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Post-treatment reading development in children with dyslexia: the challenge remains

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Abstract

The goal of this study was to examine the post-treatment development of word and pseudoword accuracy and fluency and its cognitive and linguistic predictors in Dutch children with dyslexia compared with typical readers in the upper primary grades. Word and pseudoword reading accuracy and fluency were assessed at the start and end of grade 5 and at the end of grade 6. Phonological awareness, rapid naming, verbal short-term memory, vocabulary, and visual attention span were assessed at the start of grade 5. Repeated measures ANOVAs revealed that children with dyslexia were less accurate than typical readers and showed very little improvements in accuracy over time. They were also less fluent and showed less growth in reading fluency than typical readers. The children with dyslexia did improve more in word reading fluency than in pseudoword reading fluency over time. Visual attention span and phonological awareness predicted reading accuracy development in typical readers, while rapid naming predicted individual differences in reading fluency in children with dyslexia. It can be concluded that in the upper grades, children with dyslexia not only struggled with fluent reading, but they also still struggled with accurate reading in a relatively transparent orthography like Dutch, even after they had received a reading intervention to remediate their reading difficulties.

Keywords Accuracy · Dyslexia · Fluency · Reading development · Post-intervention

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In the initial stages of learning to read, words are mostly read by sequentially connecting graphemes to their corresponding phonemes. Later on during reading development, there is a shift towards more fluent reading in which children no longer need to read familiar words sequentially, but can recognize entire word forms (Ehri 2005). While especially in transparent orthographies, children become accurate very early in development, the process of becoming a faster (more fluent) reader continues throughout the primary grades (Vaessen and Blomert 2010; Verhoeven and van Leeuwe 2009). Children with dyslexia, however, have difficulties with developing both accurate and fluent reading skills (Ziegler et al. 2003). Despite intensive reading interventions, they often continue to fall behind typical readers in their reading performance (Snowling and Hulme 2011; Morris et al. 2012). However, it remains unclear how reading accuracy and fluency develop in the upper primary grades, after remediation, as most previous studies on this topic have not taken this longitudinal perspective. In the current study, we examined reading development in Dutch children with dyslexia and their typically reading peers in the final grades of primary school. In order to distinguish between sequential reading and automatic word recognition, we measured both pseudoword and word reading skills. Moreover, as reading processes change, the contribution of underlying skills important for developing fluent reading may also change (Moll et al. 2014; Vaessen and Blomert 2010). Therefore, we also examined what underlying cognitive and linguistic skills predicted the development of word and pseudoword reading fluency in these final primary school grades.

Typical word reading development

To better understand the complexity of the reading process, computational models have explicated assumptions that model reading. Two influential frameworks modelling single-word reading are the dual-route cascaded model of reading (DRC; Coltheart et al. 2001) and the parallel distributed processing model (PDP; Harm and Seidenberg 2004; Plaut et al. 1996). The dual-route cascaded model for reading specifies two possible routes for single-word reading: a sublexical route, in which letters are translated to sounds according to grapheme-phoneme conversion rules, and a lexical route, in which words are directly retrieved from the lexicon. In the parallel distributed processing model, print is translated into meaning by a division of labour between semantic, phonological and orthographic processes (Harm and Seidenberg 2004; Plaut et al. 1996). Placed within a developmental perspective, the models predict that beginning readers mostly rely on the sublexical route for reading, or by reading from orthography to phonology to semantics. At this stage, reading can be seen as a serial process in which graphemes are translated into phonemes according to grapheme-phoneme conversion rules. When readers develop detailed orthographic representations, they start to rely more on direct retrieval of whole-word representations, or in other words on lexical reading strategies via the orthography-to-semantic route (Ziegler and Goswami 2005; Ziegler et al. 2014).

This shift from grapheme-to-phoneme conversions (phonological recoding) to word recognition is visible in increasing lexicality effects in reading. Initially, the difference between phonological recoding—often measured with pseudoword reading tests—and word recognition is small, but during the course of reading development, word recognition skills increase more than pseudoword reading abilities (Caravolas 2018; Vaessen and Blomert 2010; Zoccolotti et al. 2009).

Predictors for individual differences and reading development

Not only reading processes change, the relative contribution of underlying skills also changes throughout reading development. Phonological awareness and rapid naming have been identified as important underlying skills that explain individual differences in word and pseudoword reading accuracy and fluency over the course of reading development. First, when children rely more on sublexical reading, phonological skills predict reading strongly. Later, when reading development becomes more a matter of developing reading fluency, the contribution of phonological awareness decreases, and the contribution of rapid naming skills becomes more important (Vaessen and Blomert 2010). Studies examining the development of early word reading skills in typical readers up to the end of second grade have shown that early reading accuracy development is predicted by rapid naming, phonological awareness and letter knowledge (Caravolas et al. 2013; Compton 2000; Leppänen et al. 2004; Lervåg et al. 2009). Moreover, kindergarten measures of phonological awareness and rapid naming already predict later reading development (Snowling 2001). Rapid naming has been found to be more strongly related to word reading fluency, while phonological awareness has been found to be more strongly related to reading accuracy and to phonological recoding tasks, such as pseudoword reading (Kirby et al. 2008; Moll et al. 2014; Vaessen and Blomert 2010).

