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ABSTRACT

The current study aimed to fill the gap in research on factors predictive of word reading in French-speaking children with developmental language disorder (DLD) by finding out whether the same predictors of written word recognition evidenced in typically developing children would be retrieved in children with DLD or if some predictors could be specific to children with DLD, especially in the phonological domain. In total, 38 children with DLD and 44 control children were followed from 6 to 8 years in a longitudinal design including two time points: (1) just before explicit reading instruction, where potential predictors of reading were assessed (oral language skills and reading-related skills), and (2) after 2 years of learning to read, where isolated word reading and text reading were assessed in addition to the assessment of oral language skills and reading-related skills. The study mainly showed that the predictors of reading identified in typically developing children are retrieved in children with DLD except for phonemic awareness; the latter result was probably explained by a floor effect. Among the predictors in the phonological domain, phonological instability appeared as a promising predictor of reading irregular words. These results are consistent with the findings of many previous studies and tend to confirm the idea of a strong link between oral phonological skills and written word recognition skills; they also call for attention to specific features in the phonological development of children with DLD when learning to read,

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particularly phonological instability as a direction for future exploration.

Introduction

Developmental language disorder (DLD) refers to oral language difficulties that persist throughout childhood and into adulthood in the absence of known biomedical causes (e.g., deafness, intellectual disability). Language disorders in DLD are heterogeneous (Lancaster & Camarata, 2019); the spectrum of clinical signs is wide, with profiles varying according to the number and nature of the affected oral language domains (phonology, lexicon, morphosyntax, discourse, pragmatics), their level of impairment, and the co-occurrence of any other disorders (e.g., attention-deficit/hyperactivity disorder). Developmental language disorder is strongly associated with reading difficulties, but not all children with DLD have reading difficulties (Ziegenfusz et al., 2022). The association has been evidenced mostly in the English language, which has an opaque orthography. Longitudinal predictive studies conducted in more transparent orthographies such as French, therefore, are needed to better understand how these oral language difficulties connect with reading skills. Moreover, children with DLD often display specific difficulties that have generally not been considered as reading predictors (e.g., phonological disorders in perception and/or production, word finding difficulties). The current study used a longitudinal design conducted in the French language to identify phonological factors that are predictive of second-grade word reading in a sample including a large proportion of children with DLD.

In the early stages of learning to read in alphabetical systems, the development of written word recognition skills (based largely on the establishment of grapheme–phoneme correspondences) is mainly determined by children's phonological abilities (Snowling & Hulme, 2021). Focusing on written word recognition at the onset of literacy is central due to its role in reading comprehension (see the simple view of reading theory; Gough & Tunmer, 1986; Hoover & Gough, 1990). The development of reading comprehension skills in children who start learning to read is mainly dependent on written word recognition skills but becomes more strongly dependent on oral language skills such as vocabulary, morphology, and syntax in more experienced readers (for reviews, see Hulme & Snowling, 2014; Nation, 2019). Therefore, there are reasons to observe reading difficulties in children with DLD in written word recognition, due to their impairment in phonological skills, and in reading comprehension, due to their poor language skills. Here we focused on written word recognition, although reading comprehension tends to be more frequently and severely impaired than recognition of written words in DLD (Bishop & Adams, 1990; Conti-Ramsden et al., 2001; Simkin & Conti-Ramsden, 2006).

Reading difficulties in children with DLD

It is now widely established that children with DLD are at significant risk of reading disability (McArthur et al., 2000; Pennington & Bishop, 2009; Snowling & Hulme, 2021; Ziegenfusz et al., 2022): between 48% and 87% have significant difficulties in learning to read (depending on the reading task and definition being used; Cleaton & Kirby, 2018). There are both a severity effect and a persistence effect of DLD; the more severe, extensive, and persistent the DLD, the more likely the reading disability is to exist and be severe (Bishop, 2001; Catts et al., 2002; Conti-Ramsden et al., 2001; Snowling et al., 2000; Vandewalle, Boets, Boons, et al., 2012). Critically, there is substantial heterogeneity in reading levels, as illustrated in Haynes and Naidoo's (1991) study of 118 children with DLD with a mean age of 11.5 years. Group analyses indicate an average reading delay of 3 years. On an individual level, 4% of the children were within the norm, 8% were less than 1 year behind, 13% were 1 to 2 years behind, 17% were 2 to 3 years behind, and 58% were more than 3 years behind. Macchi et al. (2014) also observed heterogeneity among a sample of school-aged children with DLD (mean age = 10.95 years); about 80% had a reading delay of more than 2 years, 10% showed a delay of 1.5 to 2 years, and 10% showed a delay of less than 1.5 years.

The existence of such reading difficulties in a non-negligible number of children with DLD has led scientists to investigate the predictors of reading ability through longitudinal studies (Elbro & Scarborough, 2004). Indeed, the identification of early predictors of reading ability in children with DLD may help to limit the reading difficulties of these children or reduce their severity in the long term: early intervention (e.g., in kindergarten) in phonological awareness with these children tends to result in greater gains in reading than a similar intervention a few years later, for example, in Grade 3 (Ritter et al., 2013).

Main predictors of reading in typically developing children

In the general population of children, longitudinal studies indicate that predictors depend mainly on four parameters (Elbro & Scarborough, 2004). First, the predictors depend on the reading skills being assessed (Nation, 2019; Snowling & Hulme, 2021). These are (a) written word recognition, that is, the ability to decode, and (b) reading comprehension, that is, the ability to understand written words, sentences, and texts. As mentioned earlier, the current study focused on the first one, that is, word decoding.

Second, the reading predictors depend on the time when they are measured. For instance, at 2.5 and 3 years of age the best predictors of reading as measured in Grade 2 are accuracy of phonological and syntactic productions, whereas at 4.5 and 5 years of age phonological awareness becomes an important predictor (Scarborough, 2001; National Early Literacy Panel, 2008).

Third, the predictive factors depend on the time period in which reading is assessed. Factors concerning reading ability measured 1 to 2 years after learning onset are quite different from those concerning reading more than 2 years after learning onset. The National Early Literacy Panel's (2008) *meta*-analysis based on more than 200 articles on studies in alphabetic languages (English for the majority) focused on predictors of reading ability measured in Grades 1 and 2, which was the focus of the current study. These predictors are mainly measured in 4- and 5-year-olds. The four factors most predictive of decoding or written word recognition are knowledge of letter names and/or sounds, phonological awareness, rapid naming (letters, numbers, colors, and pictures), and the ability to write letters from dictation and/or one's own name. The predictors of reading comprehension are the same, with the addition of phonological short-term memory. When reading skills are assessed more than 2 years after the start of learning, the contribution of phonological processing tends to decrease and the contribution of non-phonological language processing tends to increase (Carlisle, 2000; Casalis & Louis-Alexandre, 2000; Ouellette & Beers, 2010). These include vocabulary, morphological awareness, and listening comprehension.

Fourth, the predictive factors depend on the language writing system (e.g., Caravolas et al., 2012; Holopainen et al., 2020; Landerl et al., 2019; Silinskas et al., 2024). In particular, it seems that the link between phonological awareness and reading is less pronounced in the case of transparent orthographies (e.g., Italian, Dutch) compared with more opaque orthographies (e.g., English, French to a lesser extent). Indeed, univocal grapheme–phoneme correspondences favor the rapid development of phonological awareness. The predictive power of phonological awareness, therefore, would be weaker in the case of transparent orthographies, or its predictive power would be important only at the very beginning of learning to read, particularly in Grade 1. In the case of less univocal grapheme–phoneme correspondences, phonological awareness would represent a more durable and stronger predictor (Landerl et al., 2013; Ziegler et al., 2010). Furthermore, some researchers suggest that rapid naming is a stronger predictor in transparent orthographies than in opaque ones. This is because both reading fluency and rapid naming tasks require the rapid retrieval of phonological information stored in long-term memory. In the more transparent orthographies, reading variance is primarily determined by reading fluency. In these languages, therefore, rapid naming would be more predictive of reading ability than in opaque orthographies. However, this theory is still debated given that the results of studies are rather mixed (Georgiou & Parrila, 2008; Landerl et al., 2013; Vander Stappen & Van Reybroeck, 2022; Ziegler et al., 2010). It should be noted that in French longitudinal studies to determine the predictive factors of reading in children from the general population are rare (Ecalle et al., 2023; Landerl et al., 2019; Ziegler et al., 2010), and to our knowledge they are nonexistent in children with DLD, with the exception of Zourou et al. (2010), who only investigated the predictive role of phonological awareness and expressive grammar. A longitudinal study was carried out by Piquard-Kipffer and Sprenger-Charolles (2013) with 5-year-old French children presenting low versus normal skills in phonemic discrimination, known to be affected in some children with DLD. Their results show that at the end of second grade, when children were 8 years-old, there were more children with reading disabilities in the low-skills group than in the control group (about 75% vs. 30%), and reading skills were predicted across both groups by the following predictors assessed in kindergarten: prereading level, letter–name knowledge for vowels, phonemic segmentation, and phonological short-term memory.

