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Children with dyslexia show an inhibition domain-specific deficit in reading

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Abstract
Children with dyslexia face persistent difficulties in acquiring reading skills, often making guessing errors characterized by the replacement of a word by an orthographic neighbour. These reading errors could be related to inhibition problems within the reading task. Previous studies examining inhibition skills in dyslexic children led to unclear results when inhibition in cognitive and non-reading tasks was evaluated. The present study aims to demonstrate whether dyslexic children have a specific reading inhibition deficit or if they have a general inhibition deficit. Eighteen dyslexic children (age range: 106–131 months, in Grade 4) were matched to typically developing children on both chronological age (age range: 109–128 months, in Grade 4), and on reading level (age range: 87–98 months, in Grade 2). All children were asked to perform (i) a cognitive inhibition task based on fruit colours; (ii) a reading inhibition task, consisting of reading sentences in which an expected word was replaced by a orthographic neighbour. Our results demonstrated that dyslexic children performed equally compared to the two control groups in the cognitive inhibition task, whilst they read the sentences less accurately than the two control groups in the reading inhibition task, and they were slower than children of the same age. Therefore, our results clearly demonstrate that dyslexic children have an inhibition deficit specific to the reading task. The study highlights the importance of better understanding the specific reading difficulties of dyslexic children, which in turn opens up interesting perspectives for treatment.

Keywords Dyslexia · Inhibition deficit · Executive functions · Guessing errors

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Introduction

Children with Dyslexia face persistent difficulties in acquiring either reading accuracy, reading fluency or both aspects of reading (Lyon, Shaywitz, & Shaywitz, 2003). These learning disabilities are considered to affect about 10–15% of school-age children (Vellutino, Fletcher, Snowling, & Scanlon, 2004), and the rate also depends on the opacity of the alphabetic writing system. The reading or writing performances of these children are lower than expected based on their age, their ability in other areas, or the instruction they have received. The consequences of these reading difficulties are significant for children's social, societal, and academic development. Indeed, learning and assessments are mainly done through reading and writing at school, even from an early age. Therefore, it is important to provide a better understanding of children's difficulties inherent in reading tasks. This could help to better structure the treatment that can be offered to them.

Among the large number of explanatory hypotheses of dyslexia, executive function difficulties have been proposed (Brosnan et al., 2002; Varvara, Varuzza, Sorrentino, Vicari, & Menghini, 2014). Executive functions are general cognitive abilities that control other cognitive functions and behaviours. According to Miyake et al. (2000), the three core executive functions are inhibition, working memory and cognitive flexibility. Until now, among the three executive functions, the studies on inhibition in children with dyslexia have been providing conflicting results, which can partly be explained by the fact that the tasks used varied greatly. Of particular interest to the current study, the question that arises and remains clearly open is whether the disorder in executive functions is domain-general or domain-specific for children with dyslexia. Indeed, knowing whether they are facing a general inhibition disorder (domain-general deficit) or a specific inhibition disorder related to reading tasks (reading-specific deficit) would allow to better understand their underlying reading processes, which in turn would enable to adapt the treatment. To the best of our knowledge, no study has so far provided strong empirical evidence to demonstrate that children with dyslexia have a specific reading inhibition deficit or a more general inhibition deficit. However, this kind of study could certainly help us to better understand the cognitive underpinnings of dyslexic children's reading errors, by linking them to the executive functions involved in a reading task. A better understanding of children's errors or performance in reading could in turn allow better treatment design.

Children with dyslexia

According to Morton and Frith's (1995) causal model of dyslexia, several causes and levels of description of dyslexia have been identified: the biological level, the cognitive level and the behavioural level, as well as the environmental influence on these three levels. The behavioural level corresponds to the symptoms (i.e., the observation of the reading level). The biological level corresponds to the genetic brain abnormalities or reduced activity in the left hemisphere (Paulesu et al., 2001). When we look at the behavioural level, dyslexia is characterised by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities (Lyon et al., 2003). Difficulties in word recognition could also have an impact on reading comprehension skills. At the level of word recognition, it is well established that children with dyslexia have a deficit in non-word or pseudo-word reading compared to reading-age matched children (Snowling, 2000). This deficit is linked to a failure in the application of grapheme-phoneme correspondences at the basis of the alphabetic stage of Frith (1985), or the phonological strategy of reading. This deficit prevents the development of the self-teaching mechanism of reading (Share, 1999). Similar difficulties are also observed in spelling, where children with dyslexia make more phonetically unacceptable spelling errors than reading-age matched children (Snowling, 1987). Children with dyslexia also make guessing errors in reading, which will be explained later.

Regarding the cognitive level, until now, the predominant cognitive cause of dyslexia proposed is that of the phonological core deficit hypothesis (Snowling, 2000; Stanovich, 1988). According to this hypothesis, the difficulties are observed in phonological tasks related to reading skills such as phonological awareness (Adlard & Hazan, 1998; Maïonchi-Pino, Magnan, & Écalle, 2010), rapid automatised naming (Araújo, Pacheco, Faísca, Petersson, & Reis, 2010; Papadopoulos, Georgiou, & Kendeou, 2009; Wolf & Bowers, 1999) or verbal short-term memory (Laasonen et al., 2012; Melby-Lervåg, Lyster, & Hulme, 2012). Besides the phonological hypothesis, other potential causes have been put forward more or less recently but with a less clear consensus: a visual deficit was assumed (Eden, Stein, Wood, & Wood, 1995), or a cerebellar deficit (Nicolson, Fawcett, & Dean, 2001, see Ramus et al., 2003 for an integrative perspective). Executive function deficits have also been observed in children with dyslexia but also in children with attention deficit hyperactivity disorder (ADHD, Varvara et al., 2014) or dyscalculic children (Wang, Tasi, & Yang, 2012). The presence of a high comorbidity of disorders is clearly significant (e.g., 40% of children with dyslexia exhibit ADHD, Barrouillet et al., 2007). The fact of having a high comorbidity of disorders raises the question of a potential common underlying deficit. In this way, observing an identical executive function deficit in dyslexic, dyscalculic or ADHD children is an interesting explanation of the disorders because it is valid for different disorders. To assume the same executive function disorder in children with different learning disabilities would also be an argument in favour of a domain-general deficit.