Even though phonological awareness and rapid naming are very strong predictors for reading, other underlying cognitive and linguistic skills have been found to contribute to reading development, although these results are less consistent. Some studies have found small contributions of verbal short-term memory on reading (Boets et al. 2010; Georgiou et al. 2008), while others claimed that its relation with reading is explained by shared variance with phonological awareness (Melby-Lervåg et al. 2012). Vocabulary has been found to be related to reading (Kirby et al. 2008), but mostly in opaque orthographies (Share 2008; Suggate et al. 2014). This might be because vocabulary can help to disambiguate novel or irregular words. Therefore, the influence on reading may be less important for more regular, transparent orthographies, and the effect on word reading may decrease with reading experience (Ricketts et al. 2007; Share 2008; Verhoeven et al. 2011).

Finally, an underlying skill that has received little attention so far is children's visual attention span. It is defined as the number of visual elements that can be processed in one glance (Bosse et al. 2007). In the case of reading, van den Boer and de Jong (2018) argued that it reflects fast, parallel processing of visual elements. As it is related to both word and pseudoword reading fluency, the authors argued that it more specifically reflects parallel processing of sublexical units. Studies have shown that the tasks used to measure visual attention span uniquely contribute to word and pseudoword reading accuracy and fluency skills, over and above effects of phonological awareness, rapid naming skills and verbal short-term memory (Bosse and Valdois 2009; Van den Boer et al. 2015; Van den Boer and de Jong 2018). While visual attention span has been found to explain variance in word and pseudoword reading skills, evidence for a causal relation between visual attention span and reading development is lacking.

Reading development children with dyslexia

Overall, word reading development in children with dyslexia has been studied less extensively than in typical readers. While the reading development in children at risk for dyslexia or progress during intervention of children with dyslexia has been studied, the reading development at the end of primary school, after children have completed an intervention, has received very little attention. An exception is a study by Torgesen et al. (2001), who followed the reading development of a group of poor readers during and 2 years after intervention. Improvements on a number of reading tasks, such as comprehension, word identification and nonword reading, were assessed as well as a number of underlying skills such as phonological awareness, rapid naming, verbal short-term memory, receptive language skills and attention. In the 2 years after intervention, children with lower reading scores at the end of the intervention developed less than children with higher reading scores at the end of the intervention, while growth rate of these groups did not differ during the intervention. Reading development after intervention was predicted by reading skills, attentional ratings by teachers and verbal ability.

A small number of studies have examined word reading development of children with dyslexia up to the end of primary school. For example, Dandache et al. (2014) examined children with and without dyslexia in grades 1, 3 and 6. They found that typical readers overall developed faster than children with dyslexia in both word and pseudoword reading fluency, but do not mention whether children with dyslexia had received an intervention. Second, Eklund et al. (2015), who examined reading skills in grades 2, 3 and 8, found that children with dyslexia developed faster than typical readers in overall reading fluency between grade 2 and grade 3, but this no longer differed between grade 3 and grade 8. According to Eklund et al. (2015), this larger growth compared with typical readers between grades 2 and 3 could have been caused by extra instruction children with dyslexia had received during this time. Although Eklund et al. (2015) mention that some of the children with dyslexia in the study received extra instruction or remediation, it is not clear if the children in this study received a clinical intervention beyond grade 3. Finally, in a cross-sectional study by Verhoeven and Keuning (2018), including children with and without dyslexia across grades 3 to 6, it was found that for word reading, the gap remained the same, but for pseudoword reading, the gap increased.

Not only are readers with dyslexia behind in word and pseudoword reading, they also show difficulties in underlying skills such as phonological awareness, verbal short-term memory and rapid automatized naming (Snowling and Hulme 2011; Vellutino et al. 2004; Ziegler et al. 2003). Similar to typical readers, phonological awareness and rapid naming predict individual differences in reading skills (Furnes and Samuelsson 2010; Landerl et al. 2013). Indeed, in a study by Dandache et al. (2014), reading development from first to sixth grades in children with and without dyslexia was predicted by phonological awareness and rapid naming. However, it was not further investigated whether this differed for both groups or for word and pseudoword reading (Dandache et al. 2014).

Present study

In summary, very few studies have examined longitudinal developmental trajectories in word and pseudoword reading skills in children with dyslexia. Moreover, none of these studies examined word reading development beyond third grade in more detail. While predictors for individual differences in word or pseudoword reading accuracy and fluency have been studied, very little is known about underlying cognitive and linguistic skills explaining development of reading skills.

The goal of this study was to longitudinally examine development of word and pseudoword reading accuracy and fluency in Dutch children with and without dyslexia in the upper primary grades, after children with dyslexia had received a clinical reading intervention. Dutch has a relatively transparent orthography (Seymour et al. 2003), meaning that typical readers become highly accurate very early in reading development. Reading development is therefore mostly seen as a matter of developing fluent reading skills. In the Netherlands, diagnosis of dyslexia follows a nationally standardized protocol (Blomert 2006) and includes measures of word and pseudoword reading, assessed by reading fluency measures (e.g., the number of words a child can read correctly in a minute) and spelling. In addition, assessment of underlying skills as phonological awareness and rapid automatized naming is part of the diagnosis. All children diagnosed with dyslexia receive a systematic, phonics-based reading intervention by a clinician, typically starting at the end of grade 2 and completed in grade 4. This type of intervention has been shown to be the most effective treatment for reading problems found in children with dyslexia, as it includes explicit phonics instruction, and is systematic and well structured (Galuschka et al. 2014; Snowling and Hulme 2011). Previous research has shown that during this phonics-based clinical intervention, children with dyslexia made more progress in pseudoword reading accuracy and fluency than typical readers (Tilanus et al. 2016). This consistency in diagnosis and treatment provides a strong basis for a study examining post-treatment reading development.