Predictors of reading in children with DLD

Prior longitudinal studies on predictive factors of reading in children with oral language difficulties tend to show that there are common predictive factors for reading among children with and without oral language difficulties (e.g., Aguilar-Mediavilla et al., 2014). For example, Catts et al. (2002) looked at 570 children with four different profiles: oral language difficulties of unknown origin, oral language difficulties with nonverbal intellectual deficits, nonverbal intellectual deficits without oral language difficulties, and typical development. Oral language difficulties (transient for some children, persistent for others) were identified by scores below −1.25 *SD* on at least two oral language composite scores (Records & Tomblin, 1994; Tomblin et al., 1996). In kindergarten, oral language, early written language, and nonverbal intellectual skills were measured. In Grade 2, oral language and reading were assessed. For all children with oral language disorders, letter knowledge, phonological awareness, rapid naming, and nonverbal intellectual skills in kindergarten predicted written word recognition skills in Grade 2.

However, other research suggests that there are specific predictors of reading for children with oral language difficulties. For example, the longitudinal studies by Bishop and colleagues identified the persistence and severity of oral language difficulties as predictors of reading (Bishop & Adams, 1990; Bishop & Edmundson, 1987; Snowling et al., 2000; Stothard et al., 1998). Children with language difficulties were followed from 4 years of age (*N*=87) to 15.6 years (*N*=56). At age 4, one subgroup consisted of children with oral language difficulties (expressive or both receptive and expressive difficulties) and nonverbal abilities within the norm; another subgroup consisted of children with a nonspecific oral language disorder, that is, with an IQ below 70 (Bishop & Edmundson, 1987). Resolution or persistence of oral language difficulties were tested at 5.5 and 15.5 years of age, leading to identical classification. Persistence and severity were confounded; persistent oral language difficulties were more severe than resolved oral language difficulties, and later in reading adolescents with DLD performed significantly worse than those with transient oral language difficulties. The resorption (linked to the severity) of oral language difficulties, therefore, is a protective factor specific to this population.

At a more detailed level of analysis, it is not uncommon to observe some particularities in the language skills of children with DLD. First, in speech production, some errors atypical of normal development can be observed (Dodd et al., 2018). Two studies indicate that 4- and 5-year-olds with more than 10% non-developmental phonological errors (e.g., additions, voicing of consonants) have significantly lower reading scores a few years later than children with lower rates of non-developmental errors at age 4 or 5 (Leitão & Fletcher, 2004; Preston et al., 2013). A high rate of non-developmental phonological errors, therefore, may be a predictor of reading disability in children with oral language difficulties. Other atypical phonological features found in DLD could be predictive of reading ability in these children, notably phonological instability. Phonological instability refers to the fact that the same word is produced differently from one time to the next (during free speech). To assess the rate of phonological instability, Dodd (2005) proposed the same picture-naming task on three occasions during the same test session (with a different task between each administration). An instability point is awarded if, over the three trials, the child produces the word twice in the same way and once differently. If the child produces the word three times differently, two points are awarded. The sum of the points is transformed into a percentage. On this task, typically developing children have an instability rate of less than 10%, whereas children with phonological disorders have an instability rate of more than 40% (Dodd, 2005; Holm et al., 2007). To date, no longitudinal study has tested the possible predictive power of phonological instability in children with DLD.

Second, speech perception can remain an area of difficulty in children with DLD. For example, speech perception in noise was shown to be significantly impaired in these children compared with children of the same age and even compared with younger children with the same level of oral language (Ziegler et al., 2005, 2011). Therefore, it could be a predictor of reading ability in children with DLD; this has already been observed in Dutch (Vandewalle, Boets, Ghesquière, et al., 2012a).

Third, children with DLD can show difficulty in getting quick and reliable access to lexical information in memory (Bragard et al., 2012). Other studies suggest that rapid naming skills may distinguish between children with DLD who have written word recognition difficulties (poor decoders) and those who do not (good decoders). In Bishop et al.'s (2009) cross-sectional study on 9- and 10-year-old English-speaking children with DLD, low decoders did not differ from good decoders on oral language tests except on two measures. In rapid naming and pseudoword repetition, they performed worse than good decoders. The idea that rapid naming is a predictor of reading difficulties in children with DLD is also supported by the results of a longitudinal study of Dutch-speaking children, which included 18 children with DLD and 18 typically developing children of the same age (Vandewalle, Boets, Boons, et al., 2012; Vandewalle et al., 2010; Vandewalle, Boets, Ghesquière, et al., 2012a, 2012b). In kindergarten, oral language, phonological short-term memory, phonological awareness, rapid naming, and knowledge of letter names were assessed. In Grades 1 and 3, written word recognition was assessed. A combination of phonological awareness and rapid naming scores in kindergarten predicted quite well the absence versus presence of written word recognition difficulties in Grades 1 and 3 for children with DLD (sensitivity 75%, specificity 80%). There was a moderate to strong correlation between rapid naming in kindergarten and reading at Grade 1. Thus, rapid naming seems to contribute to distinguishing poor decoders from good ones among children with DLD. However, the explanatory factor for this difference might not be a low speed of access to the phonological form of words (as measured by rapid naming) but instead might be more general difficulties in lexical access concerning the retrieval and/or organization of phonological and semantic information of words in long-term memory. Therefore, it might be interesting to study the possible predictive power of word-finding difficulties in children with DLD when learning to read.

The current study

The purpose of the current study was to fill the gap in research on factors predictive of reading in French-speaking children with DLD. In this longitudinal study, we focused on kindergarten measures that predict written word recognition in Grade 2 in children with DLD and in control children of the same age. The aim was to identify which factors in relation with oral language predict written word recognition in French-speaking children with DLD. We hypothesized, based on prior scientific literature, that second graders with DLD have a lower reading level and more frequent reading difficulties than control children.

Regarding the predictors of reading, we formulated two hypotheses. First, we assumed that the predictors of reading evidenced in typically developing children would be retrieved in children with DLD. Therefore, we should find fairly standard predictors similar to those found in the *meta*-analysis of the National Early Literacy Panel (2008): pre-reading knowledge (e.g., knowledge of letter names and/or sounds) and phonological skills (e.g., phonological awareness, rapid naming) for recognition of written words.

Second, we hypothesized that the predictors of reading ability show some peculiarities in children with DLD compared with typically developing children. Especially, we expected some phonological markers of some cases of DLD (e.g., phonological instability) to be predictors of written word recognition skills. In other words, some factors should be more strongly predictive among children with DLD compared with controls (for an English language example, see Alonzo et al., 2020). Weak language domains or atypical language characteristics of children with DLD could be these particular predictive factors. As part of this exploratory study, we examined several domains: the classic language domains (phonology, lexicon, morphosyntax, receptive, and expressive) and three original measures identified as weakness areas in these children, namely speech perception in noise, phonological instability, and lexical access difficulties.

Method

Participants

This longitudinal study included 82 children studied at two distinct time points: Time 1 (T1), just before explicit reading instruction, and Time 2 (T2), after 2 years of exposure to this instruction. There were 38 children with DLD (23 boys and 15 girls) and 44 typically developing children (23 boys and 21 girls). At T1 the average age of the children was 5.95 years (*SD*=0.26, range = 5.46–6.51), and at T2 it was 7.89 years (*SD*=0.28, range = 7.39–8.39).

Inclusion and exclusion criteria

Inclusion criteria required that all children (a) be attending kindergarten at the expected age, (b) be monolingual French speakers, and (c) have a nonverbal intelligence score at T1, T2, or both that is within the norm, that is, a score greater than −1.28 *SD* (percentile 10) on the Pattern Reasoning subtest of the KABC-II battery (Batterie pour l'examen psychologique de l'enfant–Deuxième édition [Battery for the psychological examination of the child–Second edition]; Kaufman & Kaufman, 2008; for more details on this test, see "Materials" section). Exclusion criteria included parent-reported hearing loss, neurological pathology (e.g., epilepsy), autism spectrum disorder, or uncorrected visual impairment.

To be included in the group with a DLD, children needed to show language difficulties at T1, T2, or both times. To do this, they needed to be diagnosed with language difficulties by a health-care professional (an independent speech–language therapist or a neuropediatrician experienced in child language disorders). In addition, they needed to receive speech therapy at least at T1. In addition, they needed to obtain oral language scores below −1.65 *SD* (5th percentile) at T1 in at least one of the following four standardized tests: phonological discrimination, phonological short-term memory, picture-naming, and oral comprehension of sentences (see detailed description of these tests in the "Materials" section). This pathological threshold was set at −1.65 *SD* because it corresponds to the 5% threshold generally used in group analyses in the human sciences. To confirm the persistence of DLD at T2, these children needed to obtain a score below −1.65 *SD* on at least one of the following six standardized tests: phonological discrimination, pseudoword repetition, word comprehension, word production, oral comprehension of sentences, and sentence repetition. Finally, to exclude the presence of a purely phonological disorder, these children needed to obtain a deficit score on at least one standardized language test (relating to lexicon and/or morphosyntax) at T1, T2, or both.

To be included in the control group, children needed to not have either a language disorder or a phonological disorder at T1 and T2. They should not have received speech therapy for such difficulties. In addition, their scores needed to be greater than −1.28 *SD* (10th percentile) on all the standardized language and phonological tests mentioned above at both T1 and T2.