Executive functions

Executive functions, or cognitive control, are a set of high-level skills that are required when you need to concentrate or to pay attention (Diamond, 2013). The three executive functions that are traditionally recognised are inhibition, working memory and cognitive flexibility (or shifting; Miyake et al., 2000). Working memory involves holding information in mind and mentally working with it, and cognitive flexibility concerns changing perspectives or approaches to a problem, flexibly adjusting to new demands, rules or priorities (Diamond, 2013). Inhibition includes the control of attention, behaviour, thoughts and emotions (Diamond, 2013). At the cognitive level, cognitive inhibition is defined as the ability to inhibit a prepotent mental representation, which is automatically triggered by a stimulus. Children need mental effort and time to inhibit the prepotent response and give the correct answer. In the classical Stroop task, in the incongruent trials, children need to inhibit the prepotent response which is the automatic reading of the word (e.g., red) to be able to name the colour of the ink (e.g., blue). This inhibitory control is known to be very difficult for young children who make response errors because they cannot stop the automatic response and/or are slower to answer for the same reason.

It seems obvious that executive functions are involved in reading since this activity requires concentration or attention. The way some authors tried to understand this relationship is through regression models. In particular, Borella & de Ribaupierre (2014) showed that the executive function skills of children aged 10–12 predict their level of text reading comprehension. More precisely, working memory explained a large part of variance in text comprehension performance. Resistance to distractor interference, which is part of inhibition, was also a significant predictor. Recently, Meixner, Warner, Lensing, Schiefele, and Elsner (2019) even found through a cross-lagged-panel analysis bidirectional longitudinal relations between executive functions and reading comprehension in grades 3 and 4. Cirino et al. (2018) broadened the relationship between executive functions and reading by demonstrating that executive functions had a clear and unique contribution to reading processes including reading comprehension, but also decoding and fluency.

Executive function disorders in dyslexia

The existence of executive function disorders in dyslexic children or adults has been examined in several studies but the literature has not yet reached a clear consensus concerning whether dyslexics have an executive function deficit or not. However, the studies are based on different tasks evaluating executive functions, and sometimes even different participants. In a first study based on questionnaires and behavioural data, dyslexic adults reported that their problems in executive functions have an impact on their daily functioning at the planning or organisational level (Smith-Spark & Fisk, 2007). They also showed a deficit in inhibition and shifting in behavioural measures. In another study, the task used raises questions. Varvara et al. (2014) proposed a variety of tasks evaluating executive functions and showed that dyslexic children's reading level was best explained by the task of spoonerism, which evaluates executive functions. However, the spoonerism task is also a measure of phonological awareness, known to be deficient in dyslexics, which leads to confounded effects.

Another important difference is whether the difficulties are present in verbal or non-verbal tasks. Brosnan et al. (2002) showed that dyslexic children and (compensated) dyslexic adults had deficiencies in a non-verbal inhibition task, group-embedded figures test, requiring to identify a simple form in a distracting context. This non-verbal task requires inhibitory processes to focus on the target form. A contradictory result was observed by Wang et al. (2012) who administered different inhibition tasks. They have shown that dyslexic children are deficient in inhibition tasks that involve verbal material while they behave like control children for tasks that involve inhibition of numbers for example. This opposition depending on the type of task is also present in the results of the meta-analysis of Booth, Boyle and Kelly (2010). According to this meta-analysis, the effects sizes were significantly larger when the task evaluating inhibition required a verbal response. The effects sizes also varied according to group differences. Indeed, some studies evaluated dyslexic children while the others selected the participants on the basis of a deficit in reading comprehension. In this case, the participants can be compared to the profiles of poor comprehenders (Cain & Oakhill, 2007) and not children with dyslexia.

The observation of different results according to the tasks is interesting and raises the question of whether the inhibition deficit could be general if it is present in tasks of different modalities (domain-general), or whether it is specific to reading if it is present only in a reading task (domain-specific). However, no studies have so far evaluated inhibition skills in a reading task, while the nature of some reading mistakes made by children with dyslexia may suggest an inhibition deficit in reading.

Guessing errors in children with dyslexia

In reading, in addition to reading non-word errors, children with dyslexia often make guessing errors or global errors, characterised by the replacement of a word by an orthographic neighbour (Van der Schoot, Licht, Horsley & Sergeant, 2000). For example, the word *joie* [joy] is read as *jolie* [pretty], which is a word that differs from it by only one letter. These errors are interpreted as the consequence of a failure to use the alphabetical strategy or the non-use of this strategy. They are also related to the use of a logographic strategy defined by the instant recognition of familiar words at a global level of processing. According to Frith (1985), the logographic strategy leads children to guess on the basis of contextual or pragmatic cues.

Children with dyslexia make guessing errors in an isolated word context or in a text reading context. In an isolated word reading context, the occurrence of these errors could be explained by the interactions between representations of words in the mental lexicon. Indeed, according to McClelland and Rumelhart's (1981) connectionist model—the interactive activation model, words interact with each other at the word level, either with excitatory connections or with inhibitory connections. These connections lead to excitatory neighbours or inhibitory neighbours. In the case of a global error, it is assumed that the wrong word that is read has a higher activation—and frequency—in the lexicon than the target word, and that the child was not able to inhibit the word with a higher activation. In a text reading context, it is assumed that dyslexic children rely more on context to guess words as a means of compensating for their difficulties. Even in an oral text context, it has been shown that dyslexics use greater contextual facilitation than normal readers (Nation & Snowling, 1998; Perfetti, 1985). Taken together, these guessing errors could be interpreted as difficulties in inhibiting global processing (a logographic strategy) to the detriment of the use of analytical processing (an alphabetic strategy, Brosnan et al., 2002). These elements imply a difficulty of inhibition in reading. At present, however, the possible involvement of an inhibition deficit amongst dyslexic children remains unclear.

Present study

So far, on the one hand, previous studies have examined the performance of dyslexic children in a large number of non-reading inhibition tasks while they have not examined inhibition deficit in a reading task (Booth et al., 2010; Wang et al., 2012). On the other hand, children with dyslexia produce guessing errors that can be interpreted as a consequence of an inhibition deficit inherent in the task of reading. However, there is no experimental evidence showing that children with dyslexia suffer from an inhibition deficit in reading.