The first research question was the following: How do children with and without dyslexia develop their word and pseudoword reading accuracy and fluency skills from the start to the end of grade 5, and to the end of grade 6? The children with dyslexia were expected to start out with lower word and pseudoword reading fluency skills than the typical readers, despite the intervention they had received the years before the current study started in grade 5. Because Dutch has a transparent orthography, word reading accuracy was expected to be close to ceiling for typical readers and very high for children with dyslexia.

The second research question was the following: What cognitive and linguistic skills predict individual differences in development of word and pseudoword reading in children with dyslexia and typical readers from grade 5 to the end of grade 6? In addition to phonological awareness and rapid naming, verbal short-term memory, vocabulary and visual attention span were examined. It was expected that phonological awareness, rapid naming and visual attention span would predict individual differences in reading skills in typical readers and in children with dyslexia. For verbal short-term memory and vocabulary, it was expected that effects on reading were smaller than for the other predictors. It is less clear what cognitive and linguistic skill measures would predict reading development. Based on the previous study on modelling development in children with and without dyslexia by Dandache et al. (2014), it was expected that phonological awareness and rapid naming would predict development of reading skills, but since group differences were not examined in that study, we did not have clear predictions about how predictors might be different between groups.

Method

Participants

At the start, 96 typical readers (aged *M* = 10;5 years;months, SD = 0.47 months; 51 girls) from five Dutch primary schools and 80 children with dyslexia (aged *M* = 10;8 years;months, SD =

0.49 months; 34 girls) from 65 Dutch primary schools participated in the study. Parents had given informed consent for participation of their child in this study. Parents had also completed a short questionnaire that included questions about their educational background as measure of social economic status. Distribution of parental educational background for both mothers and fathers within the sample was representative of the national distribution (Centraal Bureau voor Statistiek [Statistics Netherlands] 2018). The study was approved by the institution's ethics committee and was part of a larger longitudinal study on reading development of children with and without dyslexia in primary school (van der Kleij et al. 2017). At the final moment of testing at the end of grade 6, five children had changed schools and therefore no longer participated (three typical readers, two children with dyslexia). Of this group, one typical reader had already moved before the second measurement and was excluded from all analyses. Three children from the control group of typical readers were diagnosed with dyslexia during their participation in the longitudinal study and were therefore excluded from all analyses. Both groups had normal nonverbal cognitive abilities (percentile score control group M = 54.28, SD = 29.67, Raven's progressive matrices, 1998; standard score children with dyslexia M = 98.53, SD = 9.16, Wechsler Intelligence Scale for Children-III-NL, Kort et al. 2005).

Diagnostics of dyslexia followed a nationally standardized protocol (Blomert 2006). In order to be diagnosed with dyslexia, children had scored within the lowest 10% on word and pseudoword reading fluency (standard scores for the sample M = 3.91, SD = 1.96 and M = 5.18, SD = 1.79 respectively) and within the lowest 10% on two out of six tasks that measured phonological awareness, rapid naming and letter knowledge. All children with dyslexia were diagnosed at the end of grade 2 and had completed a phonics-based clinical reading intervention in grade 4. The children had not received specific extra remediation afterwards.

The intervention was phonics-based and consisted of 50 sessions of 45 min with a clinician. This intervention was based on a nationally standardized protocol (Blomert 2006) and was similar across participants. During the first 12 sessions, the intervention focused on learning grapheme-phoneme correspondences and applying these in decoding of transparent CVC words and spelling. In the second part of the intervention, inconsistent grapheme-phoneme correspondences were introduced, as well as more complex CCV words and morphological structures. Training sessions started with a repetition of what was learned in the previous session, and after that, a new GPC rule was introduced. Each session also included speeded reading exercises, training in spelling and ended with guided reading exercises (see Tilanus et al. 2016).

Materials

Word and pseudoword reading were measured with a standardized reading task (Verhoeven and Keuning 2018). The task consisted of four cards of either words or pseudowords, containing 150 CVC, 150 CCV, 120 two-syllable and 120 three- or four-syllable (pseudo)words respectively. For each card, children were instructed to read as many (pseudo)words as possible in 1 min, without making any errors. The reading fluency score used for the analyses was the number of items read correctly averaged over all four cards. Reading accuracy was the percentage correctly read words or pseudowords averaged over the four cards. Cronbach's alpha reliabilities for the four-word reading cards are .96, .95, .96 and .96 and for the pseudoword reading cards .96, .96, .97, and .93 respectively (Verhoeven and Keuning 2018). Correlations between cards for the current sample for words ranged between r = .81–.94, $p < .001$ for controls and between r = .71–.82, $p < .001$ for children with dyslexia.

For pseudowords, these were ranging between $r = .80–.94$, $p < .001$, for controls, and between $r = .51–.81$, $p < .001$, for children with dyslexia.

Phonological awareness was measured with the subtests deletion and spoonerism of the Dyslexia Screening Test-NL (Dutch version, Kort et al. 2005a). The deletion task consisted of 12 items for which children were asked to repeat the word and leave out a specific phoneme. The spoonerism task consisted of 11 items. Children were asked to switch the first phoneme of a first name and a last name. For each subtest, the score used in the analyses was the number of correct items. Test-retest reliability is .52 for the deletion and .60 for the spoonerism subtest (Kort et al. 2005a). Correlations between subtests for the current sample were $r = .50$, $p < .001$ for controls and $r = .22$, $p = .048$ for children with dyslexia.

