and rapid serial naming skills and literacy acquisition: The role of developmental period and reading ability. *Scientific Studies of Reading, 8*, 27–52.

Catts, H. W., Gillispie, M., Leonard, L. B., Kail, R. V., & Miller, C. A. (2002). The role of speed of processing, rapid naming, and phonological awareness in reading achievement. *Journal of Learning Disabilities, 35*, 510–525.

Chiappe, P., Stringer, R., Siegel, L. S., & Stanovich, K. E. (2002). Why the timing deficit hypothesis does not explain reading disability in adults. *Reading and Writing: An Interdisciplinary Journal, 15*, 73–107.

Clarke, P., Hulme, C., & Snowling, M. (2005). Individual differences in RAN and reading: A response timing analysis. *Journal of Research in Reading, 28*, 73–86.

Compton, D. L., DeFries, J. C., & Olson, R. K. (2001). Are RAN- and phonological awareness-deficits additive in children with reading disabilities? *Dyslexia, 7*, 125–149.

Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities, 25*, 532–538.

De Jong, P. F., & Van der Leij, A. (1999). Specific contributions of phonological abilities to early reading acquisition: Results from a Dutch latent variable longitudinal study. *Journal of Educational Psychology, 91*, 450–476.

De Jong, P. F., & Van der Leij, A. (2003). Developmental changes in the manifestation of a phonological deficit in dyslexic children learning to read a regular orthography. *Journal of Educational Psychology, 95*, 22–40.

Denckla, M. B., & Rudel, R. G. (1976a). Naming of object-drawings by dyslexic and other learning disabled children. *Brain and Language, 3*, 1–15.

Denckla, M. B., & Rudel, R. G. (1976b). Rapid "automatized" naming (RAN): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*, 471–479.

Eleveld, M. (2005). *At risk for dyslexia: The role of phonological abilities, letter knowledge, and speed of serial naming in early intervention and diagnosis*. Unpublished manuscript, Rijksuniversiteit Groningen.

Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin and Review, 2*, 460–493.

Felton, R. H., & Brown, I. S. (1990). Phonological processes as predictors of specific reading skills in children at risk for reading failure. *Reading and Writing: An Interdisciplinary Journal, 2*, 39–59.

Geelhoed, J., & Reitsma, P. (1999). *PI-dictee*. Lisse, Switzerland: Swets & Zeitlinger.

Hulslander, J., Talcott, J., Witton, C., DeFries, J., Pennington, B., Wadsworth, S., et al (2004). Sensory processing, reading, IQ, and attention. *Journal of Experimental Child Psychology, 88*, 274–295.

Jolliffe, I. T. (1972). Discarding variables in a principal component analysis: I. Artificial data. *Applied Statistics, 21*, 160–173.

Jolliffe, I. T. (1986). *Principal component analysis*. New York: Springer-Verlag.

Kail, R., & Hall, L. K. (1994). Processing speed, naming speed, and reading. *Developmental Psychology, 30*, 949–954.

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement, 20*, 141–151.

Katz, L., & Frost, R. (1992). The reading process is different for different orthographies: The orthographic depth hypothesis. In L. Katz & R. Frost (Eds.), *Orthography, phonology, morphology, and meaning*. Oxford, UK: North-Holland.

Katz, L., & Shankweiler, D. (1985). Repetitive naming and the detection of word retrieval deficits in the beginning reader. *Cortex, 21*, 617–625.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95*, 453–464.

Landerl, K., Frith, U., & Wimmer, H. (1996). Intrusion of orthographic knowledge on phoneme awareness: Strong in normal readers, weak in dyslexic readers. *Applied Psycholinguistics, 17*, 1–14.

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*, 150–161.

Landerl, K., Wimmer, H., & Frith, U. (1997). The impact of orthographic consistency on dyslexia: A German–English comparison. *Cognition, 63*, 315–334.

Levy, B. A., Bourassa, D. C., & Horn, C. (1999). Fast and slow namers: Benefits of segmentation and whole word training. *Journal of Experimental Child Psychology, 73*, 115–138.

Liao, C.-H., Georgiou, G. K., & Parrila, R. (2008). Rapid naming speed and Chinese character recognition. *Reading and Writing: An Interdisciplinary Journal, 21*, 231–253.

Lovett, M. W., Steinbach, K. A., & Frijters, J. C. (2000). Remediating the core deficits of developmental reading disability: A double-deficit perspective. *Journal of Learning Disabilities, 33*, 334–358.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53*, 1–14.