The aim of the present study was to evaluate whether children with dyslexia (DYS children) have a specific reading inhibition deficit or if they have a general inhibition deficit, compared to two control groups composed of typically developing children: chronological age-matched children (CA children) and reading age-matched children (RL children). Inhibition skills were assessed in both a non-reading cognitive inhibition task (the cognitive inhibition task) and a sentence reading task involving inhibition skills (the reading inhibition task). In the sentence reading task, to imply inhibition processes, the children had to read sentences in which an expected word based on the context was replaced by an orthographic neighbour. So, children had to inhibit the expected word in order to read the target word correctly. Within the reading inhibition task, two variables were manipulated to allow the understanding of the inhibition process. On the one hand, the word frequency was manipulated by proposing orthographic neighbours more frequent or less frequent than the expected words, the more frequent words being the most complex to inhibit, according to McClelland and Rumelhart (1981). On the other hand, the distance between two orthographic neighbours was manipulated by proposing a short distance and a long distance, neighbours with short distance being the most complex to inhibit because residual inhibition is greater (the word remains active in the lexicon, Vandierendonck, 2013).

We investigated, in the reading inhibition task, whether DYS children make more inhibition errors or are slower than CA children and RL children. We made the following predictions: (a) if DYS children have a general inhibition deficit, they should have difficulties in both in the cognitive inhibition task and in the reading inhibition task compared to the CA and RL children; (b) if DYS children have a specific reading deficit, they should show a deficit only in the reading inhibition task compared to the CA and RL children. With regard to the developmental profile, (c) if DYS children have lower scores than CA children but equivalent to RL children, this would indicate a developmental delay profile; (d) if DYS children have lower scores than control children in both groups RL and CA, this would indicate a developmental deviant profile.

Method

Participants

Eighty-four French-speaking children from several primary schools took part in the experiment. They originated from urban and rural schools in Belgium, and were of average socio- economic status. Out of those children, eighteen constituted the DYS group (children from Grade 4, five girls, 13 boys, M_{age} = 114.11 months, age range: 106–131 months). These children were mainly recruited through learning disability consultation centres or speech therapists. Among these children, fourteen had been previously diagnosed with dyslexia by a multidisciplinary team of professionals or by a professional. The remaining four children obtained deficit scores in two of our three standardised reading tests (including scores below 2 standard deviations on two tests, and at least one score below 4 standard deviations on a subtest of the Batterie Analytique du Langage Ecrit (Jacquier-Roux, Lequette, Guillemette, Valdois, & Zorman, 2010).

The DYS children were matched to typically developing children, on the one hand, to CA children who came from Grade 4 (N = 34), and on the other hand, to RL children who came from Grade 2 (N = 32). The DYS children were first matched with CA children, typically developing children matched on chronological age, and gender when it was possible (CA children, N = 18, seven girls, 11 boys, M_{age} = 115.93 months, age range: 109–128 months). The same DYS children were also matched to RL children, typically developing children matched on reading level and gender when it was possible (RL children, N = 18, six girls, 12 boys, M_{age} = 91.69 months, age range: 87–98 months). The RL control children are a subset of the participants from another previous study (Vander Stappen & Van Reybroeck, 2018). Amongst them, some were removed from the sample because they met one of the exclusion criteria: (a) eight children scored below two standard deviations for their age in one of the reading tests; (b) two children scored below two standard deviations in the estimated nonverbal IQ, as measured by the Matrices reasoning subtest of the WPPSI-IV (Wechsler, 2014).

Therefore, the present sample was composed of fifty-four children. Table 1 provides the characteristics of the participants by group. The one-way ANOVA confirmed that the children did not differ in the estimated nonverbal IQ, in vocabulary or in selective visual attention. Post hoc comparisons revealed that the DYS children were correctly matched on chronological age with the CA children. They were also correctly matched on reading level with the RL children, on both word reading accuracy (raw score) and word reading response time (raw score). The DYS children's performance in phonological awareness and in reading comprehension was lower than that of the CA children and equivalent to that of the RL children. All the children's parents gave their active consent for participation in the experiment and the children gave their verbal consent. The study was approved by the Ethics Committee of the Psychological Science Research Institute.

Measures

Control measures

Word reading Word reading skill was assessed by the standardised subtest from the Batterie Analytique du Langage Ecrit [BALE, Jacquier-Roux et al., 2010] on accuracy and speed for three kinds of words: regular words, irregular words and pseudow-

Table 1 Characteristics of the participants by group: descriptive statistics and one-way ANOVA

Measures	DYS		CA		RL		Group effects		Post hoc comparisons[a]
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	
Gender									
Girls	5		7		6				
Boys	13		11		12				
Age in months	114.11	6.75	115.93	4.71	91.69	3.57	122.28	< .001	RL < CA = DYS
Word reading accuracy									
Raw score	77.72	19.02	103.50	7.57	80.11	14.32	17.55	< .001	RL = DYS < CA
Standardised score	− 1.18	0.99	0.13	0.53	− 0.27	0.67	14.36	< .001	DYS < RL = CA
Word reading response time									
Raw score[b]	292.44	100.75	144.11	38.71	227.83	99.47	13.86	< .001	RL = DYS < CA
Standardised score	− 1.57	2.10	0.35	0.76	0.35	0.66	12.30	< .001	DYS < RL = CA
Text reading									
Raw score	64.33	15.57	101.55	13.14			60.05	< .001	DYS < CA
Standardised score	− 1.09	0.68	0.44	0.60			51.68	< .001	DYS < CA
Reading comprehension									
Raw score	− 0.41	0.80	1.09	0.71	0.05	0.89	16.52	< .001	RL = DYS < CA
Phonological awareness									
Raw score	23.89	6.59	30.83	4.02	25.05	7.13	6.76	< .01	RL = DYS < CA
Rapid automatized naming									
Composite score	0.93	0.23	1.04	0.18	0.83	0.17	5.19	< .01	RL < CA; DYS = CA and RL
Vocabulary (standardised score)	0.40	1.12	1.00	0.62	0.56	0.77	2.35	.11	
Nonverbal IQ (subtest scaled score)[c]	8.72	2.44	9.05	2.34	10.11	3.16	1.32	.27	

Table 1 (continued)

