British Journal of Developmental Psychology (2010), 28, 5–31

The British Psychological Society
www.bpsjournals.co.uk

Towards a further characterization of phonological and literacy problems in Dutch-speaking children with dyslexia

Bart Boets[1,2]*, Bert De Smedt[1], Leen Cleuren[1], Ellen Vandewalle[2], Jan Wouters[2] and Pol Ghesquière[1]

[1]Centre for Parenting, Child Welfare and Disabilities, Katholieke Universiteit Leuven, Belgium
[2]Department of Neurosciences, Laboratory for Experimental ORL, Katholieke Universiteit Leuven, Belgium

This longitudinal study examined the development of phonology and literacy in Dutch-speaking children at family risk of dyslexia and in matched controls. Measures were administered in kindergarten (before the start of formal reading instruction), in first and in third grade. Children, diagnosed with dyslexia in third grade, showed impaired phonological awareness (PA), verbal short-term memory, and rapid automatic naming ability (RAN) at all time points, with the deficit in PA aggravating over time. These children also performed more poorly in letter knowledge, word and nonword reading accuracy and speed, and spelling at each time point. Children at family risk of dyslexia who did not fulfil criteria for dyslexia, scored more poorly than low-risk controls on the literacy and phonological measures that required the most fine-grained phonological representations. This suggests that the family risk of dyslexia is continuous rather than discrete. Hierarchical regression analyses demonstrated that PA and RAN were initially the most important instigators of reading accuracy and reading speed, respectively. After 2 years of reading instruction, only RAN predicted reading speed and accuracy. Letter knowledge, reading accuracy, and reading speed also contributed to the development of PA.

It is well-established that phonological processing is closely related to the development of reading and spelling ability. Phonological deficits are also the hallmark of developmental dyslexia (hereafter referred to as dyslexia), a specific learning disability that is characterized by severe and persistent difficulties with reading and/or spelling

*Correspondence should be addressed to Dr Bart Boets, Faculty of Psychology and Educational Sciences, Centre for Parenting, Child Welfare and Disabilities, Katholieke Universiteit Leuven, Vesaliusstraat 2, B-3000 Leuven, Belgium (e-mail: bart.boets@ped.kuleuven.be).

DOI:10.1348/026151010X485223

(Vellutino, Fletcher, Snowling, & Scanlon, 2004). The present longitudinal study investigated early manifestations of phonological and literacy problems, and their interrelations, in young Dutch-speaking Belgian children with dyslexia.

Phonology and reading development

Phonological ability is an umbrella term used to describe the ability to access, process, and manipulate speech sounds. It consists of three interrelated but distinctive phonological dimensions (e.g. Wagner & Torgesen, 1987). *Phonological awareness* (PA) refers to the conscious sensitivity to the sound structure of language, which is typically assessed by tasks measuring the ability to discriminate and manipulate syllables or phonemes, such as phoneme deletion or spoonerism. *Verbal short-term memory* (VSTM) is the ability to recode and maintain auditory information into a sound-based representational system, which is typically measured with digit span or nonword repetition tasks. *Lexical retrieval of phonological codes* involves the process of recoding a visual symbol into a sound-based representation by retrieving its lexical referent from long-term memory, and is usually assessed by rapid automatic naming (RAN) tasks, such as letter or colour naming.

The interdependencies between these three phonological skills have long been debated. Originally, all three phonological skills were assumed to reflect the quality and distinctness of the underlying phonological representations, thus constituting one core phonological component (e.g. Elbro, 1996; Wagner, Torgesen, & Rashotte, 1994). This view has been questioned by others (e.g. Bowers & Ishaik, 2003), who argued that there are two phonological components, which both independently contribute to reading development. The first component involves PA and VSTM, while the second component involves the retrieval of lexical information or RAN. This two-component model is supported by various observations. First, both components can independently be affected in dyslexia, the so-called *double deficit* hypothesis (Wolf & Bowers, 1999). Second, RAN and PA appear to be related to different aspects of reading (Elbro & Scarborough, 2003): RAN is associated with reading speed and orthographic pattern recognition, while PA is mainly related to reading accuracy and nonword reading (for a review, see Allor, 2002; Savage & Frederickson, 2005; Verhagen, Aarnoutse, & van Leeuwe, 2008). Third, PA appears to be more important in the early stages of reading development (i.e. word-analytic decoding), whereas RAN has a larger impact on the development of reading fluency (i.e. word-holistic recognition) and word comprehension in proficient readers (e.g. van den Bos, Zijlstra, & Spelberg, 2002; but see Wagner, Torgesen, Rashotte, & Hecht, 1997).

It should be noted that the relative contribution of a specific phonological factor to reading development is also determined by the regularity of a language's orthographic system in terms of spelling-sound correspondence (e.g. Share, 2008; Wimmer & Goswami, 1994). Languages with a more inconsistent or opaque spelling-sound correspondence, like English, generally show a prolonged and more pronounced influence of PA on reading (e.g. Torgesen, Wagner, Rashotte, & Burgess, 1997; Wagner *et al.*, 1997; for a review, see Share, 2008), whereas individual differences in RAN may be more important for learning to read in languages with more transparent grapheme–phoneme relations, such as Greek, Finnish, German, Italian, Spanish, Turkish, and Dutch (e.g. Landerl & Wimmer, 2008; Verhagen *et al.*, 2008).

While the sensitivity to the phonological structure of words promotes reading acquisition (e.g. Bradley & Bryant, 1983), learning to read and spell also facilitates the development of subsequent PA skills (e.g. Bentin & Leshem, 1993). Evidence for this reciprocal relation was provided by studies that demonstrated poor PA skills in pre-readers (Liberman, Shankweiler, Fisher, & Carter, 1974) and illiterate adults (Morais, Cary, Alegria, & Bertelson, 1979), and by correlational studies that reported an association between letter knowledge assessed in kindergarten and performance in PA and RAN assessed in first grade (de Jong & van der Leij, 1999; Wagner *et al.*, 1994, 1997). However, a similar predictive relationship between more advanced reading measures and subsequent phonological abilities could not be demonstrated in older children (de Jong & van der Leij, 1999; Verhagen *et al.*, 2008; Wagner *et al.*, 1994, 1997).

Early phonological problems in children with dyslexia

There is consistent evidence for the presence of phonological problems in children with dyslexia. Impaired phonological processing has been observed in PA (e.g. Mann & Liberman, 1984), RAN (e.g. Bowers & Ishaik, 2003), and VSTM (e.g. Mann & Liberman, 1984). Less is known, however, about the developmental trajectories of these phonological deficits, because most studies considered phonological abilities at a single point in time when reading problems were already apparent in children with dyslexia. It therefore remains unclear whether the phonological problems were present before the onset of reading instruction and whether reading acquisition had an impact upon these problems. The present study addressed this issue by studying preschool children who are at family risk of dyslexia and by following them up in primary school. Because the incidence of dyslexia is running in families, preschoolers with dyslexic relatives are more likely than other children to develop reading problems. Gilger, Pennington, and DeFries (1991) estimated that between 30 and 50% of the children at family risk of dyslexia will ultimately become reading disabled. The selection of children at family risk of dyslexia thus increases the likelihood of rendering a final sample that includes a sufficient number of children with dyslexia.

Several studies have followed preschoolers at family risk of dyslexia and compared them to low-risk control children. Typically, these studies compared participant groups defined by family risk (i.e. high-risk vs. low-risk) and/or reading status in primary school (i.e. dyslexic vs. nondyslexic). In a pioneering study, Scarborough (1989, 1990) showed that English-speaking children with dyslexia performed more poorly on PA and letter knowledge (assessed at the age of 5), compared to nondyslexic high-risk and low-risk children. A study by Elbro, Borstrom, and Petersen (1998) followed Danish children from 1 year before the onset of formal reading instruction until the end of the first year of reading instruction. These authors showed that dyslexic readers presented significant preschool deficits in PA, VSTM, and letter knowledge, and in a specific measure assessing the distinctness of phonological representations. Nondyslexic children at high family risk did not differ from nondyslexic children at low family risk on any of the administered measures. Snowling, Gallagher, and Frith (2003) examined PA and VSTM in English-speaking children at three time points over a 4-year time period (i.e. at about 4, 6, and 8 years). They showed that high-risk dyslexic readers showed consistent impairments in PA and VSTM at each of the three time points. In the nondyslexic children at high family risk, significant weaknesses in PA, VSTM, reading, and spelling were observed, but these difficulties were less severe than those observed in dyslexic children. The finding that even unaffected members of high-risk families show some of the behavioral symptoms of dyslexia was interpreted as evidence that the family risk of dyslexia is continuous rather than discrete (Snowling *et al.*, 2003). In other words, dyslexia is probably not an all-or-none condition, but it appears to be multi-componential, with only some children reaching a threshold of impairment that is defined as dyslexia (Snowling *et al.*, 2003). Recently, de Bree, Wijnen, and Gerrits (2010) assessed VSTM (i.e. nonword repetition) in 4-year-old Dutch children at family risk of dyslexia and examined its relation with literacy achievement at the age of eight. Results indicated that high-risk dyslexic children performed significantly more poorly than nondyslexic children from low-risk and high-risk families, while the latter two groups did not differ from each other.