Manis, F. R., Doi, L. M., & Bhadha, B. (2000). Naming speed, phonological awareness, and orthographic knowledge in second graders. *Journal of Learning Disabilities, 33*, 325–333. 374.

McBride-Chang, C., & Manis, F. R. (1996). Structural invariance in the associations of naming speed, phonological awareness, and verbal reasoning in good and poor readers: A test of the double deficit hypothesis. *Reading and Writing: An Interdisciplinary Journal, 8*, 323–339.

Morris, R. D., Stuebing, K. K., Fletcher, J. M., Shaywitz, S. E., Lyon, G. R., Shankweiler, D. P., et al (1998). Subtypes of reading disability: Variability around a phonological core. *Journal of Educational Psychology, 90*, 347–373.

Neuhaus, G. F., & Swank, P. R. (2002). Understanding the relations between RAN letter subtest components and word reading in first-grade students. *Journal of Learning Disabilities, 35*, 158–174.

Patel, T. K., Snowling, M. J., & De Jong, P. F. (2004). A cross-linguistic comparison of children learning to read in English and Dutch. *Journal of Educational Psychology, 96*, 785–797.

Pennington, B. F., Cardoso-Martins, C., Green, P. A., & Lefly, D. L. (2001). Comparing the phonological and double deficit hypotheses for developmental dyslexia. *Reading and Writing: An Interdisciplinary Journal, 14*, 707–755.

Perre, L., & Ziegler, J. C. (2008). On-line activation of orthography in spoken word recognition. *Brain Research, 1188*, 132–138.

Plaza, M., & Cohen, H. (2004). Predictive influence of phonological processing, morphological/syntactic skill, and naming speed on spelling performance. *Brain and Cognition, 55*, 368–373.

Savage, R. (2004). Motor skills, automaticity, and developmental dyslexia: A review of the research literature. *Reading and Writing: An Interdisciplinary Journal, 17*, 301–324.

Savage, R., Pillay, V., & Melidona, S. (2007). Deconstructing rapid automatized naming: Component processes and the prediction of reading difficulties. *Learning and Individual Differences, 17*, 129–146.

Savage, R., Pillay, V., & Melidona, S. (2008). Rapid serial naming is a unique predictor of spelling in children. *Journal of Learning Disabilities, 41*, 235–250.

Schatschneider, C., Carlson, C. D., Francis, D. J., Foorman, B. R., & Fletcher, J. M. (2002). Relationship of rapid automatized naming and phonological awareness in early reading development: Implications for the double-deficit hypothesis. *Journal of Learning Disabilities, 35*, 245–256.

Spector, J. E. (2005). Instability of double-deficit subtypes among at-risk first grade readers. *Reading Psychology, 26*, 285–312.

Sunseth, K., & Bowers, P. G. (2002). Rapid naming and phonemic awareness: Contributions to reading, spelling, and orthographic knowledge. *Scientific Studies of Reading, 6*, 401–429.

Swanson, H. L., Trainin, G., Necoechea, D. M., & Hammil, D. D. (2003). Rapid naming, phonological awareness, and reading: A meta-analysis of the correlational evidence. *Review of Educational Research, 73*, 407–440.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities, 27*, 276–286 (discussion pp. 287–291).

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S. R., & Hecht, S. A. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second- to fifth-grade children. *Scientific Studies of Reading, 1*, 161–185.

Vaessen, A.A., & Blomert, L. (2008). *Naming speed co-varies with development of automatic word recognition*. Paper presented at the annual meeting of the Cognitive Neuroscience Society, San Francisco.

Vaessen, A. A., & Blomert, L. (2009). Cognitive dynamics of the development of fluent word reading. Submitted for publication.

Van den Bos, K. P. (1998). IQ, phonological awareness, and continuous naming speed related to poor decoding children's performance on two word identification tests. *Dyslexia, 4*, 73–89.

Van den Bos, K. P. (2003). *Snel Serieel Benoemen (SSB) [Rapid Serial Naming. Unpublished experimental version]*. Groningen, The Netherlands: Rijksuniversiteit Groningen.

Van den Bos, K. P., Lutje Spelberg, H. C., Scheepstra, A. J. M., & de Vries, J. (1994). *De Klepel. Vorm A en B. Een test voor de leesvaardigheid van pseudowoorden. [The 'clapper'. Form A and B. A test of pseudo-word reading ability]*. Nijmegen, The Netherlands: Berkhout.