Measures	DYS		CA		RL		Group effects		Post hoc comparisons[a]
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	
Selective visual attention									
Accuracy (percentile)	77.72	33.59	77.89	33.89	64.50	30.25	0.99	.38	
Response time (percentile)	44.17	24.87	62.78	21.84	46.67	25.55	3.15	.05	RL = DYS = CA

DYS Dyslexic children, *CA* chronological age matched children, *RL* reading level matched children

[a]Post hoc comparisons are Bonferroni, all $p < .05$

[b]A higher score refers to a longer response time

[c]French version of the Matrices subtest of the WPPSI-IV, M = 10, SD = 3

ords. Each type of word was evaluated using two lists composed of 20 highly frequent words and 20 low frequency words. Children were asked to read aloud the words presented in columns of 20 as quickly and accurately as possible. For the pseudowords, the experimenter explained that the words did not exist and that they did not have to try to understand them. Speed and accuracy were scored for each list, by measuring reading time in seconds and by attributing one point for each item correctly read. A global word reading accuracy score was attributed to each child, which included all types of words. The maximum accuracy score was 120. In the same way, speed measures led to one global reading speed score. The raw score is provided as well as the standardised score. The internal reliability (Cronbach's α) in the entire sample of second graders from our previous study was .90.

Text reading Text reading skill was assessed by the standardised test Marie from the ECHAS-C battery (Simonart, 2008). Children were asked to read a text aloud the best they could within a time limit of 2 min. Their score consisted of the number of words correctly read in 2 min.

Reading comprehension Reading comprehension skill was evaluated by the standardised subtest L3 from the Orlec battery (Lobrot, 1967). It consisted of a multiple-choice test involving the completion of 36 sentences by selecting the missing word out of five possible options, in a time limit of 5 min. The options included distractors such as homophones (e.g., *mère* [mother] instead of *mer* [sea]), phonological distractors (e.g., *palais* [palace] instead of *balai* [broom]), or semantic distractors (e.g., *pattes* [paws] instead of *oreilles* [ears]). The scores used consisted of the number of words correctly chosen to complete the sentences (max. score 36).

Phonological awareness The syllable and phoneme deletion task from the Battery for the Assessment of Phonological Skills (Van Reybroeck, 2003) was adapted from the initial version consisting of 60 items. Twenty-five items were removed to make a total of 35 items. First, the task consisted of repeating a nonword pronounced by the experimenter. Second, the children needed to say what would be left after taking away a designated phonological unit, either a syllable or a phoneme. Ten items required the children to remove the initial syllable of a bisyllabic nonword with a CVCV structure. Twenty-five items required the children to take away a designated phoneme of a monosyllabic nonword. The syllabic structure of the nonword and the position of the phoneme to be removed varied across the items: 9 items targeted the initial phoneme of a CVC nonword, six items targeted the initial phoneme of a CCVC nonword and 10 items targeted the second phoneme of a CCVC nonword. The test was preceded by six practice items to ensure that the children had understood the instructions. The children were given one point for each correct or self-corrected response. The maximum score on the test was 35. The internal reliability (Cronbach's α) in the previous larger sample of second graders (Vander Stappen & Van Reybroeck, 2018) was .89.

Rapid automatised naming Two matrices of objects from the Battery for the Assessment of Phonological Skills (Van Reybroeck, 2003) were presented to the participants. All the items were highly familiar French words with an age of acquisition lower than 60 months (Chalard, Bonin, Méot, Boyer, & Fayol, 2003). They were illustrated by colour photographs arranged semi-randomly in four rows of six. The matrices were composed of three items repeated eight times (RAN-R matrices). One matrix was made up of short words (one-syllable words). The other was composed of long words (two- and three-syllables words). The test matrices were preceded by a training matrix. The children had to name the objects in the matrix as quickly and accurately as possible. For each matrix, the number of errors and the time to name all of the objects were recorded. A composite score was computed by dividing the number of objects correctly named from the two matrices by the total naming time for both matrices. The internal reliability in the previous larger sample was .83.

Vocabulary The level of productive vocabulary was measured by the picture naming test of the ELO/Evaluation du Langage Oral ([Oral Language Assessment]; Khomsi, 2001). The children were asked to name a series of 42 pictures, including 32 nouns and 10 action verbs. The maximum raw score was 42. For the other larger sample, the ELO was found to have an internal consistency coefficient (Cronbach's α) of .78.

Nonverbal IQ The French version of the Matrix Reasoning subtest from the fourth edition of the WISC-IV/Wechsler Intelligence Scale for Children (Wechsler, 2005) was used to measure nonverbal reasoning. This subtest was identified as a reliable measure of fluid reasoning (Kaufman, Flanagan, Alfonso, & Mascolo, 2006). It is composed of a series of 35 incomplete matrices containing abstract patterns and designs. The children were required to select the best from one of the five response options in order to complete the matrix. The total number of correct responses (maximum 35) was converted to a subtest scaled score. The internal reliability in the previous larger sample was .86.

Selective visual attention In order to exclude visual attention difficulties, the *search in the sky* subtest from the Test d'Evaluation de l'Attention Chez l'Enfant [TEA-ch, Test of Assessment of Attention in Children] (Manly, Robertson, Anderson, & Mimmo-Smith, 2006) was administered to the children. They had to draw a circle around each identical pair of spacecrafts on a sheet of paper with 88 pairs of spacecraft. Speed and accuracy were scored, by measuring response time in seconds and by attributing one point for each pair correctly identified.

Inhibition measures

Reading inhibition In order to assess the impact of inhibition in sentence reading, 20 sentences were created. In each sentence, an expected word based on the context was replaced by an orthographic neighbour. For example, in the sentence *J'ai été courir dans les bois et depuis j'ai mal aux pieds, surtout au salon*—that replaced *au talon*—(I went running in the woods and since then my feet hurt, especially in *the living room*—instead of my heels). To correctly read its orthographic neighbour, children must inhibit the expected word *talon* (heels)—the prepotent response—to read the correct word *salon* (the living room).