A particular limitation of the abovementioned studies is that they did not investigate all three dimensions of phonological ability (Wagner & Torgesen, 1987) and that they did not assess them at multiple time points. Therefore, the relative contribution of each phonological component and its developmental trajectory remain largely unknown. To the best of our knowledge, only two longitudinal studies addressed this issue by investigating all three phonological components at various time points. Pennington and Lefly (2001) investigated PA, VSTM, and RAN in English-speaking children at four time points over a 3-year period from kindergarten to the end of second grade. They showed that high-risk dyslexic readers presented consistent phonological deficits on all measures at each time point. The high-risk nondyslexic readers performed more poorly than the low-risk nondyslexic readers on RAN and VSTM, reading and spelling, which again suggests that family risk of dyslexia is continuous rather than discrete. The rate of development did not differ between the three participant groups. Puolakanaho and colleagues (Lyytinen *et al.*, 2006; Puolakanaho, Poikkeus, Ahonen, Tolvanen, & Lyytinen, 2004, 2007) examined PA, RAN, and VSTM in Finnish children at risk of dyslexia and in low-risk controls at the ages of 3–5. Children diagnosed with dyslexia at the age of 8, performed more poorly than low-risk controls on each of the preschool phonological measures. Unfortunately, data of the high-risk children without dyslexia were not reported.

In the present study, we investigated the phonological and literacy development of children who were learning to read in Dutch, a language with a relatively transparent orthography. In this type of language, metaphonological abilities (i.e. PA) tend to develop more quickly than in languages with less transparent orthographies (Caravolas & Bruck, 1993). For example, Cossu, Shankweiler, Liberman, Katz, and Tola (1988), compared Italian- and English-speaking children on equivalent syllable and phoneme awareness tasks. They observed that by the end of first grade the Italian-, but not the English-speaking children were performing at ceiling level on both tasks. Similarly, Durgunoglu and Oney (1999) showed that Turkish-, but not English-speaking children performed at ceiling on a syllable and phonemic awareness task by the end of first grade. In line with these findings, Landerl and Wimmer (2000) and van Daal and van der Leij (1999) investigated German- and Dutch-speaking children, respectively. Both studies showed that third grade children with dyslexia did no longer differ from controls on measures of onset and rhyme awareness. These findings suggest that the PA difficulties resolve in dyslexic readers in transparent orthographies. It should be noted, however, that the measures of PA used in these studies were relatively easy and yielded ceiling effects. The administered PA tasks might thus have been not sensitive enough to capture individual differences. Indeed, de Jong and van der Leij (2003) demonstrated that Dutch children with dyslexia continued to perform more poorly in fourth grade on a complex phoneme deletion task that was sufficiently demanding in terms of phonological skills. In line with this, Patel, Snowling, and de Jong (2004) administered a complex phoneme deletion task in Dutch and English 9- to 11-years-olds, and showed that this measure yielded sufficient variability to predict later individual differences in reading in both participant groups.

Literacy problems in children with dyslexia

By definition, dyslexia is characterized by severe and persistent reading and/or spelling problems (Gersons-Wolfensberger & Ruijssenaars, 1997). Studies in English-speaking children generally focus on problems in word reading accuracy without considering measures of reading speed (Share, 2008). By contrast, word reading accuracy in more transparent orthographies is already at ceiling level after 1 year of formal reading instruction (e.g. Landerl & Wimmer, 2008; Patel *et al.*, 2004; Seymour, Aro, & Erskine, 2003; Share, 2008; Ziegler & Goswami, 2006; but see Verhagen *et al.*, 2008, for some critical methodological considerations regarding the commonly applied measures of reading accuracy). Due to the more consistent grapheme–phoneme correspondence rules, dyslexic and young typically developing readers in more transparent languages generally experience less decoding problems than their English-speaking peers. Reading speed, however, will remain a stumbling-block for the dyslexic readers, even in these more transparent orthographies (e.g. de Jong & van der Leij, 2003; Landerl & Wimmer, 2008; Landerl, Wimmer, & Frith, 1997; Patel *et al.*, 2004; Seymour *et al.*, 2003; Wimmer, 1993; Ziegler & Goswami, 2006).

Although it has been demonstrated that dyslexic readers in transparent orthographies do not show particular problems in reading accuracy, this issue should be treated with caution. A particular limitation of the existing studies deals with the reading accuracy measures that have been administered. Typically, reading accuracy is measured by counting the number of errors on standardized tests of word recognition speed. In these tests, children are asked to read as correctly and quickly as possible, and within a certain time limit, a list of words that gradually increase in difficulty. However, the simultaneous assessment of both accuracy and speed may be questioned from a psychometric point of view (see Dennis & Evans, 1996), and against the background of comparing word reading ability in dyslexic and nondyslexic readers (see also Verhagen *et al.*, 2008). There are several reasons to suggest why speeded tests are not a valid measure of word recognition accuracy. First, the speeded nature of the task may encourage typically developing readers to read too fast and, consequently, to produce errors on words that they otherwise would have read correctly. These types of errors are less likely to occur in dyslexic readers who are taking more time. Second, the dyslexic readers will typically read fewer words within a certain time limit, due to their slow reading speed. As a result, the probability of making an error is smaller in dyslexic readers than in normal readers. The absolute number of errors on a speeded reading test may thus be an underestimation of the reading accuracy difficulties in dyslexic readers. Third, the difficulty gradient and the time limit on these tasks make it difficult to compare dyslexic and nondyslexic readers because the accuracy scores of both groups are not recorded over the same number (and difficulty level) of items. Similarly, the number of words read correctly within a fixed time limit does not offer an unbiased measure of reading speed, because it does not differentiate between subjects who are reading correctly but slowly and those who are reading quickly but making a lot of errors.

Reading accuracy and reading speed should be assessed independently from each other in order to obtain unbiased measures of reading accuracy and reading speed (Verhaegen *et al.*, 2008). Reading accuracy should be assessed without any time limitation to avoid that the accuracy measure is confounded by the number and the difficulty level of the administered items and to avoid that the child could make a speed-accuracy trade off (see Dennis & Evans, 1996). The items in such an unbiased measure should be of increasing difficulty to avoid ceiling effects. Likewise, a word reading test that yields almost perfect accuracy should be used to obtain an unbiased measure of reading speed.

The present study

The present study extended previous work by simultaneously assessing all three phonological components at different time points. Different from previous studies, we used unbiased measures of reading accuracy and speed. All data were collected in Belgian children who have Dutch, a language with a relatively transparent orthography, as their mother tongue. In the Belgian school system, there is no formal reading instruction in kindergarten. Reading instruction starts in first grade, when children are on average 6 years old. We investigated phonological and literacy abilities in the last year of kindergarten, in first grade and in third grade. Participant groups were defined by combining reading status in third grade (dyslexic vs. nondyslexic readers) and family risk of dyslexia (high-risk vs. low-risk children). The study comprised three groups: (1) dyslexic readers (DR), (2) nondyslexic readers at high family risk of dyslexia (NR-HR), and (3) nondyslexic readers at low family risk of dyslexia (NR-LR).

Four research questions were put forward. First, we aimed to investigate which phonological skills differentiated the three groups of children over the 3-year period from preschool to third grade. We expected that the children with dyslexia would show poor performance on RAN and VSTM at every time point. We also expected them to perform more poorly on PA in kindergarten and first grade. Against the background of studies in transparent orthographies, it may be contended that dyslexic readers may (partially) catch up for PA in third grade. Due to the more demanding nature of our PA tasks, we, however, expected a subtle but significant deficit. Turning to the nondyslexic high-risk group, we hypothesized that these children would show mild but significant phonological deficits, particularly on the more implicit phonological VSTM and RAN tasks.