Matching criteria and description of the sample

The groups did not differ in sex ratio, $\chi^2(1) = 0.56$, *ns,* nor did they differ in age at T1, $t(80) = -1.09$, *ns,* and T2, $t(80) = -1.93$, *ns.*

Applying the above inclusion and exclusion criteria, the composition of the group of children with DLD was as follows: Of 38 children, 30 (80%) had one or more lexicon and/or morphosyntax scores below −1.65 *SD* at both T1 and T2. The remaining 8 children (20%) had a lexicon and/or morphosyntax score below this pathological threshold at only one of the two study time points. For phonology, the majority (28 children, 74%) had a score below the pathological threshold at T1 and/or T2, whereas the others (10 children, 26%) had scores above −1.65 *SD* at both T1 and T2. Overall, the majority of this group of children with DLD had phonological, lexical, and/or morphosyntactic difficulties. At T2, all the children in the DLD group were in second grade except for 5 participants (13%) who were maintained in first grade.[1] In comparison, all the children in the control group were in second grade.

Excluded data

Initially, 118 children were assessed at T1. However, data from 36 children from both groups were excluded for the following reasons. Four children were not reassessed at T2 because they had moved or refused to participate. Three other children scored below −1.28 *SD* on the Pattern Reasoning subtest of the KABC-II battery at both T1 and T2. One child had an exclusively phonological disorder. The remaining 28 children had an oral language profile intermediate between typical development and DLD, with *z*-scores between −1.28 and −1.65 *SD* at T1 and/or T2.

Materials

For the sake of clarity, we present materials separately for T1 and T2. Most skills were measured at both assessment points (but not necessarily using the same test or task). Five skills were assessed only at T1 (buccal praxis abilities, speech perception in noise, phonemic discrimination, reaction times, and visual attention). Word and text reading skills were assessed only at T2.

Assessment at T1

In this section, we present the materials used to assess at T1, parental educational level, children's nonverbal intellectual skills, and 20 potential predictors (see Table 1 in Results).

Parental education level. Parents reported their level of education in the consent form. The highest level of education of each couple was classified into one of the following categories: low level (up to high school diploma) or high level (beyond high school diploma). These two categories included the first three and second three levels of the International Standard Classification of Education (UNESCO, 1997).

Nonverbal intelligence. This was assessed using the Pattern Reasoning subtest of the KABC-II (Kaufman & Kaufman, 2008). Children were asked to complete a logical sequence of images by pointing, among several images, to the one image that correctly completed the sequence. One point was awarded for each correct answer, with a maximum of 29 points, as recommended in the administration manual for this age.

Oral language skills. Buccal praxis abilities. Children were asked to imitate 20 labial, lingual and cheek movements from the EVALO battery (ÉVAluation du développement du Langage Oral chez l'enfant de 2 ans 3 mois à 6 ans 3 mois [Evaluation of oral language development in children aged 2 years 3 months to 6 years 3 months]; Coquet et al., 2009) and the Hénin test (Hénin, 1981). One point was awarded for each correct answer. The maximum score was 20.

Speech perception in silence and in fluctuating and stationary noise. The experimental paradigm was adapted from the second experiment by Leybaert et al. (2014). Four digital sound files were presented to participants using a Dell Latitude E5520 computer and Sennheiser HD 595 headphones. The stimuli were /a–[consonant]–a/ syllabic segments, with the consonants /p, t, k, f, s, ʃ/ (e.g., /apa/) pronounced by a male voice. Six different pseudowords were repeated three times in fluctuating noise (8 Hz), in stationary noise (with a signal-to-noise ratio of − 23 dB), and in silence. Children needed to repeat the pseudowords. One point was awarded for each correct answer. Each of the three scores (in silence, in fluctuating noise, and in stationary noise) had a maximum of 18 points.

Phonological discrimination. A task of similarity judgment about 36 pairs of pseudowords was administered: ELDP (Épreuve Lilloise de Discrimination Phonologique destinée aux enfants de 5 ans à 11;6 ans [Lille phonological discrimination test for children aged 5 to 11.5]; Macchi et al., 2012, Ver-

[1] At T1 and T2, children with DLD were attending mainstream schools and not special classes for children with DLD.

Table 1
Characteristics of children with DLD and control children at T1.

Characteristics	Children with DLD (*n* = 38)		Control children (*n* = 44)		Differences between groups [a]			
	m (*SD*)	Range	*m* (*SD*)	Range	*df*	*t*	*p*	*D*
Buccal praxis abilities (/20)	14.24 (3)	9-19	15.50 (2.80)	8-20	80	-1.97	*ns*	-0.44
Speech perception (Leybaert et al., 2014) In silence (/18)	17.06 (1.06)	14-18	17.66 (0.89)	14-18	80	-2.79	.007	-0.62
In fluctuating noise (/18) [b]	9.63 (3.49)	0-15	13.32 (2.78)	5-18	80	-5.62	<.001	-1.25
In stationary noise (/18)	1.74 (1.55)	0-6	3 (2.20)	0-8	77	-3.02	.003	-0.65
Phonological discrimination (ELDP; /36)	19.79 (2.09)	16-25	24.45 (4.22)	18-33	65	-6.47	< .001	-1.37
Pseudoword repetition (SCT; /40)	13.76 (4.95)	3-27	26.41 (4.52)	18-38	80	-12.09	< .001	-2.68
Word repetition (SCT; /40)	19.87 (5.47)	10-31	33.02 (3.17)	26-39	57	-13.06	< .001	-3.00
Phonological instability (SCT; %)	66.98 (12.25)	31-90	51.93 (18.81)	0-87	75	4.35	< .001	0.93
Phonological short-term memory (KABC-II)	5.05 (1.59)	2-8	8.73 (2.05)	6-14	80	-8.96	< .001	-1.98
Picture-pointing (Bragard et al.; 2010; % corr.) [b]	83.68 (7.94)	48-95	91.44 (3.15)	85-98	80	-6.72	< .001	-1.49
Picture-naming (Bragard et al; 2010, % corr.)	62.68 (10.87)	37-80	83.31 (5.98)	71-95	56	-10.42	< .001	-2.40
Word finding difficulty (Bragard et al.; 2010; s/word) [b]	2.11 (0.31)	1.46-3.01	1.77 (0.32)	1.32-3.35	80	5.46	< .001	1.21
Oral comprehension of sentences (E.CO.S.SE.; /92)	60.47 (5.52)	48-70	76.18 (6.70)	60-87	80	-11.47	< .001	-2.54
Oral production of sentences (SCT; /80)	14.37 (4.88)	5-27	40.52 (10.04)	21-61	64	-15.31	< .001	-3.24
Syllabic awareness (THaPho, /12)	2.13 (1.92)	0-7	6.77 (2.84)	1-12	76	-8.78	< .001	-1.89
Phonemic awareness (THaPho, /12) [b]	1.08 (1.10)	0-5	3.23 (2.50)	0-8	77	-4.95	< .001	-1.07
Rapid automatized naming (DRA Enfants, corr. answers/s)	0.58 (0.13)	0.28-0.81	0.75 (0.17)	0.40-1.12	80	-5.01	< .001	-1.11
Knowledge of letters (SCT; /20) [b]	11.87 (5.09)	1-18	16.14 (3.92)	6-20	80	-4.97	< .001	-1.10
Simple reaction time (SCT; ms) [b]	592 (140)	374-979	517 (95)	332-704	80	2.75	.007	0.61
Visual attention (SCT; corr. answers/s) [b]	0.39 (0.15)	0.20-0.87	0.46 (0.18)	0.23-1.20	80	-2.26	.027	-0.50

Note. Tests used as inclusion criteria at Time 1 (T1) are shown in gray cells. DLD, developmental language disorder; T1, before explicit reading instruction; ELDP, Epreuve Lilloise de Discrimination Phonologique [Lille test of phonological discrimination] (Macchi et al., 2012); SCT, specially created task; KABC-II, Batterie pour l'examen psychologique de l'enfant–Deuxième édition [Child psychological examination battery–Second edition] (Kaufman & Kaufman, 2008); E.CO.S.SE., Epreuve de COmpréhension Syntaxico–SEmantique [Test of reception of grammar] (Lecocq, 1996); THaPho, Test d'Habiletés Phonologiques pour enfants de 5 à 8 ans [Phonological skills test for children aged 5 to 8] (Ecalle, 2007); DRA Enfants, Test de Dénomination Rapide [Rapid automatized naming test] (Plaza & Robert-Jahier, 2006).

[a] In some cases, Levene's test indicated that the variances were not equal between the groups; the calculation of the *t* test statistic then used unpooled variances and a correction to the degrees of freedom.

[b] Comparisons between groups were made on the basis of transformed data.

sion 2, subtest at normal speed). There were 18 pairs of identical pseudowords and 18 pairs of different pseudowords. One point was awarded for each correct answer. The maximum score was 36.