Two psycholinguistic variables were manipulated to allow the understanding of the inhibition process: word frequency and distance between the two orthographic neighbours. Table 2 shows the list of the sentences used in the task and the characteristics of the orthographic neighbours. The *word frequency* was manipulated at the level of orthographic neighbour using the Manulex Standard Frequency Index for Grade 2 children (Lété, Sprenger-Charolles, & Colé, 2004). The orthographic neighbour in the place of the expected word is either more frequent than the expected word (*salon*—55.15 more frequent than *talon*—49.53) or less frequent than the expected word (*litre*—51.51 less frequent than *livre*—67.17). According to McClelland and Rumelhart's connectionist model (1988), children are expected to have more difficulty inhibiting a word with a higher frequency than the word expected, than inhibiting a word which is less frequent than the expected word. Indeed, during lexical competition between words, the more frequent word has a higher level of basic activation than the less frequent word.

The *distance between the two orthographic neighbours* was also manipulated at the level of the sentences. The distance between the orthographic neighbour and the other neighbour was either one sentence or three sentences. In case of a shorter distance (one sentence) between the orthographic neighbours, the second neighbour is more complex to inhibit because it is more active in the lexicon. In case of a longer distance (three sentences) between the orthographic neighbours, the second neighbour is less complex to inhibit. Indeed, according to Vandierendonck (2013), the distance between the neighbours can influence the response time. If the distance is shorter (e.g., ABAB), the reaction time will be slower to treat the second A because the residual inhibition is greater than when the distance is longer (e.g., ACBA). Finally, in order to prevent a facilitating effect related to the similarity between the items, two measures were taken: on the one hand, the position of the letter that differentiates the two neighbours was varied so as not to have neighbours only distinguished by the initial letter (*salon–talon*); on the other hand, the grammatical category of the pairs of neighbours was varied between nouns, verbs and adjectives.

The children were asked to read the 20 sentences. Speed and accuracy were scored, by measuring reading time in seconds for the 20 sentences and by attributing one point to each neighbour correctly read. The maximum accuracy score was 20. To allow a better understanding of the inhibition processes, reading errors were divided into seven categories. Both researchers were trained to analyse the reading mistakes in the same way. The reading errors were: (a) more frequent word, which consists of replacing the target word by a more frequent word (e.g., replace *bagues* [rings] by *page* [page]); (b) less frequent word, which consists of replacing the target word by a less frequent word (e.g., replace *marin* [sailor] by *Martin* [Martin]); (c) phonological error which consist of producing a word that is phonologically inappropriate in relation to the target word (e.g., replace *cuisses* [legs] by *cuize* [pseudoword]); (d) semantic error, which consists of replacing the target word by a word having a semantic link with this word; (e) prepotent word, which consists of replacing the target word by the expected word according to the context of the sentence

Table 2 List of the sentences used in the reading inhibition task and characteristics of the orthographic neighbours

Sentences	Orthographic neighbours (frequency[a])	Distance between neighbours[a]	Prepotent response frequency
Pour faire ce gâteau, on a besoin de 100 grammes de sucre et un demi-*livre* de lait	Livre (67.17)–litre (51.51)	1	higher
To make this cake, you need 100 grams of sugar and half a *book* of milk			
Après avoir mangé, j'aime regarder la télévision dans le *talon*	Talon (49.53)–salon (55.15)	3	Lower
After eating, I like to watch TV in the *heel*			
J'aime lire, c'est déjà la troisième fois que je lis ce *litre*	Litre (51.51)–livre (67.17)	1	Lower
I like to read, it's already the third time I've read this *liter*			
Zut, j'ai une tache sur mon pantalon et Papa m'avait demandé de ne pas me *saler*	Saler (52.17)–salir (49.70)	3	Higher
Damn it, I have a stain on my pants and Dad asked me not to get *salty*			
J'ai un rhume, j'éternue et je n'arrête pas de me *coucher*	Coucher (52.59)–moucher (50.98)	1	Higher
I have a cold, I sneeze and I keep going *to bed*			
J'ai été courir dans les bois, et depuis j'ai mal aux pieds, surtout au *salon*	Salon (55.15)–talon (49.53)	3	Higher
I went running in the woods, and since then my feet hurt, especially in the *living room*			
Il est l'heure d'aller au lit, je dois aller me *moucher*	Moucher (50.98)–coucher (52.59)	1	Lower
It's time to go to bed, I have to *blow my nose*			
Il parait que le sel n'est pas bon pour la santé, il ne faut pas trop *salir* les légumes	Salir (49.70)–saler (52.17)	3	Lower
It seems that salt is not good for your health, you shouldn't get the vegetables *too dirty*			
On a enfin fini de déménager toutes les *cuisses*	Cuisses (48.20)–caisse (56.27)	1	Lower
We finally finished moving all the *legs*			
En hiver, ma grand-mère me prépare souvent de la *loupe*	Loupe (47.83)–soupe (60.17)	3	Lower
In winter, my grandmother often makes me *magnifying glasses*			
Pour le souper, Maman a préparé du poulet, j'adore ronger les os, je demande toujours une *caisse*	Caisse (56.27)–cuisses (48.20)	1	Higher
For dinner, Mom made chicken, I love eating bones, I always ask for a *crate*			
Ma soeur adore les bijoux, surtout les colliers et les *vagues*	Vague (59.26)–bague (49.73)	3	Higher

Table 2 (continued)

Sentences	Orthographic neighbours (frequency[a])	Distance between neighbours[a]	Prepotent response frequency
My sister loves jewellery, especially necklaces and *waves*			
Pour Noël, mon petit frère a reçu plein de *fouets*	Fouet (51.07)–jouet (61.51)	1	Lower
For Christmas, my little brother got a lot of *whisks*			
C'est écrit trop petit, j'ai besoin d'une *soupe*	Soupe (60.17)–loupe (47.83)	3	Higher
It's written too small, I need a *soup*			
J'adore préparer la mousse au chocolat, pour battre les blancs en neige on utilise un *jouet*	Jouet (61.51)–fouet (51.07)	1	Higher
I love to make chocolate mousse, to beat the egg whites into snow we use a *toy*			
A la mer, je m'amuse comme un fou dans les *bagues*	Bague (49.73)–vague (59.26)	3	Lower
At sea, I have a lot of fun in the *rings*			
J'aime la mer et les bateaux, quand je serai grand, je voudrais devenir *matin*	Matin (67.83)–marin (50.32)	1	Higher
I love the sea and boats, when I grow up, I would like to become a *morning*			
J'ai mal au bras, ce paquet est beaucoup trop *sourd*	Sourd (51.48)–lourd (59.37)	1	Lower
My arm hurts, this package is much too *deaf*			
J'aime manger des tartines au choco le *marin*	Marin (50.32)–matin (67.83)	1	Lower
I like to eat chocolate on toast, *sailor*			
Ne crie pas si fort, je ne suis pas *lourd*	lourd (59.37)–sourd (51.48)	1	Higher
Don't scream so loud, I'm not *heavy*			

Orthographic neighbours are shown in italic (e.g., replace *salon* [living room] by *talon* [heel]); (f) self-correction, which consists of correcting one's error; g) other errors, which consists of unclassifiable errors.