Second, we sought to determine which literacy skills differentiated the three groups of children over the investigated 3-year period. Because reading speed constitutes the main stumbling-block for dyslexic readers in transparent orthographies, we expected group differences to be most prominent on the speeded measures. With regard to reading accuracy, our hypothesis was less clear: although it has been shown that dyslexic readers in transparent orthographies quickly tend to reach ceiling levels in reading accuracy, we expected that our unbiased reading accuracy measures might be more sensitive to potential group differences. In nondyslexic readers at high family risk of dyslexia, we also predicted mild difficulties in reading. Because of the transparent nature of the Dutch orthography, these reading difficulties were mainly expected to occur in reading speed.

Third, we used the data of the whole sample to investigate the developmental relations between the administered phonological abilities and reading accuracy and reading speed. We hypothesized that PA would be the most important predictor of reading accuracy, whereas RAN would be the most important predictor of reading speed. Given the relative consistency of the Dutch orthography, we expected that the predictive relation between PA and reading would be most prominent in the early years of reading instruction and would decrease over time. RAN, on the other hand, was expected to have an increasing and continuing influence on reading development.

Fourth, we aimed to investigate whether early literacy skills have an impact upon subsequent phonological development. Because reading accuracy relates to sublexical word processing and requires the blending of individual phonemes, we expected it to stimulate the subsequent development of PA and VSTM. In line with van den Bos *et al.* (2002), we expected that reading speed would contribute to the development of RAN skills.

Method

Participants

Sixty-two children (36 boys and 26 girls) participated. These children were first tested in the last year of kindergarten, i.e. the year before the onset of formal reading instruction, at an average age of 5 years and 4 months. They were subsequently tested in first grade and in third grade (after 2 years and 2 months of reading instruction). All children were native Dutch speakers without a history of brain damage, psychiatric disorder, hearing loss, or visual problems. Half of the participants ($N = 31$) were selected because of a family history of dyslexia; i.e. they had at least one first-degree relative with a formal diagnosis of dyslexia. Because dyslexia tends to run in families, such children are expected to have a higher chance of developing reading problems (Gilger *et al.*, 1991). We refer to these children as the high-risk group (HR). The other half of the participants ($N = 31$) came from families where there was no history of reading disabilities. We refer to these children as the low-risk group (LR). For every high-risk child, we selected the best matching low-risk control child based on five criteria: (1) educational environment, i.e. same school, (2) sex, (3) age, (4) non-verbal intelligence, and (5) parental educational level. Non-verbal intelligence was assessed in kindergarten with Raven's Coloured Progressive Matrices (CPM; Raven, Court, & Raven, 1984). Only children with non-verbal IQ-scores above 80 were included into the study. The vocabulary and block design subtests of the Wechsler Intelligence Scale for Children – 3rd edition (WISC-III; Wechsler, 1992) were additionally administered in first grade, but these tests were not used for participant selection or participant matching. Parental educational level was determined with the International Standard Classification of Education scale (OECD, 1999). In order to fit the contemporary educational system in Belgium, the original seven categories of this scale were converted to three categories, comprising low, medium, and high educational level. Further details about the participants and the selection procedure are described in Boets, Wouters, van Wieringen, and Ghesquière (2006).

In line with the current practice in Belgium and The Netherlands (Gersons-Wolfensberger & Ruijssenaars, 1997), the criterion used for the diagnosis of dyslexia took into account both the severity and the persistence of a child's literacy problem. Specifically, a child had to score below the 10th percentile on a standardized word reading (van den Bos, Spelberg, Scheepstra, & de Vries, 1994) or spelling test (Dudal, 1997), in both first *and* third grade. By applying this criterion, we identified 5 children with dyslexia in the low-risk group ($5/31 = 16\%$) and 11 children in the high-risk group ($11/31 = 35\%$). By combining risk status (high or low) with the presence or absence of a diagnosis of dyslexia, we further divided children into four groups: (1) dyslexic readers at high family risk, (2) dyslexic readers at low family risk, (3) nondyslexic readers at high family risk, and (4) nondyslexic readers at low family risk. Because the dyslexic reading groups did not differ from each other on any of the administered tests (all ps $> .20$), we collapsed the data of both dyslexic groups into a single dyslexic sample to increase statistical power. Thus, three groups remained for final analyses: (1) dyslexic readers ($N = 16$), (2) nondyslexic readers at high family risk (NR-HR: $N = 20$), and (3) nondyslexic readers at low family risk (NR-LR: $N = 26$). Table 1 displays descriptive statistics for the three groups. Group comparisons showed no differences in gender ratio, age, non-verbal intelligence (Raven's CPM and block design), vocabulary, and parental educational level (all ps $> .20$). This outcome, though favourable to the final analyses, was not expected *a priori*, because the individual matching in kindergarten was originally accomplished at the level of the family risk status without considering actual reading status, and because the vocabulary and block design subtests of WISC-III were not used in the matching of the participant samples.

Table 1. Characteristics of the participants

	DR ($N = 16$)		NR-HR ($N = 20$)		NR-LR ($N = 26$)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age in months (kindergarten)	64	3	64	3	64	3
Non-verbal IQ (Raven in kindergarten)[a]	105	9	107	17	112	14
Vocabulary (WISC-III in grade 1)[b]	10	2	10	3	11	2
Block design (WISC-III in grade 1)[b]	10	3	11	2	10	3
Maternal educational level	2.5	0.7	2.6	0.6	2.6	0.6
Paternal educational level	2.4	0.6	2.1	0.8	2.3	0.6

Note. Parental educational level was calculated from ordinal data. There were no group differences (Fisher's exact test, $p > .20$).
[a] Standardized scores with population average $M = 100$ and $SD = 15$.
[b] Standardized scores with population average $M = 10$ and $SD = 3$.

Measures

Phonological awareness

First-sound, end-sound, and rhyme identity tasks. Three identification tasks were administered. The child had to select the word that had the same (a) first sound, (b) end sound, or (c) end rhyme as a given word (de Jong, Seveke, & van Veen, 2000, adapted by van Otterloo and Regtvoort). The distracter alternatives were systematically constructed to prevent guessing. All words were high frequent one-syllable Dutch words. Each item consisted of a row of five pictures. The first picture represented the given word and was separated from the other pictures by a vertical line. All items were named for the child. The child responded by naming or by pointing to the corresponding alternative. The first-sound and end-sound identity tasks consisted of 10 items. The rhyme identity task consisted of 12 items. The three tasks were each preceded by two practice items.

Rhyme production task. The child was presented with a one-syllable word and was asked to produce a rhyming word. If the child produced a rhyming nonword, this was also considered correct, as we wanted to assess children's rhyming skills irrespective of their vocabulary knowledge. The test consisted of eight items of increasing difficulty level. Two practice items were administered to familiarize children with task requirements.

First-sound and rhyme categorization tasks. Two categorization tasks were given. The first-sound categorization task had 15 items. Eight items consisted of words that started with a single consonant; seven items involved words that began with a consonant cluster. The rhyme categorization task consisted of 20 items of varying difficulty level (by using diphthongs or by manipulating the phonological similarity with the distracter item). Each item consisted of three monosyllabic words that were presented from a CD with a 1-s inter-stimulus interval. The three words were presented twice. The child was asked to name the two words that were similar to each other, i.e. those words that started with the same first-sound or that had the same rhyme. Each task was preceded by two practice items.

Phoneme deletion. The test consisted of 28 one-syllable nonwords that were presented from a CD (an adaptation of de Jong & van der Leij, 2003). Each nonword was presented twice. The child was asked to delete a particular phoneme of the nonword (i.e. a consonant from a consonant cluster). For the first 10 items, the deletion of the phoneme resulted in the disclosure of an existing word. For the next 18 items, the residual phonological string remained meaningless after phoneme deletion. Each subtest was preceded by two practice items. The maximum score on the test was 28.

Spoonerism. The test consisted of 3 sets of 10 items. For all sets, the first 5 items resulted in the disclosure of existing words, and the remaining 5 items yielded nonwords. In the first set, the child was required to replace the onset (consonant or consonant cluster) of a word with another consonant in order to create a new word or nonword (e.g. *KAT* with/m/becomes *MAT*). In the second and third set, 2 one-syllable words were given and the child was instructed to swap their consonant onset in order to reveal two new words or nonwords (e.g. *MUS-KAT* becomes *KUS-MAT*). In the second set, words started with a single consonant; in the third set, words started with a consonant cluster. Each set was preceded by two practice items. Each correctly produced word and nonword was rewarded with one point, with a maximum score of 50. Every child completed all items of the first set. The second and third sets were discontinued after four consecutive errors (0/2 for an item). The third set was only presented to those children who obtained a score equal to or above 6/20 on the second set.