Repetition of pseudowords and words and phonological instability. To assess phonological production abilities, we designed a repetition task comprising 32 stimuli divided into two categories of 16 pseudowords and 16 familiar words. Each category comprised 4 items of one, two, three, and four syllables (see Appendix A). The stimuli, prerecorded in digital format, were broadcast via headphones. One point was awarded for each correctly repeated syllable (maximum score for words: 40; for pseudowords: 40). Internal consistency was high (Kuder–Richardson Formula 20 [KR-20] for pseudowords = .89; for words = .91).

This word and pseudoword repetition task was also used to assess children's phonological instability at the syllable level (rather than at the word level for better sensitivity). The test was administered at two time points at least 15 min apart (T1a and T1b). We examined whether the erroneous syllables at both T1a and T1b were different from each other or the same. Phonological instability was defined as the following percentage: (number of syllables repeated incorrectly and differently at T1a and T1b) × 100 / (number of syllables repeated incorrectly at T1a and T1, regardless of whether these erroneous productions were different or identical). For example, for the word *supermarché* (/sypɛʁmaʁʃe/ [supermarket]) repeated /si-piʁ-naʁ-ʃe/ at T1a and /ʃy-pʁi-naʁ-se/ at T1b, the first three syllables are pronounced incorrectly both times but identically for the third syllable, so the percentage of phonological instability is 66% (2 × 100 / 3). The purpose of this rate was to measure the number of times the iterative presentation of a phonological model causes children to change their production without allowing them to correct it.

Phonological short-term memory. In the Number Recall subtest from the KABC-II battery (Kaufman & Kaufman, 2008), children were asked to repeat sets of digits of increasing length ranging from two to nine digits. The subtest comprised 22 items, and children were awarded 1 point for each correctly repeated set for a maximum possible score of 22 points. We followed the administration and scoring instructions from the manual, which included specific starting and stopping criteria adapted to the age of the children and their success on the items.

Picture-pointing, picture-naming, word-finding difficulty. The lexical assessment (reception and production) was performed using a short (60-item) version of the computerized test about word-finding difficulties (Bragard et al., 2010).[2] In the picture-pointing test, children needed to point out the correct picture among several distractors. In the picture-naming test (same target words as for picture-pointing), children needed to name pictures as quickly as possible. For both tasks, 1 point was awarded for each correct answer, and the accuracy scores were expressed as percentages. To assess possible word-finding difficulties, we developed another measure: the mean latency of picture-naming (in seconds per word). This measure was the total naming time for correctly named words divided by the number of correctly named words, so the score was expressed as an average second per word. It increased with word-finding difficulty.

Oral comprehension of sentences. During the administration of the E.CO.S.SE. (Epreuve de Compréhension syntaxico–semantique [Syntax–semantic comprehension test]; Lecocq, 1996), the French version of the TROG (Test for Reception of Grammar; Bishop, 1983), children were asked to point to one of four images corresponding to the sentence pronounced by the examiner. One point was awarded for each correct answer, with a maximum of 92 points.

Oral production of sentences. We created a syntactic production task inspired by the test of Leuwers and Bourdin (2003). An examiner described a first picture with a sentence, and then the children needed to produce a sentence with similar syntax to describe a similar situation illustrated by a second picture. One point was awarded for each correct response, with a maximum of 80 points.

Reading-related measures. Syllabic awareness and phonemic awareness. Four subtests were extracted from the THaPho test (Test d'habiletés phonologiques pour enfants de 5 à 8 ans [Phonological skills test for children aged 5 to 8]; Ecalle, 2007). In the syllabic categorization task, the examiner named

[2] To reduce administration time, 20 items (with ages of acquisition more than 8.5 years) were removed from the original 80-item version. The pathological thresholds of this version were established thanks to data from the general population encountered by Bragard et al. (2010).

four pictures, two of which shared a syllable. Children needed to circle these two pictures. In the syllable extraction task, the examiner spoke two words that shared a syllable that the children needed to identify. Similar categorization and extraction tasks were performed at the phonemic level. One point was awarded for each correct response, with a maximum score of 12 for syllabic awareness and 12 for phonemic awareness.

Rapid automatized naming. Rapid automatized naming (RAN) was assessed with the test DRA Enfants (Test de Dénomination Rapide Enfants [Rapid naming test for children]; Plaza & Robert-Jahier, 2006). A 6 columns × 8 rows table contained four different pictures (corresponding to familiar monosyllabic words, e.g., *chien* [dog]), each one repeated 12 times at random locations. Children needed to name the 48 pictures as quickly as possible. The score was the number of pictures correctly named per second.

Knowledge of letters. Children were asked to point to each of these 20 most frequent letters in French (according to the Lexique 3 database; New et al., 2001), named successively by the examiner: a, b, c, d, e, é, f, g, h, i, l, m, n, o, p, r, s, t, u, v. The maximum score was 20.

Other skills. Simple reaction time. Children needed to look at a black dot in the center of a white screen. After a random time of 1500, 2000, or 2500 ms, a black cross appeared in place of the dot, which the children needed to make disappear as quickly as possible by clicking on the switch of an SRBox. There were 21 items. The score was the average of the reaction times (ms) after deleting the extreme values.[3]

Visual attention. This was assessed using the RAN stimulus card, on which the children needed to cross out all 12 dogs as quickly as possible. The score was the number of dogs crossed out per second.

Assessment at T2

Oral language skills. Phonological discrimination. We used the same ELDP subtest as at T1.

Pseudoword repetition. We used the subtest of the L2MA-2 battery (Langage oral, Langage écrit, Mémoire, Attention [Oral language, written language, memory, attention]; Chevrie-Muller et al., 2010) containing 20 pseudowords. One point was awarded for each correctly repeated syllable, with a maximum of 74 points.

Phonological short-term memory. We used the same Number Recall subtest from the KABC-II Battery (Kaufman & Kaufman, 2008) as at T1.

Word comprehension. The Receptive in Lexicon subtest of the ELO battery (Evaluation du Langage Oral [Oral language assessment]; Khomsi, 2001), using a picture-pointing task among four pictures, enabled the assessment of children's ability to understand isolated words spoken by the experimenter, with a maximum of 20 points.

Word production. The Lexicon in Production subtest of the same ELO battery was used to assess children's ability to produce isolated words using a picture-naming task with a maximum score of 50 points (1 point per item).

Oral comprehension of sentences. The Oral Comprehension subtest of the BALE battery (Batterie Analytique du Langage Ecrit [Analytic Battery for Written Language]; Jacquier-Roux et al., 2010) is composed of items taken from the French version of the TROG (E.CO.S.SE.). One point was awarded for each image correctly designated when listening to the sentence spoken by the examiner, with a maximum of 20 points.

Sentence repetition. The Sentence Repetition subtest of the L2MA-2 battery (Chevrie-Muller et al., 2010) consisted of repeating 13 sentences with an average of 12.08 words per sentence (*SD*=2.60, range = 6–16). These sentences were presented to the children using a laptop computer and headphones. The score was the total number of correctly repeated words, with a maximum of 157 points.

[3] Two categories of extreme values were removed from the analysis because they were deemed unrepresentative of the true reaction time: reaction times below 200 ms, totaling 42 observations (17 from children with DLD and 25 from control children) and those above 2000 ms, totaling 22 observations (16 from children with DLD and 6 from control children). Thus, 64 of 1701 observations, representing 3.76% of the data, were removed from the analysis.

Reading-related measures. Phonemic awareness. It was assessed using the 12 items of the EVALEC Battery subtest (Batterie informatisée d'évaluation diagnostique des troubles spécifiques d'apprentissage de la lecture [Computerized battery for the diagnostic evaluation of specific learning difficulties in reading]; Sprenger-Charolles et al., 2005, 2019) during which the children needed to remove the initial consonant of consonant–consonant–vowel syllables. The score was the percentage of correct responses.

Rapid automatized naming. We used the same RAN test as at T1 (Plaza & Robert-Jahier, 2006).

Knowledge of letters. This was assessed by a designation task of 15 moderate- to low-frequency letters according to the Lexique 3 database (New et al., 2001): b, c, d, g, h, j, k, m, n, q, s, w, x, y, z. The maximum score was 15 points.

Reading. Text reading. The Alouette test was used to assess the reading of a text (Lefavrais, 1967, 2005). The final score provided a reading age considering both accuracy and speed.

Reading of isolated words. Four measures were used to assess this skill. The ability to read a list of single words as accurately and quickly as possible was assessed using the one-minute reading test of the LMC-R battery (Lecture de Mots et Compréhension–Révisée [Word reading and comprehension–Revised]; Khomsi, 1999). The score was the number of words correctly read in 1 min. For three other lists (36 regular words, 12 irregular words, and 36 pseudowords) from the EVALEC computerized battery (NivOrt and LexOrt subtests; Sprenger-Charolles et al., 2005, 2010), the scores corresponded to the percentages of correct answers.