Cognitive inhibition Since some of the participants were weak readers or young readers, the classical Stroop test could not be administered to them. Indeed, the test is based on reading and assumed an automatic reading process to be inhibited which makes no sense if the children have not yet automatised reading. That is why a version of the Stroop fruit, inspired by Archibald and Kerns (1999)'s version was administered. In the first part, the children were facing a matrix with three fruits repeated 14 times. They had to name the colour of the fruit, which was congruent with its real colour (e.g., a red strawberry). In the second part, called *interference*, the colours of the fruit did not correspond to the real colours (e.g., a yellow strawberry). The children had to name the original colour of the fruit by inhibiting the colour they have before their eyes (e.g., name red against a yellow strawberry). Speed and accuracy were scored, by measuring response time in seconds for the matrix and by attributing one point to each fruit correctly named. The maximum accuracy score was 42.

To confirm the presence of an inhibition deficit, the child must have a lower performance in the interference condition than in the naming condition, which shows a cost of interference. For this reason, a difference score was computed by subtracting the naming score from the interference score.

Procedure

All testing took place at school for the CA and RL children and either at school or at the consultation centre for the DYS children. Participants were assessed by three experimenters. All the tasks were conducted individually in a quiet room in one 50-min session for the fourth graders and the DYS children. The tasks were administered in one or two sessions of 40-min maximum for the second graders. Since fatigue was more a concern than order effects, the tasks were administered in the same order to all the children, by balancing tasks that required more attention with those that required less. All the tasks were presented over a period of 3 months (February–April). To ensure a blind process, the score sheets were anonymised prior to scoring.

Results

Descriptive statistics for the variables are displayed in Table 3. Statistical analyses were run using SPSS 25. Preliminary analyses were conducted to examine whether the data met the normality assumption of parametric procedures. The analyses revealed no distributional problems since the absolute values of skewness and kurtosis did not exceed 3.0 and 10.0 (Kline, 2005). A Generalised Linear Mixed Model (GLMM) was run instead of a classical analysis of variance for the measures for which we had information by item and by participant, which could take them both into account in a single analysis. GLMM was run for the

Table 3 Means and standard deviations for dependent variables by group

Measures	DYS		CA		RL	
	M	*SD*	*M*	*SD*	*M*	*SD*
Cognitive inhibition						
Naming time	45.28	8.78	34.00	6.13	45.55	8.51
Naming errors	1.61	1.65	0.72	1.13	1.50	1.38
Interference time	71.67	16.08	56.17	12.65	78.55	18.29
Interference errors	2.72	1.41	1.33	1.19	2.94	1.98
Difference naming-interference time	26.38	11.90	22.17	11.97	33.00	12.76
Difference naming-interference errors	1.11	1.64	0.61	1.42	1.44	1.46
Reading inhibition accuracy	0.82	0.02	0.90	0.02	0.92	0.02
High frequency–short distance	0.82	0.04	0.89	0.03	0.96	0.02
High frequency–long distance	0.89	0.04	0.94	0.03	0.93	0.03
Low frequency–short distance	0.67	0.05	0.83	0.04	0.79	0.05
Low frequency–long distance	0.87	0.04	0.91	0.03	0.94	0.02
Reading inhibition response time	201.05	73.01	102.12	16.80	179.40	60.22
Reading inhibition errors						
Total	0.56	0.06	0.31	0.06	0.26	0.06
More frequent word	1.17	1.25	0.28	0.57	0.39	0.50
Less frequent word	0.05	0.23	0.00	0.00	0.05	0.23
Phonological error	0.78	1.21	0.11	0.32	0.50	0.71
Semantic error	0.00	0.00	0.00	0.00	0.00	0.00
Prepotent word (expected)	0.72	1.07	0.39	0.60	0.39	0.70
Self-correction	1.17	1.54	1.33	1.41	0.50	0.71
Other errors	0.00	0.00	0.05	0.23	0.00	0.00

reading inhibition accuracy dependent variable, while analyses of variance were run for cognitive inhibition time and errors, and for reading inhibition time and errors. GLMM was chosen where possible because it allowed us to consider the variability of the items and the variability of the participants. Indeed, an analysis of variance does not take into account both the variability introduced by participants and the variability introduced by items in the same analysis, which could possibly lead to high Type 1 error rates (Baayen, Davidson, & Bates, 2008). For the one-way ANOVAs, the assumption of homogeneity of variances was checked with Levene's test. For the repeated measures ANOVAs, the assumption of sphericity was checked with Mauchly's test. We applied Greenhouse–Geisser corrections for data violating the sphericity assumption. The alpha level was set at 0.05 for all the analyses.

The correlations between cognitive inhibition, reading inhibition and control measures are provided in Table 4. The reading inhibition accuracy score was not correlated with cognitive inhibition scores but rather with all reading, phonological and vocabulary control scores. The reading inhibition response time was correlated to the same measures, but it also correlated with speed measurements of