Rapid automatic naming

Serial rapid-naming speed was assessed with four types of familiar stimuli: objects, colours, digits, and letters (van den Bos *et al.*, 2002). The objects represented five high-frequent, one-syllable words: boom 'tree', eend 'duck', stoel 'chair', schaar 'scissors', and fiets 'bicycle'. The colours were represented by small rectangles in five colours: black, blue, red, yellow, and green. The digit card depicted five arabic digits in random order: 2, 4, 8, 5, and 9. The letter card depicted five lowercase letters in random order: d, o, a, s, and p. For each type of symbol, a card consisting of 50 symbols in a random order (5 columns of 10 symbols), was presented. The child had to name the symbols on the card as fast and accurately as possible. Prior to testing, the child was asked to name the symbols of the last column of a card to determine whether he or she was familiar with all the presented symbols. For each card, the number of errors and the time to complete were recorded. The time to complete was transformed to the number of symbols named per second to enhance interpretation, with a higher score indicating better performance.

Verbal short-term memory

Digit span forward. This test assessed the immediate serial recall of spoken lists of digits presented from a CD. Testing started with a sequence of two digits. Three trials of the same list length were presented and list length was increased by one digit if the child recalled at least two of three trials of the same list length. If the child failed to do this, testing was terminated. The test score was the number of correctly recalled lists (De Smedt *et al.*, 2009).

Nonword repetition test. This test involved a Dutch adaptation (Scheltinga, 2003) of the nonword repetition test developed by Gathercole, Willis, Baddeley, and Emslie (1994). Because neither the nonwords nor their constituent syllables correspond to existing words, the use of long-term memory representations to support recall is prevented. The test consisted of 48 nonwords, gradually increasing in word length from two to five syllables. Two practice items preceded the test administration. All nonwords were presented auditorily from a CD and the child had to repeat them as accurately as possible. The test had a maximum score of 48.

Literacy measures

Letter knowledge. The 16 most frequently used letters in Dutch books were presented on a card and the child had to name each of these letters. Both the sound and the name of a letter were considered correct. The maximum score on the test was 16. The Cronbach's alpha reliability coefficient of this test was .72.

Grapheme knowledge: Accuracy and speed. This test measured accuracy and speed for recalling the sound of Dutch letters and letter combinations. In the first part of the test, the child had to name 34 graphemes (presented on a card) as accurately and fast as possible. Both accuracy and time to complete the task were recorded. In the second part, 8 more difficult graphemes or grapheme combinations were presented and the child had to read them as accurately as possible without any time limit. Accuracy scores were combined for both parts of the test, yielding a maximum score of 42. The Cronbach's alpha coefficient for this combined score was .83. The time to complete the first card was transformed to the number of graphemes named per second.

Standardized word reading test. The One-Minute Reading test (van den Bos *et al.*, 1994) was used as a standardized measure of single word identification. This test combines speed and accuracy into one index score. The child had to read a list of words of increasing difficulty as correctly and quickly as possible. The score on the test is the number of words read correctly within 1 min. The test–retest reliability, as listed in the manual, is .94 in first grade and .90 in third grade.

Word reading accuracy. The construction of this test was similar to the one described by de Jong and Wolters (2002). The test consisted of 40 items that were gradually increasing in difficulty level. This was accomplished by increasing the word length and by using less frequent letters, letter clusters, and words. The systematic increase in difficulty level was assured by systematically selecting every third item from a standardized word reading test (Three-Minute Reading test; Verhoeven, 1995) for which the gradual increase in difficulty level was demonstrated. The child was instructed to read the words as accurately as possible. There was no time limit. Testing was terminated if the child failed on six consecutive items. Cronbach's alpha of the test was .90 in typically developing children in first grade (Peeters, 2005).

Nonword reading accuracy. This test was similar to the word reading accuracy test but it consisted of nonwords instead of real words. The test consisted of 40 items that gradually increased in difficulty level. The systematic increase in difficulty level was assured by selecting every third item from a standardized nonword identification test (Pseudoword Reading test, version B; van den Bos, Spelberg, Scheepstra, & de Vries, 1994) for which this gradual increase in difficulty level was demonstrated. The child was instructed to read the nonwords as accurately as possible. There was no time limit. Testing was terminated if the child failed on six consecutive items. Cronbach's α of the test was .91 in typically developing first graders (Peeters, 2005).

Word reading speed. We used a reading test with items that were of equal difficulty level and that yielded nearly perfect accuracy (Peeters, 2005). The test consisted of 150 high-frequent one-syllable words with a consonant–vowel, vowel–consonant, or consonant–vowel–consonant structure. All words were known by more than 90% of the Dutch-speaking 6-year-olds (Schaerlaekens, Kohnstamm, & Lejaeghere, 1999). The child was instructed to read the list of words as correctly and quickly as possible. The number of words read within 1 min was transformed into the number of words read per second, to enhance interpretation.

Nonword reading speed. This test was similar to the word reading speed test. It consisted of items that were of equal difficulty level and that yielded nearly perfect accuracy (Peeters, 2005). The test consisted of 150 one-syllable nonwords with a consonant–vowel, vowel–consonant, or consonant–vowel–consonant structure. These items were constructed by decomposing and recombining the items of the word reading speed test. The number of nonwords read within 2 min was transformed into the number of nonwords read per second.

Spelling. A standardized spelling achievement test (Dudal, 1997) was used to assess children's spelling abilities. Children were asked to spell single words presented in isolation, single words presented in a sentence context, and short sentences. The maximum score on this test was 60. Grade-appropriate versions of this test were used in first and third grade. Cronbach's alpha of the test, as listed in the manual, was .92 in first grade and .90 in third grade.

Articulation speed

A measure of articulation speed was administered as a control variable to rule out that associations between reading speed and RAN occurred due to their common relation with articulation speed. In the articulation speed task, children were asked to serially repeat a word five times, speaking as rapidly and smoothly as possible. Four words of varying length and articulatory difficulty level were presented. Utterances were digitally recorded and were analysed with Cool Edit software. We administered each word twice and took the average reaction time to name both items. A summary composite score for articulation speed was calculated by averaging the z scores over all words.

Data collection

The tests for non-verbal intelligence and spelling were group based. The other measures were administered individually. Phonological skills were assessed at three time points, separated about 18 months from each other: (1) beginning of the last year of kindergarten (mean age = 5 years 4 months), (2) middle of first grade (mean age = 6 years 10 months), and (3) beginning of third grade (mean age = 8 years 4 months). Reading and spelling skills were assessed at the end of first grade and at the beginning of third grade. The measures and the occasion(s) at which they were administered are given in Table 2. All measures were collected for all children at each time point.

Table 2. Occasions of test administration

	Kindergarten, begin (5;4 years)	Grade 1, middle (6;10 years)	Grade 1, end (7;1 years)	Grade 3, begin (8;4 years)
Non-verbal intelligence (Raven)	x			
Vocabulary (WISC-III)		x		
Block design (WISC-III)		x		
PA				
Rhyme production	x			
Rhyme identity	x			
First-sound identity	x			
End-sound identity	x			
Rhyme categorization		x		
First-sound categorization		x		
Phoneme deletion		x		x
Spoonerism		x		x
RAN				
Colour naming	x	x		x
Object naming	x	x		x
Digit naming		x		x
Letter naming		x		x
VSTM				
Digit span	x	x		x
Nonword repetition test	x	x		x
Articulation speed		x		
Letter knowledge	x			
Grapheme knowledge: accuracy and speed		x		
Word reading			x	x
Word reading: accuracy			x	x
Word reading: speed			x	x
Nonword reading: accuracy			x	x
Nonword reading: speed			x	x
Spelling			x	x

Statistical analysis

For one participant of the nondyslexic high-risk group, the scores on the nonword repetition test and the RAN picture test assessed in kindergarten were discarded because of irregularities during testing. The scores on the letter knowledge task administered in kindergarten were log-transformed, to obtain normally distributed residuals. Group comparisons were analysed with linear mixed models analysis (MMA; Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006), which take into account the clustered nature of the data (i.e. matched pairs of children that attended the same school). Mixed model repeated measures analyses were carried out with pair as a random variable, group as a fixed between-subject variable and time as a fixed within-subject variable. *Post hoc* analyses were corrected for multiple comparisons using Tukey adjustments. The component structure of the phonological tests was examined by means of principal component analyses with varimax rotation. Relationships between variables were analysed using Pearson correlation coefficients and hierarchical regression analyses.