Nonverbal intelligence. We used the same Pattern Reasoning subtest from the KABC-II battery as at T1, with a maximum of 49 points, as recommended in the administration manual for this age. The final nonverbal intelligence score retained to perform statistical analyses (see below) was the average of the two scores at T1 and T2.[4]

Finally, for all children, the reading-aloud advance or delay was calculated by subtracting their chronological age from their reading age on the Alouette test. Children were divided into three subgroups: (1) children with a reading level corresponding to their chronological age or a few months ahead, (2) children with a reading delay of less than 1 year, and (3) children with a reading delay of 1 year or more. For children with DLD, the percentages were 24%, 37%, and 39% for subgroups (1), (2), and (3), respectively. For the control children, the percentages were 55%, 41%, and 4%, respectively. These two distributions differed, $\chi^2(2) = 16.91$, $p < .001$; reading difficulties were more frequent in children with DLD compared with control children. Finally, 21% of the children with DLD scored below the 5th percentile, whereas 2.27% of the control children did, reaching the criteria for dyslexia regarding reading delay.

Procedure

The children with DLD were recruited in the Hauts-de-France region in France through an independent speech–language pathologist or a neuropediatrician practicing in a language disorder diagnostic center. The children in the control group came from public kindergarten and elementary school in the same region.

For each child, all assessments took place in a quiet room (at school or at home) in two 1-hr sessions at T1 and in one 1-hr session at T2. An additional session was necessary for some children with manifest language and/or attentional difficulties. The tests were administered in a fixed order except for a few children whose outright refusal of a test necessitated a slight adaptation of the order.

At T1, the first author administered the tests, assisted by a temporary research assistant. At T2, the first author assumed this task entirely. These examiners were informed of the planned (but not necessarily final) group for each child. The scoring of the tests was generally done online during the tests. However, some tests were recorded on dictaphone and played back later for accurate and complete scoring. At T1, these were repetition of pseudowords and words, phonological instability, picture-

[4] This non-standard choice was made because each score on the Pattern Reasoning subtest is somewhat imprecise. Averaging the scores at T1 and T2 is expected to provide a more accurate quantification of each child's nonverbal intellectual skills compared with each score taken individually.

naming, oral production of sentences, and RAN. At T2, they were RAN, reading of regular words, irregular words, and pseudowords from the EVALEC computerized battery. For the other tests, if there was any doubt about the scoring, the recordings were systematically replayed to guarantee the accuracy of the scoring on a case-by-case basis.

Parents were informed that the collected data would be treated anonymously and that they could withdraw from the experiment at any time without justification. They had signed a consent form allowing their children to participate. Their children had given oral assent. The ethical rules set out in the Helsinki guidelines for human experimental work were followed.

Statistical analysis

We conducted *t* tests to compare the scores of children with DLD with those of control children on potential predictive factors at T1 as well as on reading and related skills at T2.

To investigate the 20 potential predictors of reading for each of the five reading measures, we ran 100 multiple linear regression models. Because the scores of children with DLD were significantly lower on average than those of the control children for nonverbal intellectual skills and parent education level (see Results), we statistically controlled for both variables in these regressions.

Each regression was run with one reading measure as the response (dependent) variable and with the following measures as predictor (independent) variables: parental educational level, nonverbal intellectual skills, group (DLD vs. control), one of the potential predictive factors, and the interaction of this factor with the group.

We checked for the validity and robustness of our linear regression models as follows. For robustness, we ensured that no observation had an undue influence on the results. For each potential predictive factor, the children with extreme values were identified via three boxplots performed for the whole group of participants, for the group of children with DLD, and for the group of control children. If necessary, we used an appropriate nonlinear transformation of the predictor to reduce extreme values and hence reduce the potential influence of the corresponding observations. We conducted each regression analysis including all participants. When the result was significant and extreme values persisted, we excluded the corresponding observations[5] and verified that the regression result remained significant, as detailed later.

The results of a multiple linear regression are valid under two conditions that pertain to residuals[6]: be normally distributed and have homogeneous variances, although linear regression models are known to be robust to a slight departure from these assumptions. To identify an adequate transformation of each reading measure (dependent variable) to meet these assumptions across most regression models, we assessed the normality of the reading measure within each group using histograms and the Kolmogorov–Smirnov test, and we compared its variances across groups using Levene's test. For the one-minute reading test, both conditions were fulfilled, and transformation was unnecessary. For the Alouette text reading-aloud score, the $-1/x$ transformation led to both normality and similar variances. For the other reading measures, both assumptions could not be satisfactorily met simultaneously. We used a transformation to obtain similar variances because this assumption is more critical: arcsine square root for irregular word reading, $-\text{Log}_{10}(101-x)$ for regular work reading, and $-\text{Log}_{10}(110-x)$ for pseudoword reading. After performing each multiple linear regression, we validated our analyses by checking the normality and homogeneous variance using the model's residuals. First, we created quantile–quantile plots of residuals. In most cases, the points were aligned, showing that the residuals followed a normal distribution. The plots deviated slightly from a straight line only for regular word reading predicted by pseudoword repetition and for comprehension of written sentences predicted by syllabic awareness or by oral comprehension of sentences. However, these deviations were small, and normality is not a critical assumption of regression models. Second, we plotted the standardized residuals versus the predicted reading values. Points were randomly and evenly dispersed on most graphs, consistent with a homogeneous variance, except in two cases: the repetition of pseudowords predicting

[5] Observations from 4 control children were excluded (extreme values were removed when they were more than 1.5 interquartile ranges from the hinges).

[6] The differences between observed responses and the responses predicted by the regression model.

text reading and, to a lesser extent, predicting regular word reading. For these two models, the *p* values of the predictive effect, therefore, were imprecise and represented approximations of the true *p* values. But because these values were very low (.004 and.001, respectively), it was reasonable to conclude that statistical significance was reached.

Because we conducted multiple statistical tests, we calculated an adjustment to control the false discovery rate (FDR), which is the expected proportion of false results among all results that are declared statically significant. We used the method by Benjamini and Hochberg (1995) to calculate an adjusted *p* value called a *q* value (Storey & Tibshirani, 2003) and then considered effects with $q < .10$. We did this adjustment for all 100 tests of the potential predictor's main effect (one for each of five reading measures and 20 potential predictors) and separately for all 100 tests of interaction effects.

Results

Scores at T1 regarding potential predictive factors

As mentioned above, parents of children with DLD had lower levels of education than parents of control children, $\chi^2(1) = 9.18$, $p = .002$ (children with DLD: 21 low, 17 high; control children: 10 low, 34 high).

Children with DLD had significantly lower averages than control children for the following measures: speech perception in silence, in fluctuating and in stationary noise, phonological discrimination, pseudoword repetition, word repetition, phonological short-term memory, picture-pointing, picture-naming, oral comprehension of sentences, oral production of sentences, syllabic awareness, phonemic awareness, RAN, knowledge of letters, nonverbal intelligence, and visual attention. Children with DLD did not differ, on average, from control children for buccal praxis abilities. Children with DLD had statistically higher scores on average than control children for simple reaction time (ms), word finding difficulties (second/correctly named word), and phonological instability (%). See Table 1 for detailed results.

Scores at T1 and T2 for nonverbal intellectual skills

Children with DLD had significantly lower scores than controls for nonverbal intelligence at T1, $t(80) = -5.65$, $p < .001$ (children with DLD: M=6.61, SD=2.60, range = 2–14; control children: M=10.43, SD=3.40, range = 2–20); at T2, $t(71) = -3.13$, $p = .003$ (children with DLD: M=14.92, SD=3.72, range = 9–28; control children: M=18.45, SD=6.33, range = 6–33); and for the average of these scores at T1 and T2 used later in regression analyses, $t(68) = -4.99$, $p < .001$ (children with DLD: M=10.76, SD=2.30, range = 7–17; control children: M=14.44, SD=4.22, range = 8–26.50).

Scores at T2 for reading and related skills

At T2, the average reading score of children with DLD was lower than that of control children on all the following measures: Alouette text reading, one-minute reading test, reading of regular and irregular words and pseudowords, and comprehension of written sentences. Regarding reading-related skills, the average score of children with DLD was lower than that of control children for phonemic awareness, RAN, and knowledge of letters. See Table 2 for detailed results.

Factors at T1 predicting reading at T2

For 81 of the 100 regression models, the predictive effect of the factor of interest and the interaction of this factor with the group were not significant. The following 12 factors did not predict reading: buccal praxis abilities, speech perception in silence, in fluctuating noise, in stationary noise, phonological discrimination, phonological short-term memory, picture-pointing, picture-naming, oral comprehension of sentences, syllabic awareness, simple reaction time, and visual attention.

Table 2
Characteristics of children with DLD and control children at T2.