Rapid naming was measured with two subtests: letters and digits (Continue Benoemen & Woorden Lezen [Continuous Naming & Word Reading], Van den Bos and Lutje Spelberg 2010). Both tests consisted of five rows of 10 items. For each subtest, the score was the time in seconds to name all 50 items. Test-retest reliability of both subtests are .82 and .84 respectively (Van den Bos and Lutje Spelberg 2010). Correlations between subtests for the current sample were $r = .73$, $p < .001$ for controls and $r = .65$, $p < .001$ for children with dyslexia.

Verbal short-term memory was measured with the digit span forward and backward of the Wechsler Intelligence Scale for Children-III-NL (WISC-III-NL, Dutch version, Kort et al. 2005). Children were asked to repeat a series of digits in the same (forward) or reversed (backward) order. The digit span forward consisted of eight series of digits and the digit span backward of seven series of digits increasing in length, with two attempts at each length. The task was discontinued if the child failed to repeat both attempts correctly. For each subtest, the score was the total of correctly repeated items. Cronbach's alpha of the digit span task is .57 (Kort et al. 2005). Correlations between subtests for the current sample were $r = .59$, $p < .001$ for controls and $r = -.07$, $p = .52$ for children with dyslexia.

Vocabulary was measured with the subtest 'Woordkennis' [word knowledge] of the WISC-III-NL (Kort et al. 2005). The task consisted of 35 items. Children were asked to describe the meaning of the word that was presented to them verbally. The response was scored with 2 (correct), 1 (correct, but incomplete) or 0 points (incorrect). The items increased in difficulty, and the task was discontinued when the child received 0 point for four consecutive items. Cronbach's alpha of this subtest is .79 (Kort et al. 2005).

Visual attention span was measured with an experimental task by Valdois et al. (2003). The task consisted of five-letter strings composed of 10 different consonants (B, D, F, H, L, M, P, R, S, T). The letter strings were presented for 200 ms on a laptop screen. Each consonant was presented twice in each letter position. For each of the letter strings, children were asked to repeat as many letters as possible. The task consisted of 20 items, and the score was the total number of letters across items that were repeated correctly (regardless of whether the letters were repeated in the correct order). Van den Boer et al. (2015) reported Cronbach's alpha in Dutch children between 9 and 11 years old to be .76 and .77 for odd and even items respectively.

Procedure

Children were individually tested at their primary school on three occasions: at the start and end of grade 5 and at the end of grade 6. The phonological awareness, rapid naming, vocabulary, verbal short-term memory and visual attention span measures were administered during the first measurement at the beginning of grade 5. The reading measures were administered at all three time points. The tests were administered in the same fixed order for all participants across two 30–45-min sessions, alternating between reading and cognitive and linguistic tasks to keep the testing sessions varied.

Data analysis

To answer the first question, repeated measures ANOVAs were performed to test the difference in progress between children with dyslexia and typical readers. To answer the second question, linear mixed-effects models were fitted using the lme4 package in R (R Core Team 2013) to model what underlying cognitive and linguistic skills predicted word and pseudoword reading development in typical readers and children with dyslexia. Rapid naming, phonological awareness, visual attention span, verbal short-term memory and vocabulary were added as predictors for word and pseudoword reading development. Chi-squared tests were used for model comparisons. A maximum random effect structure was applied, with random intercepts for participants and random slopes for the development of reading skills (Barr et al. 2013). p values within the models were estimated using Satterthwaite approximations (Kuznetsova et al. 2015). All predictors were standardized and centred.

For the rapid naming and phonological awareness subtests, z scores were calculated and averaged. However, for verbal short-term memory, the subtests did not correlate for the children with dyslexia ($r = -.07$, $p = .52$); therefore, only the digit span backward task was added, because this was considered to be a better reflection of verbal short-term memory capacity than the digit span forward.

Results

Descriptive statistics

The descriptive statistics for the reading and cognitive and linguistic measures in grades 5 and 6 of children with dyslexia and their typically reading peers are displayed in Table 1 as well as scores for the individual reading cards (Table 2). At all three measurements, the children with dyslexia read fewer words and pseudowords correctly within 1 min and were less accurate than their typically reading peers. Considering the large differences in reading accuracy scores between both groups, the distribution of word and pseudoword accuracy scores was further explored with density plots (Fig. 1). The density plots show that there was large variation in pseudoword accuracy scores within the group of children with dyslexia. At the end of grade 6, the mean percentage correct is still below 80% (whereas only 7.6% of the typical readers scored below 80%). Moreover, the pseudoword reading accuracy scores of the children with dyslexia only show overlap with pseudoword reading accuracy scores of the typical readers at the lower end of the distribution. At the start of grade 5, children with dyslexia also scored lower on all cognitive and linguistic tasks compared with the typical readers.

Reading accuracy

Reading accuracy development was examined using a repeated measures ANOVA with time (start grade 5, end grade 5 and end grade 6) and lexicality (words, pseudowords) as the within-

Table 1 Descriptive statistics of cognitive and linguistic (grade 5) and reading (grades 5 and 6) measures for typical readers and children with dyslexia