Results

Reliability, structure, and stability of the phonological measures

Table 3 displays the Cronbach's alpha for the administered phonological measures. The phonological tests were selected to reflect three domains: PA, RAN, and VSTM. Because the number of participants was not large enough to perform a reliable confirmatory factor analysis, principal component analyses with varimax rotation were carried out to examine the data structure. Because we were interested in the pattern of *specific* phonological deficits in relation to dyslexia, and in the *unique* contribution of the different phonological skills to reading development, we calculated unrelated (i.e. orthogonal) phonological factors. This also yielded the statistical advantage that it prevented multicollinearity occurring in the regression analyses.

Table 3 shows the factor loadings of the phonological measures collected in kindergarten, first grade, and third grade. Based on the eigenvalue and scree-rule criterion, a three-factor structure encompassing PA, RAN, and VSTM was observed at every time point. Three orthogonal phonological factors were calculated for every time point.

The stability of the administered phonological abilities refers to the consistency of individual differences from one measurement occasion to the next. Pearson correlations between phonological factors assessed at different time points were calculated. Results indicated that performance on the various phonological factors was stable (all ps $< .001$). Particularly, the correlations between first and third grade phonological factors were very high: .75, .85, and .79 for PA, RAN, and VSTM, respectively. Correlations between kindergarten and first grade PA, RAN, and VSTM were .59, .67, and .65, respectively. Correlations between kindergarten and third grade PA, RAN, and VSTM were .64, .57, and .60, respectively.

Group comparisons on phonological ability measures and articulation speed

Descriptive statistics on the phonological measures are presented in Figure 1 and Table 4. Factor scores were transformed to effect sizes relative to the mean and standard deviation of the nondyslexic low-risk group to enhance the interpretation of the results. There were no group differences on the composite measure of articulation speed (see Table 4).

The dyslexic group scored significantly lower than the nondyslexic low-risk group on all phonological measures, except on rhyme production and first-sound identification in kindergarten, and on digit span at all time points. The dyslexic readers performed more poorly on every phonological factor at each time point. The effect sizes suggest that the phonological deficit increased with time, particularly pertaining to PA. The nondyslexic high-risk group performed at an intermediate level between both other groups, although their performance was generally somewhat closer to the level of the nondyslexic low-risk group.

Table 3. Principal component analysis with varimax rotation: factor loadings of the phonological measures

	Cronbach's α	Factor 1, PA	Factor 2, RAN	Factor 3, VSTM
Kindergarten measures				
Rhyme production	(.88)	.68		
Rhyme identity	(.69)	.83		
First-sound identity	(.59)	.82		
End-sound identity	(.63)	.80		
Colour naming			.91	
Picture naming			.92	
Digit span				.83
Nonword repetition	(.84)			.74
First grade measures				
Rhyme categorization	(.69)	.83		
First-sound categorization	(.71)	.74		
Phoneme deletion	(.84)	.74		
Spoonerism	(.91)	.80		
Colour naming			.83	
Picture naming			.84	
Digit naming			.90	
Letter naming			.81	
Digit span				.82
Nonword repetition	(.79)			.84
Third grade measures				
Phoneme deletion	(.92)	.88		
Spoonerism	(.92)	.89		
Colour naming			.84	
Picture naming			.75	
Digit naming			.86	
Letter naming			.84	
Digit span				.90
Nonword repetition	(.79)			.84

Note. Only factor loadings above .40 are shown.

To investigate developmental trends, repeated measures mixed models were calculated for each phonological task that was assessed at multiple time points (see Figure 1). The effect of time was significant (ps $<$ .0001) for every task. There was a main effect of group for all tasks (ps $<$ .01), except for digit span ($p = .11$). *Post hoc* tests revealed that the dyslexic group scored significantly below both nondyslexic groups on every task except on digit span. The nondyslexic high-risk group performed significantly poorer than the nondyslexic low-risk group on spoonerism and nonword repetition. The group × time interaction was not significant for the rapid naming tasks, the digit span task and the nonword repetition test ($F < 1$). This suggests that the three participant groups showed a similar development over time, but that the performance of the dyslexic group continued to be delayed for rapid naming and nonword repetition. The group × time interaction was significant for phoneme deletion and spoonerism (ps $<$ .05), which indicates that the dyslexic group showed less progression on these PA

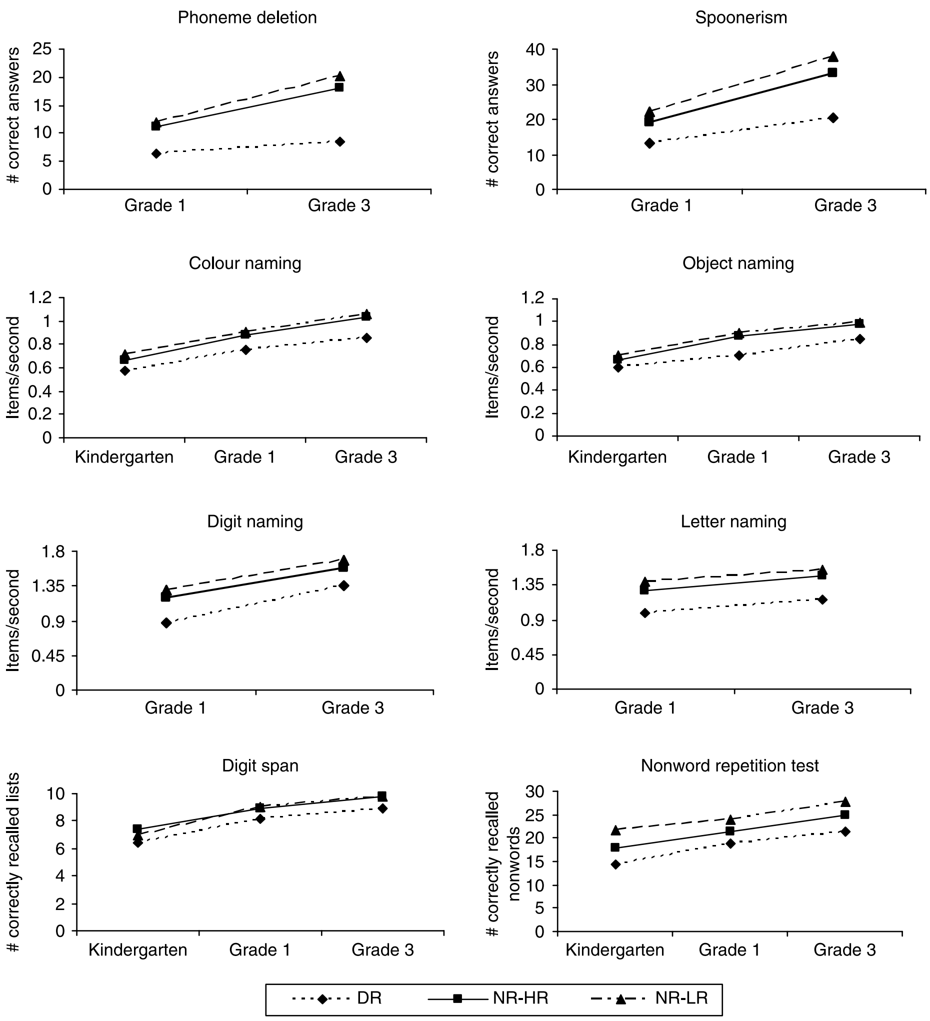

Figure 1. Development in phonological ability: mean performance for children of the dyslexic reading group (DR), nondyslexic reading high-risk group (NR-HR), and nondyslexic reading low-risk group (NR-LR) on each of the administered phonological measures.

tasks. This finding was particularly prominent in phoneme deletion, where *post hoc* testing indicated that children in the dyslexic group did not make any significant progress from first to third grade.