Characteristics	Children with DLD (n = 38)		Control children (n = 44)		Differences between groups [a]			
	m (SD)	Range	m (SD)	Range	df	t	p	d
Phonological discrimination (ELDP; /36)	22.89 (2.87)	19-31	29.77 (3.39)	22-36	80	-9.83	< .001	-2.18
Pseudoword repetition (L2MA-2; /74)	34.08 (7.56)	20-49	54.75 (6.63)	43-68	80	-13.20	< .001	-2.92
Phonological short-term memory (KABC-II)	7.32 (1.89)	5-13	10.55 (1.78)	6-13	80	-7.95	< .001	-1.76
Word comprehension (ELO, /20)	14.34 (2.02)	9-18	16.91 (1.60)	14-20	80	-6.43	< .001	-1.42
Word production (ELO, /50)	22.89 (4.25)	13-33	32.23 (4.94)	24-42	80	-9.10	< .001	-2.02
Oral comprehension of sentences (BALE, /20)	12.55 (2.50)	8-17	16.14 (1.84)	13-20	67	-7.30	< .001	-1.65
Sentence repetition (L2MA-2, corr. words, /157)	85.79 (21.23)	19-124	133.52 (13.34)	107-157	60	-11.97	< .001	-2.74
Phonemic awareness (suppression of initial phoneme, EVALEC, % corr.)	36.84 (28.65)	0-83	64.20 (23.95)	0-100	72	-4.65	< .001	-1.04
Rapid automatized naming (DRA Enfants; corr. answers/s)	0.83 (0.16)	0.51-1.14	1.06 (0.21)	0.51-1.47	80	-5.49	< .001	-1.22
Knowledge of letters (SCT; /15)	12.63 (1.98)	8-15	14.59 (0.79)	12-15	47	-5.73	< .001	-1.34
Text reading (Alouette; years; months) [b]	7;1 (0;6)	6;6-8;3	8;2 (1;0)	6;10-10;7	80	-7.12	< .001	-1.58
One-minute reading test (LMC-R; corr. words/min)	31.34 (14.98)	6-57	55.09 (15.22)	31-88	80	-7.10	< .001	-1.57
Regular words (EVALEC; % corr.) [b]	64.04 (27.51)	0-100	91.04 (6.93)	75-100	80	-6.28	< .001	-1.39
Irregular words (EVALEC; % corr.) [b]	39.25 (25.99)	0-83	73.48 (20.67)	17-100	80	-6.44	< .001	1.43
Pseudowords (EVALEC; % corr.) [b]	41.08 (24.11)	0-81	73.30 (12.87)	44-100	80	-7.52	< .001	-1.66
Comprehension of written sentences (BALE, /12) [b]	6.37 (2.03)	3-11	8.91 (1.27)	6-11	80	-5.85	< .001	-1.30

Note. Tests used as inclusion criteria at Time 2 (T2) are shown in gray cells. DLD, developmental language disorder; T2, after 2 years of explicit reading instruction; ELDP, Epreuve Lilloise de Discrimination Phonologique [Lille test of phonological discrimination] (Macchi et al., 2012); L2MA-2, Langage oral, Langage écrit, Mémoire, Attention, 2ème édition [Oral language, written language, memory, and attentional skills] (2nd ed.) (Chevrie-Muller et al., 2010); KABC-II, Batterie pour l'examen psychologique de l'enfant–Deuxième édition [Child psychological examination battery–Second edition] (Kaufman & Kaufman, 2008); ELO, Evaluation du Langage Oral [Oral language assessment] (Khomsi, 2001); BALE, Batterie Analytique du Langage Ecrit [Written language analytical battery] (Jacquier-Roux et al., 2010); EVALEC, Batterie informatisée d'EVAluation diagnostique des troubles spécifiques d'apprentissage de la LECture [Computerized diagnostic assessment battery for specific learning disabilities in reading] (Sprenger-Charolles et al., 2005, 2019); DRA Enfants, Test de Dénomination Rapide [Rapid automatized naming test] (Plaza & Robert-Jahier, 2006); SCT, specially created task; LMC-R, Lecture de Mots et Compréhension–Révisée [Word reading and comprehension–Revised] (Khomsi, 1999).

[a] In some cases, Levene's test indicated that the variances were not equal between the groups; the calculation of the t test statistic then used unpooled variances and a correction to the degrees of freedom.

[b] Comparisons between groups were made on the basis of transformed data.

For another 15 models, the predictive effect was significant (p < .05), but the interaction with the group was not. All slopes of the regression lines for both groups were positive; the higher children's scores at T1, the better their reading at T2.

Consistent with a lack of interaction, the regression lines had similar slopes for both groups of children; the factor's predictive power was similar between the two groups. These predictive factors were as follows:

- For the Alouette text reading: pseudoword repetition and RAN;
- For the one-minute reading test and for reading regular words and pseudowords: pseudoword repetition, RAN, and knowledge of letters;

— For reading irregular words: repetition of pseudowords and words, knowledge of letters, and oral production of sentences.

For the four remaining models, the interaction between the factor and the group was significant. After further regression analyses without the extreme data (1 control participant per model), only three interactions remained significant. The factor word finding difficulty no longer interacted with the group, and it did not predict the reading of irregular words. Table 3 presents the models with a significant predictive factor and/or interaction between this factor and the group, with one row per model and associated p values (for these models, confidence intervals for the predictor and interaction effects are shown in Appendix B). For example, for the first row, pseudoword repetition predicts reading the Alouette text ($p = .004$), such that at a fixed parental educational level and nonverbal intellectual skills, the better children repeated pseudowords at T1, the better they read the Alouette text at T2, with or without DLD ($p = .93$).

Table 4 shows more details on the regression lines for the three models in which an interaction remained significant after removing the extreme values before correction for multiple testing. The first model uses phonemic awareness to predict reading of the Alouette text. The regression slope is slightly positive in the control group but not discernibly different from zero ($p = .25$) and is negative in the DLD group, although with weak evidence ($p = .060$). Likewise, for the second model, phonological instability does not predict the score on the one-minute reading test in the control group, and there is only weak evidence for a negative slope in the DLD group ($p = .071$). The third model uses phonological instability to predict the reading level of irregular words (Fig. 1). In children with DLD, there is evidence that the slope is negative ($p = .003$). The higher the percentage of instability at T1, the lower the irregular word reading at T2. In contrast, for control children, the data are consistent with a zero slope ($p = .72$). In summary, phonological instability appears to be the most predictive factor specifically associated with the group of children with DLD.

After adjustment for multiple testing, 12 of the main effects had a q value below.10. Of these 12, the largest q value was.067 (Table 5). Pseudoword repetition predicted the five reading measures: text reading, one-minute reading test, and reading regular and irregular words and pseudowords. Rapid automatized naming predicted one-minute reading and reading regular words and pseudowords. Knowledge of letters predicted the one-minute reading test and irregular word reading. Irregular word reading was also predicted by word repetition and phonological instability.

As for interactions, none had a q value below.10. The smallest q value was.71. Notably, phonological instability had a q value of.71 as a specific predictor of irregular word reading, such that there is no statistical evidence for this DLD-specific predictor after correction.

Oral language profile of children with DLD and phonological instability

Because phonological instability was found to be a potential predictor of written word recognition, we further explored the oral language profile of children with DLD and phonological instability. The group of 38 children with DLD was divided into two subgroups according to the phonological instability scores at T1: the 19 children with phonological instability scores above the median and the 19 children with lower scores. The two groups did not differ on most oral language tasks. However, children with higher instability scored lower than the others at T1 and T2 on the following tasks:

— At T1: buccal praxis abilities, $t(36) = 3.70$, $p < .001$, pseudoword repetition, $t(36) = 2.09$, $p = .04$, digit short-term memory, $t(36) = 2.13$, $p = .04$, and syllabic awareness, $t(30) = 2.86$, $p = .008$;
— At T2: phonological discrimination, $t(36) = 2.26$, $p = .03$, and pseudoword repetition, $t(32) = 2.88$, $p = .007$.</DL>

Discussion

The aim of this exploratory study was to identify, in a longitudinal study with a large proportion of children with DLD, factors related to oral language processing that might predict reading difficulties in French-speaking children with DLD. Our study showed that children with DLD have lower reading

Table 3
Factors at T1 predicting reading at T2.

Reading measurement	Predictive factor	Analysis of the whole data set (*N* = 82)		Analysis after removal of extreme values (*N* = 81)	
		p of the predictive effect	*p* of the interaction (predictive effect x group)	*p* of the predictive effect [a]	*p* of the interaction (predictive effect x group) [a]
Text reading (Alouette)	Pseudoword repetition (SCT)	**.004**	.93		
	Phonemic awareness (THaPho)	.34	**.027**		
	Rapid automatized naming (DRA Enfants)	**.016**	.21		
One-minute reading test (LMC-R)	Pseudoword repetition (SCT)	**.002**	.25		
	Phonological instability (SCT)	.37	**.028**	.46	**.025**
	Rapid automatized naming (DRA Enfants)	**.002**	.24		
	Knowledge of letters (SCT)	**.002**	.95		
Regular words (EVALEC)	Pseudoword repetition (SCT)	**.001**	.37		
	Rapid automatized naming (DRA Enfants)	**.008**	.47		
	Knowledge of letters (SCT)	**.027**	.95		
Irregular words (EVALEC)	Pseudoword repetition (SCT)	**<.001**	.13		
	Word repetition (SCT)	**.005**	.70		
	Phonological instability (SCT)	**.006**	**.015**	**.012**	**.013**
	Word finding difficulty (Bragard et al.; 2010)	.47	**.037**	.47	.058
	Oral production of sentences (SCT)	**.014**	.59		
	Knowledge of letters (SCT)	**.002**	.62		
Pseudowords (EVALEC)	Pseudoword repetition (SCT)	**<.001**	.40		
	Rapid automatized naming (DRA Enfants)	**.004**	.79		
	Knowledge of letters (SCT)	**.013**	.89		