		Typical readers		Children with dyslexia		
		n	*M*(SD)	*n*	*M*(SD)	*d*
Precursor measures (T1 start grade 5)		92		80		
Phonological awareness	Deletion	10.41 (1.19)		8.93 (1.59)		1.05***
	Spoonerism	7.90 (2.55)		3.91 (2.63)		1.54***
Rapid naming	Digits	24.51 (5.21)		30.20 (6.25)		0.99***
	Letters	25.31 (5.90)		32.43 (8.26)		0.99***
Working memory	Forward	8.08 (1.77)		6.63 (1.22)		0.95*
	Backward	4.73 (1.76)		3.96 (1.16)		0.51**
Vocabulary		34.51 (5.67)		32.54 (4.74)		0.38*
Visual attention span		77.74 (13.72)		63.45 (11.74)		1.12***
Reading measures						
T1 start grade 5		92		80		
Words	Fluency	74.36 (19.04)		42.05 (10.25)		2.11***
	Accuracy	96.63 (3.46)		88.36 (7.22)		1.46***
Pseudowords	Fluency	45.05 (14.29)		21.60 (6.55)		2.11***
	Accuracy	86.55 (9.47)		70.23 (11.25)		1.57***
T2 end grade 5		92		80		
Words	Fluency	81.66 (17.70)		47.01 (11.87)		2.30***
	Accuracy	97.44 (2.50)		90.06 (6.24)		1.55***
Pseudowords	Fluency	51.25 (14.98)		24.71 (7.56)		2.24***
	Accuracy	90.19 (7.18)		74.51 (11.17)		1.67***
T3 end grade 6		90		78		
Words	Fluency	88.37 (18.98)		53.17 (12.44)		2.19***
	Accuracy	98.25 (2.72)		92.22 (6.15)		1.27***
Pseudowords	Fluency	57.06 (15.82)		28.77 (9.05)		2.20***
	Accuracy	93.05 (7.82)		78.15 (11.88)		1.48***

*$p < .05$, **$p < .01$, ***$p < .001$

subject factors and group (typical readers, children with dyslexia) as the between-subject factor. The development of word and pseudoword reading fluency and accuracy is displayed in Fig. 2. The main effects for time, $F(2, 159) = 85.91, p < .001, \eta^2_p = .35$, lexicality, $F(2, 160) = 611.48, p < .001, \eta^2_p = .79$, and group, $F(1, 160) = 124.80, p < .001, \eta^2_p = .44$, were significant, as were the interactions between time × lexicality and lexicality × group. The interaction between time × lexicality, $F(2, 159) = 28.63, p < .001, \eta^2_p = .15$, indicated that the mean difference between words and pseudowords was smaller at time 3, $M = 9.35$, SD = 8.64, than at time 1, $M = 13.83$, SD = 8.94, $t(167) = -7.52, p < .001, d = 0.79$. Overall, the groups improved more on pseudoword reading accuracy than on word reading accuracy. The significant interaction between lexicality × group, $F(1, 160) = 75.24, p < .001, \eta^2_p = .32$, indicated that the difference between word and pseudoword reading accuracy was larger for children with dyslexia ($M = 15.96$, SD = 6.64) than for typical readers ($M = 7.58$, SD = 5.31), $t(147.02) = -8.95, p < .001, d = 1.39$. The interactions between time × group $F(2, 159) = 2.43, p = .09, \eta^2_p = .02$ and time × lexicality × group were not significant, $F(2, 159) = 0.68, p = .51, \eta^2_p = .004$.

Reading fluency

To examine reading fluency development of children with and without dyslexia, a repeated measures ANOVA was performed with time (start grade 5, end grade 5 and end grade 6) and

Table 2 Descriptive statistics for CVC, CCV, two-, three- and four-syllable words and pseudowords in typical readers and children with dyslexia

			Typical readers		Children with dyslexia		
		n	*M*	*SD*	*n*	*M*	*SD*
Reading measures start Grade 5		92			80		
Words	CVC		95.74	19.80		65.94	13.95
	CCV		84.90	21.42		47.23	14.56
	2 syllable		66.50	20.70		31.25	9.29
	3/4 syllable		50.28	18.06		23.78	7.58
Pseudowords	CVC		66.23	16.76		37.03	10.19
	CCV		53.92	18.14		24.65	8.74
	2 syllable		34.32	13.93		14.29	6.18
	3/4 syllable		25.72	11.61		10.45	4.39
Reading measures end Grade 5		92			80		
Words	CVC		102.39	18.76		70.46	14.81
	CCV		91.27	19.35		52.40	16.65
	2 syllable		73.97	19.20		36.64	11.23
	3/4 syllable		59.01	17.33		28.55	9.33
Pseudowords	CVC		74.22	18.36		41.53	11.28
	CCV		60.97	19.96		28.28	10.83
	2 syllable		39.16	13.93		16.56	6.54
	3/4 syllable		30.66	11.16		12.48	4.82
Reading measures end Grade 6		90			78		
Words	CVC		109.21	18.07		76.82	16.59
	CCV		96.06	19.52		59.01	16.80
	2 syllable		83.86	23.55		42.64	12.46
	3/4 syllable		66.18	20.04		34.36	9.28
Pseudowords	CVC		81.18	17.86		46.88	14.34
	CCV		66.16	20.59		32.19	11.24
	2 syllable		45.79	15.44		20.51	7.60
	3/4 syllable		36.04	13.37		15.31	5.92