Group comparisons on literacy measures

Descriptive statistics of performance on the literacy measures are presented in Table 5 and Figure 2. The children in the dyslexic group scored about 1.5 *SD* below the population average on the literacy measures that were used to define the reading groups. Children in the dyslexic group performed significantly poorer than children in both nondyslexic groups on each literacy measure at each time point. Although the nondyslexic high-risk group consisted of children who did not show any clinical

Table 4. Descriptive statistics on phonological measures and articulation speed for the three participant groups

		DR		NR-HR		NR-LR	
	Maximum	*M*	*SD*	*M*	*SD*	*M*	*SD*
Kindergarten measures							
Factor PA		-1.16_a	1.35	-0.58_{ab}	1.22	0.00_b	1.00
Rhyme production	8	6.1	2.5	6.5	2.3	7.3	1.9
Rhyme identity	12	8.0_a	2.9	9.2_{ab}	2.4	10.1_b	1.5
First-sound identity	10	4.1	2.2	5.1	2.1	5.7	2.3
End-sound identity	10	3.9_a	2.2	5.0_a	2.4	6.2_b	2.2
Factor RAN		-0.75_a	0.75	-0.29_{ab}	0.71	0.00_b	1.00
Colour naming (items/s)	–	0.58_a	0.10	0.66_{ab}	0.13	0.71_b	0.17
Object naming (items/s)	–	0.60_a	0.14	0.66_{ab}	0.12	0.70_b	0.16
Factor VSTM		-0.85_a	0.72	-0.18_{ab}	0.87	0.00_b	1.00
Digit span	21	6.4	1.3	7.4	1.6	7.0	1.6
Nonword repetition test	48	14.4_a	5.4	17.8_a	5.7	21.7_b	6.1
First grade measures							
Factor PA		-1.79_a	0.66	-0.31_b	1.17	0.00_b	1.00
Rhyme categorization	20	10.1_a	2.1	13.5_b	3.1	14.5_b	3.1
First-sound categorization	15	7.9_a	1.7	12.0_b	3.3	12.0_b	2.1
Phoneme deletion	28	6.4_a	3.6	11.2_b	4.6	12.0_b	4.4
Spoonerism	50	13.3_a	6.7	19.0_b	10.6	22.1_b	8.9
Factor RAN		-1.55_a	0.81	-0.32_b	1.02	0.00_b	1.00
Colour naming (items/s)	–	0.75_a	0.18	0.88_b	0.19	0.91_b	0.18
Object naming (items/s)	–	0.71_a	0.12	0.87_b	0.19	0.90_b	0.15
Digit naming (items/s)	–	0.87_a	0.24	1.20_b	0.21	1.29_b	0.29
Letter naming (items/s)	–	0.98_a	0.21	1.28_b	0.24	1.39_b	0.30
Factor VSTM		-0.91_a	0.97	-0.32_{ab}	1.05	0.00_b	1.00
Digit span	21	8.1	1.5	8.9	1.6	9.0	1.4
Nonword repetition test	48	18.7_a	4.8	21.4_{ab}	5.7	24.0_b	5.6
Articulation speed		−0.36	0.80	−0.13	1.09	0.00	1.00
Third grade measures							
Factor PA		-1.98_a	0.93	-0.50_b	0.84	0.00_b	1.00
Phoneme deletion	28	8.6_a	5.4	18.2_b	5.0	20.1_b	6.4
Spoonerism	50	22.1_a	9.4	33.2_b	8.7	37.9_b	8.5
Factor RAN		-1.18_a	0.72	-0.19_b	0.89	0.00_b	1.00
Colour naming (items/s)	–	0.86_a	0.14	1.04_b	0.22	1.06_b	0.20
Object naming (items/s)	–	0.85_a	0.13	0.98_b	0.16	0.99_b	0.17
Digit naming (items/s)	–	1.36_a	0.41	1.59_b	0.27	1.68_b	0.31
Letter naming (items/s)	–	1.16_a	0.24	1.47_b	0.23	1.54_b	0.33
Factor VSTM		-1.04_a	1.19	-0.35_{ab}	1.07	0.00_b	1.00
Digit span	21	8.9	1.8	9.8	1.7	9.8	1.5
Nonword repetition test	48	21.4_a	5.6	24.8_{ab}	5.1	27.7_b	5.1

Note. Pairs with different subscript letters differ significantly (univariate MMA, Tukey contrasts, $p < .05$).

evidence of dyslexia, these children performed more poorly than the children in the nondyslexic low-risk group, with significant group differences on grapheme knowledge and spelling in first grade and on nonword reading accuracy and spelling in third grade.

Repeated measures mixed models were calculated for word and nonword reading speed and accuracy, to investigate developmental trends. These analyses revealed main

Table 5. Descriptive statistics on literacy measures for the three participant groups

		DR		NR-HR		NR-LR	
	Maximum	*M*	*SD*	*M*	*SD*	*M*	*SD*
Kindergarten measures							
Letter knowledge	16	0.5_a	0.5	2.8_b	4.0	3.5_b	3.6
Grade 1 measures							
Grapheme knowledge: accuracy	42	32_a	5	37_b	3	39_c	2
Grapheme knowledge: speed (items/s)	–	0.79_a	0.17	1.09_b	0.26	1.23_b	0.29
Word reading: accuracy	40	11_a	10	29_b	8	31_b	8
Nonword reading: accuracy	40	6_a	6	19_b	10	23_b	9
Word reading: speed (items/s)	–	0.33_a	0.14	0.69_b	0.23	0.76_b	0.22
Nonword reading: speed (items/s)	–	0.27_a	0.15	0.51_b	0.16	0.56_b	0.20
Word reading (standard score)[a]	–	80_a	8	100_b	8	104_b	10
Spelling (standard score)[a]	–	76_a	14	94_b	11	101_c	12
Grade 3 measures							
Word reading: accuracy	40	26_a	10	37_b	2	39_b	2
Nonword reading: accuracy	40	13_a	12	25_b	8	30_c	5
Word reading: speed (items/s)	–	0.91_a	0.50	1.37_b	0.20	1.42_b	0.26
Nonword reading: speed (items/s)	–	0.68_a	0.41	0.96_b	0.27	1.01_b	0.24
Word reading (standard score)[a]	–	69_a	18	96_b	10	103_b	13
Spelling (standard score)[a]	–	74_a	8	92_b	10	100_c	11

Note. Pairs with different subscript letters differ significantly (univariate MMA, Tukey contrasts, $p < .05$).
[a] Standardized scores with population average $M = 100$ and $SD = 15$. These literacy measures were used to define the dyslexic and normal reading groups.

effects of group (ps < .001) and time (ps < .0001) for all administered measures. *Post hoc* tests indicated that the dyslexic group performed more poorly than the nondyslexic groups on all reading measures, and that the nondyslexic high-risk group performed more poorly than the nondyslexic low-risk group on nonword reading accuracy. There were no group × time interactions ($F < 1$), except for word reading accuracy ($p = .02$). This interaction occurred due to ceiling effects in the nondyslexic groups. In all, these findings indicate that the three participant groups showed a similar developmental trajectory, with the dyslexic group consistently lagging behind the two other groups.

Contributions of phonological abilities to reading achievement

A third aim of the study was to examine the specific phonological correlates of reading accuracy and reading speed. In a first step, we investigated the unique contribution of the three phonological factors to *concurrently* assessed reading measures by means of hierarchical regression analyses (Table 6). Letter knowledge was used as a preschool literacy measure. In all analyses, non-verbal intelligence, vocabulary and speed of articulation were entered first, in the order listed. The R^2 reported for PA, RAN, and VSTM represents the proportion of variance this factor uniquely accounted for after all other variables (including both other phonological factors) were taken into account. PA and RAN contributed to different aspects of the reading process in both first and third grade. PA was more strongly related to reading accuracy, whereas RAN was particularly related

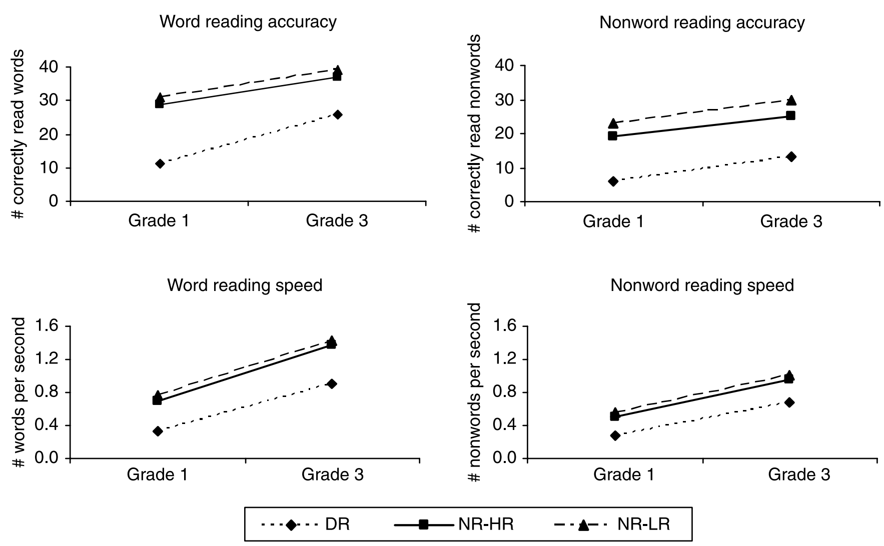

Figure 2. Development in reading ability: mean performance from the end of first grade to the beginning of third grade for children of the dyslexic reading group (DR), nondyslexic reading high-risk group (NR-HR), and nondyslexic reading low-risk group (NR-LR) on the reading speed and accuracy measures.

to reading speed. VSTM contributed a small but significant proportion of unique variance to reading accuracy. In kindergarten, only PA was uniquely related to letter knowledge.