Note. p Values less than.05 are in bold. Regression models for which there is an interaction between the predictor and the group are shown in gray cells. T1, Time 1, before explicit reading instruction; T2, Time 2, after 2 years of explicit reading instruction; DLD, developmental language disorder; SCT, specially created task; THaPho, Test d'Habiletés Phonologiques pour enfants de 5 à 8 ans [Phonological skills test for children aged 5 to 8] (Ecalle, 2007); DRA Enfants, Test de Dénomination Rapide [Rapid Automatized Naming test] (Plaza & Robert-Jahier, 2006); LMC-R, Lecture de Mots et Compréhension–Révisée [Word reading and comprehension–Revised] (Khomsi, 1999); EVALEC, Batterie informatisée d'EVAluation diagnostique des troubles spécifiques d'apprentissage de la LECture [Computerized diagnostic assessment battery for specific learning disabilities in reading] (Sprenger-Charolles et al., 2005, 2019); BALE, Batterie Analytique du Langage Ecrit [Written language analytical battery] (Jacquier-Roux et al., 2010); KABC-II, Batterie pour l'examen psychologique de l'enfant–Deuxième édition [Child psychological examination battery–Second edition] (Kaufman & Kaufman, 2008); E.CO.S.SE., Epreuve de COmpréhension Syntaxico–SEmantique [Test of reception of grammar] (Lecocq, 1996).

[a] Empty cells correspond to regression models whose raw data did not contain extreme values.

Table 4
Characteristics of the regression lines for interactions between the predictive factor and the group.

Reading measure	Predictive factor	Analysis of the whole data set				Analysis after removal of extreme values			
		Children with DLD (n = 38)		Control children (n = 44)		Children with DLD (n = 38)		Control children (n = 43)	
		Slope coefficient	p	Slope coefficient	p	Slope coefficient[a]	p[a]	Slope coefficient[a]	p[a]
Text reading (Alouette)	Phonemic awareness (THaPho)	−.018	.060	.007	.25				
One-minute reading test (LMC-R)	Phonological instability (SCT)	−.368	.071	.156	.19	−.365	.075	.184	.172
Irregular words (EVALEC)	Phonological instability (SCT)	−**.013**	**.003**	−.0009	.72	−**.013**	**.003**	−.0002	.95

Note. Slopes associated with p values < .05 are in bold. DLD, developmental language disorder; THaPho, Test d'Habiletés Phonologiques pour enfants de 5 à 8 ans [Phonological skills test for children aged 5 to 8] (Ecalle, 2007); LMC-R, Lecture de Mots et Compréhension–Révisée [Word reading and comprehension–Revised] (Khomsi, 1999); SCT, specially created task; EVALEC, Batterie informatisée d'EVAluation diagnostique des troubles spécifiques d'apprentissage de la LECture [Computerized diagnostic assessment battery for specific learning disabilities in reading] (Sprenger-Charolles et al., 2005, 2019).
[a] Empty cells correspond to regression models whose raw data did not contain extreme values.

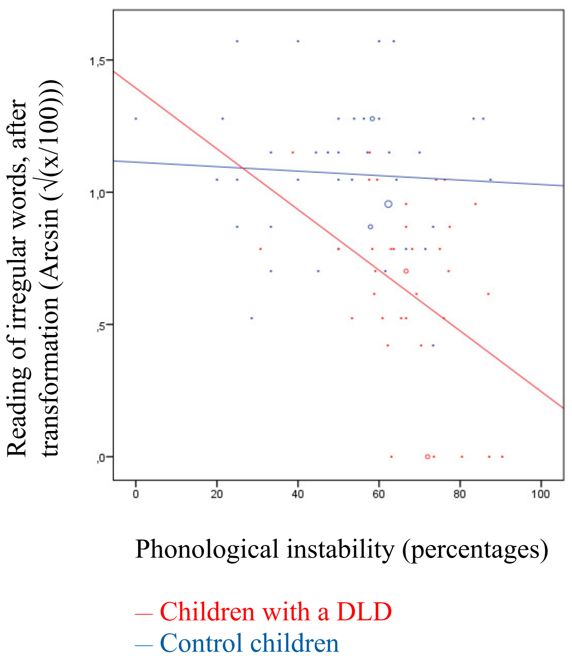

Fig. 1. Irregular word reading scores at Time 2 (T2) as a function of group and phonological instability at Time 1 (T1). T2 is after 2 years of explicit reading instruction. T1 is before explicit reading instruction. The horizontal (blue) line represents control children. The slanted (red) line represents children with developmental language disorder (DLD). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 5
Reading measures and predictive factors corresponding to the 12 tests with a *q* of false discovery rate below.10.

Reading measurement	Predictive factor	*p* of the predictive effect	*q* of the false discovery rate
Text reading (Alouette)	Pseudoword repetition	.0035	.0438
One-minute reading test (LMC-R)	Pseudoword repetition	.0020	.0318
	Rapid automatized naming	.0018	.0318
	Knowledge of letters	.0016	.0318
Regular words (EVALEC)	Pseudoword repetition	.0010	.0318
	Rapid automatized naming	.0081	.0674
Irregular words (EVALEC)	Pseudoword repetition	<.001	.0002
	Knowledge of letters	.0022	.0318
	Word repetition	.0045	.0450
	Phonological instability	.0057	.0521
Pseudowords (EVALEC)	Pseudoword repetition	.0003	.0128
	Rapid automatized naming	.0042	.0450

skills than control children and that reading difficulties are more frequent in DLD but are not systematic. Among children with DLD, the percentage of individuals without an associated oral phonological disorder (26%) is very similar to the number of individuals without a delay in written word recognition (24%). These results are consistent with the findings of many studies cited earlier and tend to confirm the idea of a strong link between oral phonological skills and written word recognition skills. Critically, our data were obtained in French-speaking children, that is, in a language with a more transparent orthography than English. Some results, however, are interesting to discuss, especially regarding the irregular word reading output. The reading of irregular words is predicted by the production of utterances, although the evidence is weak after correction for multiple testing. This finding is consistent with other work showing that semantic–syntactic processing favors the reading of words that are misidentified by the use of grapheme–phoneme correspondences alone (Nation & Snowling, 1998a, b).

We included many measures that are known to be deficient in children with DLD in order to determine whether each one, taken individually, could have a predictive value for the development of word recognition. Our study found that many factors, including some associated with language disorders, are not predictors of reading success (e.g., buccal praxis abilities; speech perception in silence, fluctuating noise, or stationary noise; phonological discrimination; picture-pointing; picture-naming). Nonetheless, some negative results may be due to a lack of power to identify predictive effects with precision given the sample size and range of predictor values. For example, in the control group, the effect of decreasing phonological instability by 10 percentage points (similar to the decrease between the control and DLD groups) on the one-minute reading test had a wide confidence interval including 0 (no effect) but also 7.68 extra words per minute—an effect that may be deemed important in practice.

The following factors were predictors overall (both groups taken together) of at least one measure of reading skills after correction for multiple testing: pseudoword and word repetition, RAN, knowledge of letters, and phonological instability. The latter is interesting because our study is the first, to our knowledge, to consider phonological instability as a possible predictor of reading. Phonological instability, therefore, should be considered for inclusion in assessment tests for children with DLD.

We had two main hypotheses. First, we expected the classical predictors of reading to also be predictors of reading skills in children with DLD. Second, we expected to find additional specific predictors in this group. Regarding the first hypothesis, we did find the factors classically identified as predictors of reading in the general population except for phonemic awareness. An inspection of Table 1 indicates that children performed very low on phonemic awareness, especially in the DLD group. The floor effect prevented this measure from being evidenced as a predictor. Except for this measure, known predictors were retrieved in our study. Second, we hypothesized that some predictors might be more specific to children with DLD. That is the reason why we included several measures known to reveal difficulties in language processing (e.g., speech perception in noise, phonological instability, word finding difficulties). Only phonological instability appeared to have an important predictive value in DLD children specifically. However, statistical evidence for this finding was lost after correction for multiple testing to account for the large number of factors that we tested. The importance of phonological instability as a predictor of reading in children with DLD specifically, therefore, should be confirmed in future research. Interestingly, when we compared children with DLD displaying and not displaying phonological instability, we found that these groups differed in classical predictors of reading: syllable awareness, pseudoword repetition, pseudoword discrimination, and (surprisingly) buccal praxis at T1. This indicates that phonological instability should be studied in future research.