lexicality (words, pseudowords) as the within-subject factors and group (typical readers, children with dyslexia) as the between-subject factor. The assumption of sphericity was violated for time; therefore, Greenhouse-Geiser corrections are reported, $\chi^2(2) = 8.32$, $p = .02$. The main effects for time, $F(1.91, 164) = 309.53$, $p < .001$, $\eta^2_p = .65$, lexicality, $F(1, 165) = 2185.69$, $p < .001$, $\eta^2_p = .93$, and group, $F(1, 165) = 206.30$, $p < .001$, $\eta^2_p = .57$, were all significant, as were all two-way interactions between these variables, time × group, $F(1.91, 164) = 10.44$, $p < .001$, $\eta^2_p = .06$ and time × lexicality, $F(1.99, 164) = 13.05$, $p < .001$, $\eta^2_p = .07$. The mean difference between typical readers and children with dyslexia was larger at time 3, $M = 31.75$, SD = 2.19, than at time 1, $M = 27.61$, SD = 2.01, $t(165) = 4.15$, $p < .001$, $d = 0.65$. The mean difference between words and pseudowords was larger at time 3 compared with time 1, T1 $M = 28.08$, SD = 9.22, T3 $M = 25.19$, SD = 9.76, $t(167) = 5.01$, $p < .001$, $d = 0.37$. That is because word reading fluency had increased more than pseudoword reading fluency. The significant interaction between lexicality × group, $F(1, 165) = 49.39$, $p < .001$, $\eta^2_p = .23$, indicated that the mean difference between the number of words and pseudowords read correctly within 1 min was larger for typical readers ($M = 91.01$, SD = 21.71), than for children with dyslexia, $M = 67.25$, SD = 21.97), $t(165) = 7.02$, $p < .001$, $d = 1.08$. The interaction between time × lexicality × group was not significant, $F(1.99, 164) = 1.62$, $p = .20$, $\eta^2_p = .01$.

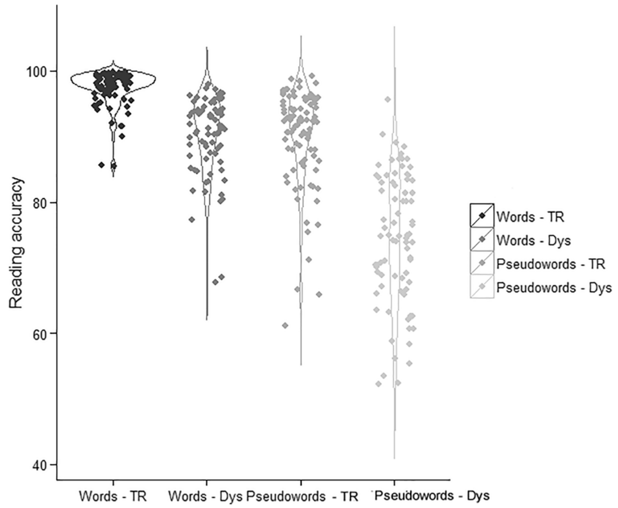

Fig. 1 Density plots of reading accuracy for words and pseudowords in children with dyslexia (Dys) and typical readers (TR). Scores are the mean accuracy scores over the three measurements

Predicting development of word and pseudoword reading skills

The second goal was to examine what cognitive and linguistic skills predicted individual differences in the development of word and pseudoword reading. First, to test whether there was sufficient variance in reading development to justify testing individual differences, we fitted growth models using linear mixed-effects modelling with group and time as fixed effects and time added as random effect for both groups. A nonsignificant random effect for time indicates a lack of variance in growth in reading skills. Correlations between the reading and cognitive and linguistic measures are presented in Table 3.

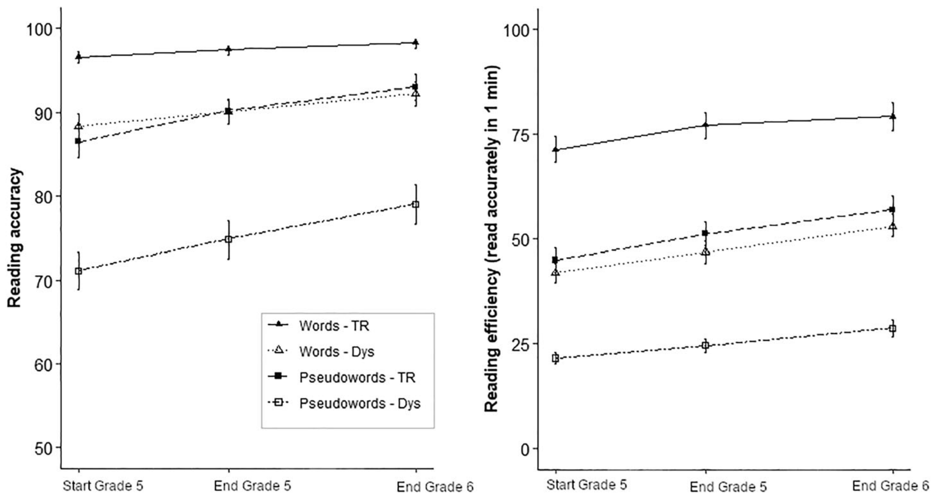

Fig. 2 Reading accuracy (percentage correct; left panel) and fluency (correctly read in 1 min) for words and pseudowords across development in grades 5 and 6 for typical readers (TR) and children with dyslexia (Dys). Error bars represent standard errors of the mean

Table 3 Pearson correlations between reading measures and cognitive and linguistic measures assessed at the first measurement. Above the diagonal typical readers (n = 92), below the diagonal children with dyslexia (n = 80)

	1	2	3	4	5	6	7	8	9
1. T1 word fluency	–	.55**	.52**	.87**	.25*	− .56**	.15	.30**	.40**
2.T1 word accuracy	.55**	–	.77**	.57**	.32**	− .07	− .03	.19	.45**
3. T1 pseudoword fluency	.70**	.47**	–	.68**	.34**	− .53**	.17	.24*	.53**
4. T1 pseudoword accuracy	.25*	.53**	.62**	–	.42**	− .12	.11	.19	.44**
5. Phonological awareness	.08	.37**	.32**	.21	–	− .24**	.34**	.28**	.13
6. Rapid naming	− .42**	− .20	− .13	− .59**	− .06	–	− .27*	− .21*	− .33**
7. Verbal STM	− .07	.05	.25*	.17	.33**	− .05	–	.12	.12
8. Vocabulary	.09	.30**	.16	.08	.21	− .02	.07	–	.18
9. Visual attention span	.19	.26*	.21	.35**	.14	− .14	.17	.13	–