Next, we investigated the *predictive* relationship between the phonological factors and subsequent reading achievement. Two sets of regression analyses were calculated (Table 7): one analysis predicted reading at the end of first grade by phonological measures collected in kindergarten; the other analysis predicted reading at the start of third grade by phonological measures collected in the middle of first grade. Regression models with (bottom panel) and without (top panel) inclusion of the autoregressive effect of previous reading skills were calculated. Inclusion of the autoregressive effect of prior reading level is crucial to determine whether phonological ability independently influences *growth* in reading over the developmental period in question (see Torgesen *et al.*, 1997).

Table 6. Unique variance (R^2) in reading explained by individual differences in concurrently assessed phonological abilities

	Kindergarten	First-grade		Third-grade	
Predictors	Letter knowledge	Word reading accuracy	Word reading speed	Word reading accuracy	Word reading speed
1. Raven CPM	.05	.03	.00	.02	.00
2. Vocabulary	.03	.03	.00	.01	.01
3. Articulation speed	.00	.04	.02	.04	.02
PA	.13**	.30***	.19***	.27***	.02
RAN	.01	.09**	.38***	.13***	.40***
VSTM	.00	.05*	.01	.05*	.02
Total R^2	.23	.52	.69	.52	.48

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

Table 7. Unique variance (R^2) in reading explained by individual differences in phonological ability

	First-grade reading predicted by kindergarten phonology		Third-grade reading predicted by first grade phonology	
Predictors	Word reading accuracy	Word reading speed	Word reading accuracy	Word reading speed
1. Raven CPM	.03	.00	.02	.00
2. Vocabulary	.03	.00	.01	.01
3. Articulation speed	.04	.02	.04	.02
PA	.23***	.11**	.10**	.01
RAN	.02	.06*	.25***	.42***
VSTM	.11**	.07*	.02	.00
Total R^2	.37	.24	.44	.49
1. Autoregressor	.29***	.14**	.50***	.45***
2. Raven CPM	.00	.01	.00	.00
3. Vocabulary	.01	.01	.01	.00
4. Articulation speed	.01	.02	.00	.00
PA	.09**	.04	.00	.00
RAN	.01	.05*	.09**	.06**
VSTM	.12**	.08*	.00	.00
Total R^2	.51	.33	.61	.55

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

Results for the transition from kindergarten to first grade indicated that PA and VSTM assessed in kindergarten uniquely contributed to reading accuracy in first grade, even when the autoregressive effect of letter knowledge was taken into account. PA, RAN, and VSTM in kindergarten uniquely contributed to reading speed in first grade, but the contribution of PA was no longer significant when the autoregressive effect of letter knowledge was controlled for.

Analyses involving the development from first to third grade indicated that RAN was the most prominent predictor of third grade reading speed and accuracy, even when the autoregressive effect of prior reading level was controlled for. PA also explained significant unique variance in reading accuracy, but this influence disappeared after taking into account the autoregressive effect.

Contributions of reading ability to phonology

The fourth aim of this study was to examine whether learning to read also affects the development of subsequent phonological abilities. If this is the case, additional effects of reading achievement on each of the phonological abilities should be observed after their autoregressive effect has been taken into account. We therefore calculated similar hierarchical regression analyses as those reported above, but now with phonological skills as the outcome and reading ability as the predictor (Table 8). The phonological autoregressor was entered first, followed by non-verbal intelligence, vocabulary, articulation speed, and the reading measures. Because Dutch children do not receive formal reading instruction in kindergarten, letter knowledge was used as an indicator of their preschool reading ability. Preschool letter knowledge had a significant unique influence on the development of PA in first grade, but not on RAN or VSTM. Turning to the evolution from first to third grade, both reading accuracy and reading speed had a unique influence on the development of subsequent PA skills. Performance in RAN or VSTM, however, was not affected by earlier reading achievement.

Table 8. Unique variance (R^2) in phonological ability explained by individual differences in literacy ability

	First-grade phonological factors		
Kindergarten predictors	PA	RAN	VSTM
1. Autoregressor	.20***	.32***	.30***
2. Raven CPM	.04	.05*	.00
3. Vocabulary	.00	.00	.02
4. Articulation speed	.02	.03	.07*
5. Letter knowledge	.05*	.01	.00
Total R^2	.32	.41	.39
	Third-grade phonological factors		
First grade predictors	PA	RAN	VSTM
1. Autoregressor	.45***	.67***	.51***
2. Raven CPM	.01	.01	.00
3. Vocabulary	.00	.00	.01
4. Articulation speed	.00	.01	.00
5. Word reading accuracy	.13***	.00	.00
5. Word reading speed	.11***	.01	.01
6. Word reading accuracy	.05**	.00	.00
6. Word reading speed	.03*	.01	.01
Total R^2	.62	.70	.54

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

Discussion

Phonological ability covers a number of interrelated but distinctive phonological processes. Traditionally, three components have been distinguished: PA, VSTM, and RAN. There exists consistent evidence that children with dyslexia show impairments in each of these phonological components. Few studies, however, have examined all three phonological components in the same children at multiple time points before and after the start of formal reading instruction. Accordingly, the relative importance and the developmental pattern of the phonological deficits in dyslexia remain unknown. The present study addressed these issues by longitudinally following up preschool children at high family risk of dyslexia and comparing them to low-risk controls. We investigated the development of both phonological and literacy skills. Reciprocal developmental relations between phonological ability and literacy achievement were additionally examined.

Phonological processing

Our data confirm that phonological processing constitutes a multidimensional ability and has a firm longitudinal stability (cf. Wagner & Torgesen, 1987). A three-dimensional phonological structure with PA, RAN, and VSTM as separate factors was found at every time point. Together, with the observation that the different phonological components are related to particular reading skills, this adds to the validity of identifying specific phonological subcomponents.

The group comparisons show that children with dyslexia[1] scored significantly lower on all phonological factors, at each time point. This indicates that a general phonological deficit (covering PA, RAN, and VSTM) was present before the onset of formal reading instruction, in the early phases of learning to read, and after 2 years of formal reading instruction. The observed phonological impairments cannot be explained by a more general language or cognitive impairment, because there were no group differences in expressive vocabulary and non-verbal intelligence. The findings are in line with the longitudinal at-risk studies of Pennington and Lefly (2001) and of Puolakanaho *et al.* (2004, 2007), who also showed consistent deficits in all phonological areas in young children with dyslexia.

Our data reveal that children with dyslexia followed a delayed but similar developmental trajectory for RAN and VSTM as compared to their nondyslexic peers. In contrast to our expectations, children with dyslexia showed significantly less progress in PA than nondyslexic children, which resulted in larger group differences in third than in first grade. These findings contradict those of Landerl and Wimmer (2000) and van Daal and van der Leij (1999), who showed that group differences in PA tended to decrease (or even disappear) at the end of third grade in languages with a more transparent orthography, such as German or Dutch. Together, with de Jong and van der Leij (2003), we contend that these conflicting findings may be explained by differences in task difficulty. Indeed, tasks such as phoneme deletion and spoonerism, which were not assessed by Landerl and Wimmer (2000) and van Daal and van der Leij (1999), target phonemic awareness more explicitly, than tasks that merely involve awareness of onset and rhyme. Our data are in accordance with de Jong and van der Leij (2003), who showed that dyslexic children's awareness of phonemes continued to be impaired when task demands were increased.

Children of the nondyslexic high-risk group performed significantly poorer than nondyslexic low-risk children on the spoonerism and the nonword repetition task. The poor performance on spoonerism was unexpected on the basis of previous PA studies in transparent orthographies, but fits with the high sensitivity of this task as discussed above. Spoonerism and nonword repetition are tasks that require fine-grained sublexical phonological representations. These subtle sublexical phonological impairments may contribute to moderate and selective difficulties in literacy achievement in the nondyslexic high-risk children, as we will discuss below in greater detail. On the more lexically based phonological tasks, such as RAN and digit span, no group differences were observed between the nondyslexic children at high versus low family risk.