Table 4 Correlations coefficients between measures by group

	Measures	1	2	3	4	5	6	7	8	9	10	11	12
RL Children													
1	Difference naming-interference time	–											
2	Difference naming-interference errors	− .18	–										
3	Reading inhibition accuracy	− .03	− .11	–									
4	Reading inhibition response time	.31	− .08	− .26	–								
5	Word reading accuracy	− .51*	− .01	.58*	− .57*	–							
6	Word reading response time	.25	.16	− .25	.92**	− .55*	–						
7	Reading comprehension	− .59**	− .06	.18	− .74**	.60**	− .65**	–					
8	Phonological awareness	− .58*	.36	− .06	− .35	.29	− .09	.61**	–				
9	Rapid automatized naming	− .21	.21	.00	− .39	.17	− .31	.30	.27	–			
10	Vocabulary (standardised score)	− .07	.14	.15	.35	.31	.43	− .00	.18	− .37	–		
11	Nonverbal IQ (subtest scaled score)[c]	− .41	− .14	− .07	− .16	.29	− .09	.51*	.62**	− .35	.38	–	
12	Selective visual attention accuracy	− .57*	− .01	.17	− .74**	.55*	− .68**	.94**	.49*	.27	− .09	.44	–
13	Selective visual attention response time	− .40	.07	.03	− .53*	.14	− .39	.57*	.44	.83**	− .37	− .01	.51*
CA Children													
1	Difference Naming-Interference Time	–											
2	Difference Naming-Interference Errors	.21	–										
3	Reading inhibition accuracy	− .31	− .61**	–									
4	Reading inhibition response time	.18	.12	− .54*	–								
5	Word reading accuracy	− .29	− .22	.64**	− .56*	–							
6	Word reading response time	− .01	.04	− .31	.84**	− .48*	–						
7	Reading comprehension	− .13	.19	.39	− .75**	.75**	− .65**	–					
8	Phonological awareness	.05	− .29	.62**	− .65**	.61**	− .73	.49*	–				
9	Rapid automatized naming	− .42	.21	.13	− .31	.35	− .28	.54*	.02	–			

Table 4 (continued)

	Measures	1	2	3	4	5	6	7	8	9	10	11	12
10	Vocabulary (standardised score)	− .60**	− .26	.34	.11	.38	.17	.04	− .02	.34	–		
11	Nonverbal IQ (subtest scaled score)[c]	− .13	.33	.00	− .50*	.44	− .60**	.51*	.28	.26	.03	–	
12	Selective visual attention accuracy	− .28	− .03	.10	.28	.12	.52*	.02	− .49*	.21	.42	− .3	–
13	Selective visual attention response time	.32	.10	− .18	.26	− .03	.31	.01	− .50*	.10	.10	− .09	.61**
DYS Children													
1	Difference Naming-Interference Time	–											
2	Difference Naming-Interference Errors	.19	–										
3	Reading inhibition accuracy	.06	.21	–									
4	Reading inhibition response time	.23	− .23	− .45	–								
5	Word reading accuracy	− .32	.15	.52*	− .64**	–							
6	Word reading response time	− .10	− .47	− .39	.69**	− .14	–						
7	Reading comprehension	− .05	.25	.29	− .82**	.66**	− .55*	–					
8	Phonological awareness	− .24	.29	.31	− .23	.40	− .24	.52*	–				
9	Rapid automatized naming	− .29	− .19	.31	− .62**	.73**	− .14	.65**	.25	–			
10	Vocabulary (standardised score)	− .08	.34	.41	− .37	.57*	− .18	.58*	.67**	.48*	–		
11	Nonverbal IQ (subtest scaled score)[c]	.08	.29	.32	− .44	.26	− .44	.29	.08	− .13	.03	–	
12	Selective visual attention accuracy	− .05	− .07	− .23	.16	− .28	− .05	− .11	− .04	− .28	− .44	.19	–
13	Selective visual attention response time	.03	− .03	.22	− .30	.38	.08	.29	− .10	.36	.09	.19	− .14

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

rapid automatised naming, selective visual attention response time, and difference naming-interference time score.

Cognitive inhibition

The interference cost was analysed by means of a one-way analysis of variance using group [DYS, CA, RL] as a between-participants factor for the two dependent variables: difference naming-interference time and difference naming-interference errors. For the difference naming-interference time, the ANOVA showed a significant effect of group $F(2, 53) = 3.59$, $p = .03$, $\eta^2 p = .12$. Post hoc Bonferonni showed that the RL children had a higher interference cost than the CA children ($p = .03$). The DYS children did not differ from the two control groups (DYS-CA: $p = .91$; DYS-RL: $p = .33$). For the difference naming-interference errors, the ANOVA did not show any significant effect of group, $F(2, 53) = 1.37$, $p = .26$, $\eta^2 p = .05$. The interference cost on naming errors was similar for all three groups.

Reading inhibition accuracy

Reading inhibition accuracy was submitted to a $3 \times 2 \times 2$ GLMM with Group [DYS, CA, RL] × Distance Between Neighbours [short, long] × Word frequency [high, low] entered as fixed effects. One random effect was included in the model for participants, allowing us to consider the dependence between our observations due to repeated measures. The effect of group was significant, $F(2, 1068) = 6.28$; $p = .002$. Sequential Bonferonni post hoc showed that the DYS children read the words less accurately ($M = 0.82$, $SE = 0.02$) than the children in the other two groups CA ($M = 0.90$, $SE = 0.02$, $p = .02$) and RL ($M = 0.92$, $SE = 0.02$; $p = .003$). The effect of word frequency was significant, $F(1, 1068) = 8.09$; $p = .005$. Children read high frequency words more accurately ($M = 0.92$, $SE = 0.01$) than less frequent words ($M = 0.86$, $SE = 0.02$). The effect of distance between neighbours was significant, $F(1, 1068) = 10.10$; $p = .002$. Children read words with a long distance between neighbours more accurately ($M = 0.92$, $SE = 0.01$) than words with short distance between neighbours ($M = 0.85$, $SE = 0.02$). The interaction Word frequency × Distance between neighbours effect was significant, $F(1, 1068) = 4.44$; $p = .03$. Sequential Bonferonni post hoc comparing the effect of word frequency were conducted for each distance separately. They showed that, when the distance between orthographic neighbours is long, the words of both frequencies are read equally accurately ($p = .64$ for both frequencies). On the other hand, when the distance is short, rare words ($M = 0.77$, $SE = 0.03$) are read less accurately than frequent words ($M = 0.91$, $SE = 0.02$; $p < .001$ for both frequencies). Interactions Group × Word frequency and Group × Distance between neighbours and Group × Word frequency × Distance between neighbours were not significant.

Reading inhibition response time

For reading inhibition response time, we only had the reading time information for all the sentences. We conducted a one-way ANOVA with group [DYS, CA, RL] as between participants factor. The effect of group was significant $F(2, 53) = 15.81$; $p < .001$, $\eta^2\ p = .38$. Bonferonni post hoc showed that the DYS children ($M = 201.05$, $SD = 73.01$) read more slowly than the CA children ($M = 102.12$, $SD = 16.80$; $p < .001$) and that they read at the same rate as the RL children ($M = 179.40$, $SD = 60.22$; $p = .74$), who also read more slowly than CA children ($p < .001$).