**p < .01, *p < .05

Reading accuracy

The results for the reading accuracy measures showed that there was significant variance in growth in reading accuracy for typical readers, words $\Delta\chi^2(2) = 13.72$, $p = .001$, pseudowords $\Delta\chi^2(2) = 18.53$, $p < .001$, but not for children with dyslexia, in words $\Delta\chi^2(2) = 3.66$, $p = .16$ and pseudowords $\Delta\chi^2(2) = 0.48$, $p = .79$. For the typical readers, the predictor variables were added to the model to test if they explained variance in initial reading accuracy (added as fixed effect) and in growth in reading fluency accuracy (interaction time × predictor variable). The final model for word reading accuracy included phonological awareness, $\beta = 1.22$, $p < .001$, visual attention span, $\beta = 1.93$, $p < .001$, and verbal short-term memory, $\beta = -.55$, $p = .01$ as predictors for initial word reading accuracy. Phonological awareness, $\beta = -.03$, $p = .04$, and visual attention span, $\beta = -.05$, $p = .003$, also predicted growth in word reading accuracy. Typical readers with lower phonological awareness skills and a smaller visual attention span showed more growth in word reading accuracy. For pseudoword reading phonological awareness, $\beta = 2.77$, $p < .001$, and visual attention span, $\beta = 5.05$, $p < .001$, predicted initial pseudoword reading accuracy and only visual attention span also predicted growth in pseudoword reading accuracy, $\beta = -.14$, $p = .005$. Children with a smaller visual attention span showed more growth in pseudoword reading accuracy.

Reading fluency

Regarding the reading fluency measures, there was a lack of variance in growth in reading fluency skills in the typical readers, for words $\Delta\chi^2(2) = 0.89$, $p = .64$, and pseudowords $\Delta\chi^2(2) = 5.78$, $p = .06$, while children with dyslexia did show variance in growth in word, $\Delta\chi^2(2) = 11.14$, $p = .004$, and pseudoword reading fluency, $\Delta\chi^2(2) = 34.80$, $p < .001$. For the children with dyslexia, the predictor variables were added to the model to test if they explained variance in initial reading fluency and growth in reading fluency. The final model for word reading included rapid naming, $\beta = -3.20$, $p < .001$, as a predictor for word reading fluency. Adding the interaction between time × rapid naming did not improve the model, $\Delta\chi^2(1) = 3.17$, $p = .07$, and the other variables did not predict individual differences in growth in word reading fluency in this group ($p > .05$) either. The final pseudoword model included rapid naming, $\beta = -2.60$, $p < .001$, and visual attention span, $\beta = 1.80$, $p = .01$, as predictors for initial reading fluency. As for the word reading model, the interaction between time × rapid naming did not improve the fit, $\Delta\chi^2(1) = 3.27$, $p = .07$, nor did the interaction between time and any of the other predictor variables ($p > .05$).

Discussion

In the present study, we examined the development of word and pseudoword accuracy and fluency and its cognitive and linguistic predictors in children with dyslexia and typical readers in the upper primary grades. The results showed that children with dyslexia, who all had received a clinical reading intervention in previous years, were less accurate than typical readers and, as the typical readers, they showed very little development in reading accuracy over time. They were also less fluent and, as a group, showed less development in reading fluency than typical readers throughout grades 5 and 6. Both the children with dyslexia and the typical readers improved more in word than in pseudoword reading fluency.

To answer the first research question, we compared reading development of typical readers and children with dyslexia at the group level in the upper primary grades using repeated measures ANOVAs. The repeated measures analyses revealed no group differences between the children with dyslexia and typical readers in growth in reading accuracy from grade 5 to the end of grade 6. This was unexpected, considering that typical readers, on average, were already highly accurate from the start of the study in grade 5 and therefore had little room to grow. In contrast, the children with dyslexia were still behind on typical readers in their mean reading accuracy, but did not catch up with the typical readers throughout grades 5 and 6, despite the fact that they still had room to grow in reading accuracy. They did not reach ceiling for word or pseudoword reading accuracy, even though they learned to read in a relatively transparent orthography. Consistent with findings by Verhoeven and Keuning (2018), the children with dyslexia particularly struggled with accurate pseudoword reading.

Compared with typical readers, children with dyslexia were behind on reading fluency as well. The repeated measures analyses also revealed that the children with dyslexia improved less than typical readers in reading fluency from grade 5 to the end of grade 6, although this effect was small. Overall, for both groups, growth in reading fluency at the end of primary school was small. In line with Eklund et al. (2015) and Dandache et al. (2014), the children with dyslexia were not able to catch up with typical readers at the end of primary school, despite having received an intensive phonics intervention the previous years.