Van den Bos, K. P., Zijlstra, B. J. H., & lutje Spelberg, H. C. (2002). Life-span data on continuous-naming speeds of numbers, letters, colors, and pictured objects, and word-reading speed. *Scientific Studies of Reading, 6*, 25–49.

Van den Bos, K. P., Zijlstra, B. J. H., & Van den Broeck, W. (2003). Specific relations between alphanumeric-naming speed and reading speeds of monosyllabic and multisyllabic words. *Applied Psycholinguistics, 24*, 407–430.

Vellutino, F. R. (1979). *Dyslexia: Theory and research*. Cambridge, MA: MIT Press.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*, 2–40.

Vukovic, R. K., & Siegel, L. S. (2006). The double-deficit hypothesis: A comprehensive analysis of the evidence. *Journal of Learning Disabilities, 39*, 25–47.

Vukovic, R. K., Wilson, A. M., & Nash, K. K. (2004). Naming speed deficits in adults with reading disabilities: A test of the double-deficit hypothesis. *Journal of Learning Disabilities, 37*, 440–450.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192–212.

Wagner, R. K., Torgesen, J. K., Laughon, P., Simmons, K., & Rashotte, C. A. (1993). Development of young readers' phonological processing abilities. *Journal of Educational Psychology, 85*, 83–103.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30*, 73–87.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., Hecht, S. A., Barker, T. A., Burgess, S. R., et al (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. *Developmental Psychology, 33*, 468–479.

Wile, L. T., & Borowsky, R. (2004). What does rapid automatized naming measure? A new RAN task compared to naming and lexical decision. *Brain and Language, 90*, 47–62.

Wimmer, H. (1996). The nonword reading deficit in developmental dyslexia: Evidence from children learning to read German. *Journal of Experimental Child Psychology, 61*, 80–90.
Wimmer, H., & Hummer, P. (1990). How German-speaking first graders read and spell: Doubts on the importance of the logographic stage. *Applied Psycholinguistics, 11*, 349–368.
Wimmer, H., & Mayringer, H. (2001). Is the reading-rate problem of German dyslexic children caused by slow visual processes? In M. Wolf (Ed.), *Dyslexia, fluency, and the brain* (pp. 93–102). Timonium, MD: York.
Wimmer, H., & Mayringer, H. (2002). Dysfluent reading in the absence of spelling difficulties: A specific disability in regular orthographies. *Journal of Educational Psychology, 94*, 272–277.
Wimmer, H., Mayringer, H., & Landerl, K. (1998). Poor reading: A deficit in skill-automatization or a phonological deficit? *Scientific Studies of Reading, 2*, 321–340.
Wimmer, H., Mayringer, H., & Landerl, K. (2000). The double-deficit hypothesis and difficulties in learning to read a regular orthography. *Journal of Educational Psychology, 92*, 668–680.
WISC-R, Project Group (1986). *Wechsler Intelligence Scale for Children-Revised*. Lisse, The Netherlands (in Dutch).
Wolf, M. (1986). Rapid alternating stimulus naming in the developmental dyslexias. *Brain and Language, 27*, 360–379.
Wolf, M. (1991). The word-retrieval deficit hypothesis and developmental dyslexia. *Learning and Individual Differences, 3*, 205–223.
Wolf, M. (1997). A provisional, integrative account of phonological and naming-speed deficits in dyslexia: Implications for diagnosis and intervention. In B. A. Blachman & A. Benita (Eds.), *Foundations of reading acquisition and dyslexia: Implications for early intervention* (pp. 67–92). Mahwah, NJ: Lawrence Erlbaum.
Wolf, M., Bally, H., & Morris, R. (1986). Automaticity, retrieval processes, and reading: A longitudinal study in average and impaired readers. *Child Development, 57*, 988–1000.
Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*, 415–438.
Wolf, M., Bowers, P. G., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33*, 387–407.
Yap, R., & Van der Leij, A. (1993). Word processing in dyslexics: An automatic decoding deficit? *Reading and Writing: An Interdisciplinary Journal, 5*, 261–279.
Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 3–29.
Ziegler, J. C., & Muneaux, M. (2007). Orthographic facilitation and phonological inhibition in spoken word recognition: A developmental study. *Psychonomic Bulletin Review, 14*, 75–80.