A question is to understand why phonological instability may be predictive of reading irregular words (orthographic processing) but not regular words or pseudowords (phonological processing) in children with DLD. Differences in item properties other than irregularity do not seem to be an explanation. The irregular words are unlikely to be more complex given that regular and irregular words are matched for length (number of letters, phonemes, and syllables), bigram and lexical frequency, and the type of phoneme that begins the words (vowel or consonant); pseudowords are matched for the same criteria except for lexical frequency (Pourcin et al., 2016; Sprenger-Charolles et al., 2005). A possible explanation for this relationship could be the impact of phonological disorders on the building of the reading process. In two previous studies (Macchi et al., 2014, 2019), the performance pattern of children with DLD on a visual lexical decision task and a read-aloud task suggested that their phonological difficulties had hindered the development of their phonological reading processing, which in turn had hindered the development of their orthographic processing. Furthermore, the observation that phonological instability affects only the reading of irregular words and not that of pseudowords and regular words can be interpreted using the hypothesis of Elbro et al. (2012). These researchers suggest that the reading of irregular words during reading acquisition requires the memorization of a verbal association between the result of phonological recoding (e.g., /was/), also called "spelling pronunciation," and the lexical form stored in the long term (e.g., /woz/). Phonological instability might compromise this association, affecting the accuracy of the phonological representation and its motor program. In contrast, the reading of pseudowords and regular words would remain intact thanks to the direct application of direct grapheme–phoneme correspondences, which would support access to an adequate phonological representation and the corresponding motor program.

Limits of the current study

Our study has the following limitations. First, our sample had a relatively small number of children. Second, our recruitment method for children with DLD was based on a clinical sample (children already being followed by speech and language therapists). Such samples tend to overestimate the prevalence of comorbidities, in this case reading difficulties, compared with samples representative of the general population. Third, the exploratory nature of our study led us to consider a large number of hypotheses, with adjustments for multiple comparisons causing a decrease in power. In the future, it would be beneficial to conduct research on larger epidemiological samples and on a focused number of predictors to obtain more generalizable results.

Implications for clinical practice

Our results raise a number of issues for clinical practice. In this area, the tools available to assess predictive reading skills are rather imperfect and could be improved. In so-called predictive French-language batteries (e.g., Deltour & Hupkens, 2011; Inizan, 2000) the main predictive tasks (e.g., repetition of pseudowords, rapid naming, letter knowledge) are absent, and in generalist batteries (e.g., EVALO; Coquet et al., 2009) these skills are assessed, but with tests that sometimes lack sensitivity.

Conclusion

This longitudinal study of 38 children with DLD and 44 control children followed from 6 to 8 years of age confirms that DLD is a risk factor for reading difficulties. It also suggests that these two populations share many factors that predict reading ability. Irrespective of language status, written word recognition is predicted by pre-reading skills and phonological processing skills.

This study is a first step in identifying factors that help to predict reading in children with DLD. Our study allowed us to identify one such candidate factor—phonological instability. Our results do not have the power to conclude with strong evidence that this factor is specifically more predictive in children with language disorders than in those without them given the large number of factors that we considered. This conclusion needs to be tested in future studies. Now that phonological instability has been identified as a factor worth studying further, it will be appropriate to conduct a larger longitudinal study focusing on phonological instability and other identified factors and to examine their respective weights in learning to read. Such a study would also provide an opportunity to observe whether the weight of these factors varies between children with and without language impairment. The current study makes it possible to select relevant factors, including phonological instability in particular.

CRediT authorship contribution statement

Lucie Macchi: Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Marie-Anne Schelstraete:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Cécile Ané:** Writing – review & editing, Software, Resources, Formal analysis, Data curation. **Françoise Boidein:** Resources, Project administration, Investigation, Funding acquisition. **Audrey Riquet:** Resources. **Séverine Casalis:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

Data availability

Data will be made available on request.

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Appendix A. Repetition of pseudowords and words

Items		Sublexical variables		
Pseudowords	Words	Number of syllables	Initial phoneme	Number of simple and complex syllables per set
/za/	pou /pu/ [head louse]	1	Consonant	2 simple syllables
/syʒ/	singe /sɛ~ʒ/ [monkey]	1	Consonant	
/pybʁ/	zèbre /zɛbʁ/ [zebra]	1	Consonant	2 complex syllables
/ɔ~f/	œuf /œf/ [egg]	1	Vowel	
/sɑ~vɛ/	savon /savɔ~/ [soap]	2	Consonant	4 simple syllables
/tuʃɔɲ/	châtaigne /ʃatɛɲ/ [chestnut]	2	Consonant	
/gʁinɛj/	grenouille /gʁənuj/ [frog]	2	Consonant	4 complex syllables
/ivlap/	enveloppe /ɑ~vlɔp/ [envelope]	2	Vowel	
/pɛstɛ~la/	pistolet /pistɔlɛ/ [gun]	3	Consonant	6 simple syllables
/tʁitənɑ̃t/	trottinette /tʁotinɛt/ [scootering]	3	Consonant	
/dotafʁɛs/	dentifrice /dɑ~tifʁis/ [toothpaste]	3	Consonant	6 complex syllables
/ekwiʁjɛm/	aquarium /akwaʁjɔm/ [aquarium]	3	Vowel	
/pisɛʁmœʁʃo/	supermarché / sypɛʁmaʁʃe/ [supermarket]	4	Consonant	8 simple syllables
/boblajetak/	bibliothèque / biblijotɛk/ [library]	4	Consonant	
/kɔlkalitʁɛs/	calculatrice / kalkykatʁis/ [calculator]	4	Consonant	8 complex syllables
/akstʁɛtiʁustʁ/	extraterrestre / ɛkstaʁtɛʁɛstʁ/ [alien]	4	Vowel	

Appendix B. Confidence intervals for the effect and interaction effect of factors at time 1 predicting reading at time 2

Reading measurement	Predictive factor	95% confidence interval of the slope coefficient in the control group	95% confidence interval of the interaction effect: difference in slope coefficients between the DLD and control groups
Text reading (Alouette)	Pseudoword repetition (SCT)	(0.000030, 0.001484)	(-0.000989, 0.001086)
	Phonemic awareness (THaPho)	(-0.035917, 0.000772)	(0.002808, 0.046237)
	Rapid automatized naming (DRA Enfants)	(-0.017142, 0.037818)	(-0.012462, 0.055313)
One-minute reading test (LMC-R)	Pseudoword repetition (SCT)	(0.523317, 2.403245)	(-2.123836, 0.557305)
	Phonological instability (SCT)	(-0.768395, 0.032652)	(0.059349, 0.988775)
	Rapid automatized naming (DRA Enfants)	(-12.556848, 57.483000)	(-17.551003, 68.820128)
	Knowledge of letters (SCT)	(-0.316394, 37.972959)	(-22.066716, 23.406041)
Regular words (EVALEC)	Pseudoword repetition (SCT)	(0.013548, 0.063288)	(-0.051570, 0.019369)
	Rapid automatized naming (DRA Enfants)	(-0.361324, 1.562058)	(-0.758255, 1.613604)
	Knowledge of letters (SCT)	(-0.152897, 0.907316)	(-0.649986, 0.609132)
Irregular words (EVALEC)	Pseudoword repetition (SCT)	(0.024429, 0.060355)	(-0.045177, 0.006061)
	Word repetition (SCT)	(0.010141, 0.045343)	(-0.039918, 0.026949)
	Phonological instability (SCT)	(-0.020768, -0.004517)	(0.002354, 0.021210)
	Word finding difficulty (Bragard et al.; 2010)	(-0.128653, 2.706441)	(-3.712246, -0.114083)
	Oral production of sentences (SCT)	(-0.003181, 0.038039)	(-0.029335, 0.016902)
	Knowledge of letters (SCT)	(0.047502, 0.855739)	(-0.600156, 0.359713)
Pseudowords (EVALEC)	Pseudoword repetition (SCT)	(0.006727, 0.026868)	(-0.020422, 0.008303)
	Rapid automatized naming (DRA Enfants)	(-0.065670, 0.724878)	(-0.420788, 0.554094)
	Knowledge of letters (SCT)	(-0.056431, 0.374481)	(-0.238745, 0.273010)

Note. Confidence intervals are from the analysis of the whole data set (*N*=82), listing the same reading measurements and predictive factors as in Table 3 and prior to multiple comparison adjustment. As in Table 3, models with evidence for an interaction between the predictor and the group are shown in gray and correspond to intervals that exclude 0 for the interaction effect. Wide intervals indicate that a future study with a larger sample size may have power to discern an effect of interest if present. Time 1 is before explicit reading instruction. Time 2 is after 2 years of explicit reading instruction. DLD, developmental language disorder; SCT, specially created task; THaPho, Test d'Habiletés Phonologiques pour enfants de 5 à 8 ans [Phonological skills test for children aged 5 to 8] (Ecalle, 2007); DRA Enfants, Test de Dénomination Rapide) [Rapid automatized naming test] (Plaza & Robert-Jahier, 2006); LMC-R, Lecture de Mots et Compréhension–Révisée [Word reading and comprehension–Revised] (Khomsi, 1999); EVALEC, Batterie informatisée d'EVAluation diagnostique des troubles spécifiques d'apprentissage de la LECture [Computerized diagnostic assessment battery for specific learning disabilities in reading] (Sprenger-Charolles et al., 2005, 2019); BALE, Batterie Analytique du Langage Ecrit [Written language analytical battery] (Jacquier-Roux et al., 2010); KABC-II, Batterie pour l'examen psychologique de l'enfant–Deuxième édition [Child psychological examination battery–Second edition] (Kaufman & Kaufman, 2008); E.CO.S.SE., Epreuve de COmpréhension Syntaxico-SEmantique [Test of Reception of Grammar] (Lecocq, 1996).

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