Our second research question regarded the contribution of underlying cognitive and linguistic skills to individual differences in initial reading levels and development of word and pseudoword reading accuracy and fluency. While repeated measures analyses were used to investigate how the two groups overall developed their reading skills over time (first research question), the purpose of the mixed-effects models was to investigate whether we could explain individual differences in (development of) reading skills within the groups. With respect to reading accuracy, we found significant variance in growth for typical readers, but not the children with dyslexia, and therefore could only further inspect individual differences in growth in reading accuracy within the typical readers. We had not expected this given the high reading accuracy scores of this group and the small improvement between grades 5 and 6. However, the correlation between the intercept and slope was negative, indicating that typical readers with lower accuracy scores showed more growth over time. Children with higher reading accuracy scores could hardly increase in accuracy, because of ceiling effects. It has been shown that typical readers and even poor readers in transparent orthographies reach high levels of accuracy very early in reading development (Verhoeven and van Leeuwe 2009; Landerl and Wimmer 2008; Zoccolotti et al. 1999), but when we looked at individual differences in reading accuracy within typical readers in the upper primary grades, our study revealed that typical readers with lower accuracy scores at the start of the study improved more over time. This was especially the case for children with weaker phonological awareness skills and a smaller visual attention span in grade 5. Previous literature has established an association between phonological awareness and reading accuracy (Caravolas et al. 2013; Compton 2000; Leppänen et al. 2004; Lervåg et al. 2009; Vaessen and Blomert 2010), but in our study, at this stage of reading development, the effect was in the opposite direction. The typically reading children with weaker phonological awareness skills still improved in word reading accuracy, whereas the children with better phonological awareness skills had reached ceiling levels of reading accuracy.

With respect to reading fluency, there was very little variance in reading fluency development in the typical readers, possibly because they started to reach ceiling effects at the end of primary school. We therefore were not able to examine individual differences in reading fluency development in this group. We were able to examine individual differences in growth in reading fluency within the group of children with dyslexia, as they showed significant variance in growth in reading fluency. Note that even though there was significant variance in reading fluency development in the children with dyslexia, as a group, they showed little growth in reading fluency skills. This might explain why the effect of rapid naming on word and pseudoword reading development did not reach significance. Rapid naming skills did predict individual differences in initial reading fluency in the children with dyslexia, but did not predict any additional variance in growth in reading fluency over and above the strong effect of initial reading fluency skills on growth in reading fluency (correlations between time points T1–T2, r = .88, T2–T3, r = .90). Previous studies do show that rapid naming skills predict reading development in children with (Furnes and Samuelsson 2010; Landerl et al. 2013) and without dyslexia (Caravolas et al. 2013; Compton 2000; Vaessen and Blomert 2010; Vaessen et al. 2010), but this no longer seemed to be the case in our study, at the end of primary school.

While rapid naming was not related to growth in reading fluency, it was associated with the initial word and pseudoword reading fluency skills of the children with dyslexia at the start of grade 5. Better initial word and pseudoword reading fluency skills of the children with dyslexia were associated with better rapid naming skills. In addition, visual attention span also predicted individual differences in initial pseudoword reading fluency in children with dyslexia, over and above rapid naming speed. This suggests that the better readers can process more visual elements in parallel than the readers with lower reading skills (see van den Boer and de Jong 2018). In line with van den Boer and de Jong (2018), we found no evidence for a causal relation between visual attention span and growth in reading fluency. Importantly, contrary to Dandache et al. (2014), individual differences in both word and pseudoword reading fluency in children with dyslexia were not predicted by phonological awareness skills. Considering the scores on both phonological awareness tasks, this is unlikely to be due to floor or ceiling effects within the group of children with dyslexia. Despite the strong focus on phonological skills and grapheme-phoneme correspondences in the clinical reading intervention (see Tilanus et al. 2016), the results of the present study suggest that due to long-lasting difficulties with phonological abilities, the children with dyslexia rely less on this skill for fluent word and pseudoword reading in the upper grades of primary school. However, another explanation could be that phonological awareness no longer contributed to reading at this stage of their reading development, as is more often found in transparent orthographies, especially for reading fluency (Vaessen and Blomert 2010).

A limitation of the study was the psychometric quality of the phonological awareness and verbal short-term memory tasks. These measures are widely used in clinical practice and were therefore included in the study, but reliability was just moderate for this age group; therefore, the conclusion for these tasks should be taken with caution. The phonological awareness subtests were only weakly correlated in the children with dyslexia, and the typical readers started to perform at ceiling on the deletion subtest. Also, the two working memory subtests did not correlate for the children with dyslexia, possibly due to a restriction of range effect on the digit span backward task. A second limitation of the study was that a single reading test was used to measure both accuracy and fluency. To ensure that readers did not become inaccurate at the cost of trying to read as fast as possible, and to further examine why some children still struggle with accurate reading, adding an untimed reading measure could provide more insight in strategies used for single (pseudo)word reading.

The results of this study emphasize the importance of not only monitoring reading fluency but also reading accuracy in children with dyslexia throughout the upper grades of primary school. Although it has been argued that reading fluency skills are a better measure for differentiating between children with and without dyslexia in a transparent orthography (see De Jong and van der Leij 2003), we showed that a substantial number of the children with dyslexia kept struggling with accurate pseudoword reading and that they showed very little improvements in reading accuracy. In addition, the fact that after intervention the gap in reading fluency skills between children with and without dyslexia further increased in the upper primary grades also asks for further attention and perhaps further remediation in educational practice.

To conclude, we showed that at the end of primary school, children with dyslexia in a relatively transparent orthography such as Dutch are not just behind on typical readers in fluent word and pseudoword reading, but still experience difficulties with accurate reading as well, even after completing an intensive clinical reading intervention. Nevertheless, children with dyslexia do show larger improvements over time in word than in pseudoword reading, and in line with previous literature, rapid naming skills explained individual differences in reading fluency skills at the end of primary school.

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