Literacy achievement

Children in the dyslexic group showed impairments on each literacy measure at each time point.[2] The deficit in letter knowledge is consistent with other longitudinal studies of children at family risk of dyslexia (e.g. Elbro *et al.*, 1998; Lyytinen *et al.*, 2006; Pennington & Lefly, 2001; Snowling *et al.*, 2003). Our data extend these findings by showing that the deficit concerns both the speed and accuracy of grapheme recognition. With regard to

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[1] *It should be noted that the dyslexic group was a heterogeneous group with regard to family risk. Although both dyslexic subgroups (low-risk and high-risk) did not significantly differ from each other on any of the phonological measures, dyslexic individuals from the high-risk group tended to show more severe phonological problems then dyslexic individuals of the low-risk group.*

[2] *Although both dyslexic subgroups (low-risk and high-risk) did not differ significantly on any of the literacy measures, dyslexic individuals from the high-risk group tended to show more severe literacy problems than dyslexic individuals of the low-risk group.*

reading speed, our data corroborate earlier studies which showed that extreme slow reading speed constitutes the major problem for poor readers in orthographically transparent languages (e.g. Wimmer, 1993). With regard to reading accuracy, however, the significant impairment contrasts with previous studies, which showed that both good and poor readers obtain high accuracy levels in phonologically transparent orthographies (e.g. de Jong & van der Leij, 2003; Landerl & Wimmer, 2008; Wimmer, 1993; but see Sprenger-Charolles, Colé, Lacert, and Serniclaes (2000) who showed that word and nonword reading accuracy can differentiate between French-speaking 10-year-old children with dyslexia and age-matched controls). The observed impairment in word and nonword reading accuracy in our study may be explained by the use of more sensitive graded and untimed reading accuracy tests, as suggested by Verhagen *et al.* (2008). Although the apparent recovery in word reading accuracy suggests that group differences may disappear, this relative improvement appears to result from task characteristics, because a ceiling effect prevented nondyslexic children from showing further development. Indeed, the three groups of participants showed a similar developmental trajectory on the more difficult nonword reading accuracy test, which indicates that the dyslexic readers did not catch up with their nondyslexic peers. In general, these findings resemble those regarding PA: by administering sufficiently sensitive measures, a continuous deficit in reading accuracy and PA can be observed in children with dyslexia, even in orthographically transparent languages.

Although the children of the nondyslexic high-risk group did not fulfil the criteria for dyslexia, they performed significantly more poorly than nondyslexic low-risk children on letter knowledge and spelling in first grade and on nonword reading accuracy and spelling in third grade. There were, however, no group differences in reading speed. The observation of poorer literacy performance in these so-called 'unimpaired' readers fits with findings of Pennington and Lefly (2001) and Snowling *et al.* (2003). Different from these studies, the nondyslexic high-risk children in our study still performed significantly better than the children with dyslexia. The poorer performance in nonword reading accuracy and spelling, but not in reading speed, is unexpected, but fits with the phonological profile of these nondyslexic high-risk children. Their sublexical phonological impairments might have affected performance on those literacy measures that require the most exact phoneme representations and phoneme–grapheme associations, i.e. nonword reading accuracy and spelling. In line with Pennington and Lefly (2001) and Snowling *et al.* (2003), the significant phonological and literacy deficits in nondyslexic high-risk children suggest that the family risk of dyslexia is continuous rather than discrete. We have extended these findings by showing that this pattern is also observed in children who are learning to read in an orthographically transparent language.

Contributions of phonological abilities to reading achievement

In line with other longitudinal studies (e.g. de Jong & van der Leij, 2002; Wagner *et al.*, 1997), we have demonstrated the time-dependent unique contribution of each of the phonological skills to reading development. Regression analyses (including the autoregressor) show that PA and VSTM uniquely predicted individual differences in reading ability in first but not in third grade. RAN, on the other hand, only marginally predicted reading (speed) in first grade, but it was a powerful unique predictor of reading ability in third grade. Similar results were reported by de Jong and van der Leij (2002) in Dutch-speaking children and by Landerl and Wimmer (2008) in a German-speaking sample. Both of these studies showed that PA was more important in the early stages of reading development, whereas RAN became a more prominent predictor for later reading development. Our findings differ from those obtained in English-speaking children (e.g. Torgesen *et al.*, 1997; Wagner *et al.*, 1997), in which PA continues to have an influence on reading acquisition over a longer time period, because the less transparent orthography makes it harder to comply with phonological demands (Verhagen *et al.*, 2008).

Consistent with other studies (e.g. Savage & Frederickson, 2005; Verhagen *et al.*, 2008), PA is a stronger associate of reading accuracy, whereas RAN is more closely related to reading speed. Because both RAN and reading speed were unrelated to articulation speed, the relation between both measures cannot be explained by a general processing speed mechanism or by the timed nature of the administered measures (see de Jong & van der Leij, 2002). Strong associations between PA and reading accuracy and between RAN and reading speed are observed in the concurrent hierarchical regressions and in the regression analysis in which phonological measures in kindergarten predicted first-grade reading. When the autoregressive effect of prior reading level was accounted for, PA in first grade did no longer predict reading ability in third grade. By contrast, RAN in first grade still added a unique contribution to growth in reading speed and reading accuracy in third grade. This all suggests that in the early stages of learning to read, PA and RAN are the most important instigators of word reading accuracy and word reading speed, respectively. After 2 years of reading instruction only RAN contributes uniquely to growth in reading speed and accuracy.

Reciprocal relations between phonology and reading ability

The present study shows a reciprocal relation between literacy achievement and phonological ability. Early literacy acquisition affected further phonological development, which is in line with previous studies that showed poor PA in pre-readers (Liberman *et al.*, 1974), in illiterate adults (Morais *et al.*, 1979), and in readers who have learned a nonalphabetic language (Read, Zhang, Nie, & Ding, 1986). In line with other correlational studies (de Jong & van der Leij, 1999; Wagner *et al.*, 1994), we demonstrate that preschool letter knowledge uniquely contributed to the development of PA in first grade. Individual differences in first grade reading speed and reading accuracy uniquely contributed to the development of PA in third grade. To our knowledge, this is the first study that demonstrates a direct predictive relation between reading ability (rather than letter knowledge) and subsequent phonological ability (see de Jong & van der Leij, 1999; Verhagen *et al.*, 2008; Wagner *et al.*, 1994, 1997 for similar approaches which yielded non-significant predictive correlations). As expected, the association with reading accuracy was slightly more substantial than the one with reading speed. Contrary to the hypothesis of van den Bos *et al.* (2002), we could not demonstrate a unique predictive contribution of reading speed to RAN.

The children with dyslexia in our study had an increasing delay in PA. They also showed, by definition, persistent impairments in reading ability. Against the background of the observed bidirectional relations between reading ability and PA skills, we contend that this increasing delay in PA ability is not only the cause but also the consequence of their reading impairments.

Conclusion

This study shows that children with dyslexia, who are learning to read in a transparent orthography, present consistent deficits in PA, RAN, and VSTM. Phonological impairments are present before the onset of formal reading instruction, in an early phase of learning to read and after completing 2 years of formal reading instruction. In contrast to previous findings in transparent orthographies, the impairment in PA increases over time. The children with dyslexia also show consistent impairments on all of the administered literacy measures. The persistent problems in reading accuracy contradict previous findings in transparent orthographies. The observation of persistent difficulties with PA and reading accuracy in the dyslexic children in our study may be due to the use of more sensitive and demanding measures of phonological and literacy skills, compared to other studies in transparent orthographies. Nondyslexic children at high family risk show poor performance on those phonological and literacy tasks that require the most fine-grained phonological representations, which suggests that family risk of dyslexia is continuous. Hierarchical regression analyses show that PA and RAN are initially the most important unique predictors of reading accuracy and reading speed, respectively. After 2 years of reading instruction, only RAN uniquely add to improvement in reading speed and reading accuracy. Finally, letter knowledge, reading accuracy, and reading speed are uniquely related to the further development of PA skills.

Acknowledgements

Bart Boets and Bert De Smedt are post-doctoral research fellows of the Research Foundation Flanders (FWO), Belgium. The research was funded by FWO, Belgium, Grant G0216.02 and G0331.08 and by a grant of the Research Council of Katholieke Universiteit Leuven, OT/07/034. We are grateful to all children, teachers, and schools that participated in this study. Special thanks are due to Peter de Jong for fruitful discussion and for using his PA tasks.

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Received 15 July 2009; revised version received 16 December 2009