Reading inhibition errors

For reading inhibition errors, we conducted a 3 (Group [DYS, CA, RL] × 7 Type of errors [more frequent word, less frequent word, phonological error, semantic error, prepotent word, self-correction, other errors] ANOVA with repeated measures on the second factor. Since the Mauchly's test was significant, we rejected the sphericity assumption and applied the Greenhouse-Geisser corrections to the data. The effect of group was significant, $F(2, 51) = 7.51$; $p < .01$, $\eta^2\ p = .23$). Bonferonni post hoc showed that the DYS children ($M = 0.56$, $SD = 0.06$) made more reading mistakes than the CA children ($M = 0.31$, $SD = 0.06$) and RL children ($M = 0.26$, $SD = 0.06$; $p < .05$). The effect of type of errors was significant ($F(12, 306) = 2.19$; $p = .05$, $\eta^2\ p = .08$). The interaction between the type of errors and the group was also significant, $F(6, 306) = 13.75$; $p < .001$, $\eta^2\ p = 0.21$. One-way ANOVAs for each type of error with group as factor showed that the effect of group was only significant for the more frequent word errors ($F(2, 53) = 5.92$; $p = .005$). Bonferonni post hoc for more frequent word errors showed that the DYS children ($M = 1.17$, $SD = 1.25$) made more errors of this type than the CA children ($M = 0.28$, $SD = 0.57$) and the RL children ($M = 0.39$, $SD = 0.50$; $p < .05$).

For the sake of accuracy, a mixed ANOVA was conducted to check whether performance varies within the two tasks, cognitive inhibition and reading inhibition, for speed and accuracy separately, after standardizing the measures. For speed measures, we conducted a 3 Group [DYS, CA, RL] × 2 Task [cognitive inhibition, reading inhibition] ANOVA with repeated measures on the second factor. The effect of group was significant, $F(2, 51) = 10.97$; $p < .001$, $\eta^2\ p = .30$. Bonferonni post hoc showed that the DYS children answered more slowly than the CA children ($p < .001$) and that they answered at the same rate as the RL children ($p = 1.00$). The effect of task was not significant, $F(2, 51) = 0.00$; $p = 1.00$, $\eta^2\ p = .00$. The interaction between the group and the task was significant, $F(2, 51) = 4.92$; $p < .01$, $\eta^2\ p = .16$. Tests of simple main effects revealed a significant difference between the two tasks for DYS children, $F(1, 17) = 4.84$; $p = .04$, $\eta^2\ p = .22$, and not for RL children, $F(1, 17) = 0.52$; $p = .48$, $\eta^2\ p = .03$, or CA children, $F(1, 17) = 4.39$; $p = .051$, $\eta^2\ p = .20$. For DYS children, follow-up analyses showed that they read more slowly in the reading inhibition task than they answered in the cognitive inhibition task ($p = .04$).

For accuracy measures, we conducted a 3 Group [DYS, CA, RL] × 2 Task [cognitive inhibition, reading inhibition] ANOVA with repeated measures on the second factor. The effect of group was significant, $F(2, 51) = 4.91$; $p = .01$, $\eta^2 p = .16$. Bonferonni post hoc showed that the DYS children made more reading mistakes than the RL children ($p = .01$) and that they made an equivalent number of errors as the CA children ($p = .51$). The effect of task was not significant, $F(2, 51) = 0.00$; $p = 1.00$, $\eta^2 p = .00$. The interaction between the group and the task was significant, $F(2, 51) = 3.54$; $p = .04$, $\eta^2 p = .12$. Tests of simple main effects revealed a significant difference between the two tasks for DYS children, $F(1, 17) = 4.82$; $p = .04$, $\eta^2 p = .22$, and not for RL children, $F(1, 17) = 0.32$; $p = .58$, $\eta^2 p = .02$, or CA children, $F(1, 17) = 1.83$; $p = .19$, $\eta^2 p = .09$. For DYS children, follow-up analyses showed that they made more reading mistakes in the reading inhibition task than they did naming errors in the cognitive inhibition task ($p = .04$).

Discussion

As explained earlier, the aim of the study was to examine whether children with dyslexia have a domain-general inhibition deficit or whether they have a domain-specific deficit in a reading inhibition task. In the former alternative, we anticipated that they would have difficulties in the interference condition of the cognitive inhibition task but also in the reading inhibition task. In the latter alternative, we assumed that they would have difficulties in the task of reading inhibition only.

Children with dyslexia and control children were asked to perform a non-reading inhibition task and a reading specific inhibition task. In the latter, children had to read a sentence in which a word expected by the semantic context of the sentence was replaced by an orthographic neighbour. To be able to read the sentence correctly, children had to inhibit this expected word, potentially active in their mental lexicon.

The results provided clear experimental evidence in favour of the second alternative. Indeed, children with dyslexia performed equally to the two control groups for the cognitive inhibition task (in both time and errors). At the same time, the group effect was significant for the reading inhibition task (accuracy score), showing that the children with dyslexia read the words less accurately than the children from the two control groups. They also read the sentences more slowly than children of the same age. Finally, they made more reading mistakes consisting of replacing the target word by a more frequent word than the children in the two control groups. The results of the three scores of the reading inhibition task therefore clearly indicate that children with dyslexia have difficulties in handling a reading task that significantly requires inhibition skills.

Our results in favour of an inhibition domain-specific deficit in reading are inconsistent with previous studies by Brosnan et al. (2002) or Wang et al. (2012), which identified an inhibition deficit in non-verbal tasks. However, Booth et al.'s meta-analysis (2010) has already made it possible to explain the results since the inhibition deficit was more pronounced in tasks requiring a verbal response. Again, our results are inconsistent with the other studies in the meta-analysis showing that children with dyslexia are deficient in an inhibition task requiring a verbal response. Indeed, in our case, the response modality of the cognitive inhibition task is verbal, and dyslexic children performed equally compared to control children in this task. However, we took a methodological precaution that could explain these discrepancies, since we corrected the interference scores based on the naming scores. Moreover, our results would seem to indicate a difficulty specific to written language—in the reading task—and not involving oral language. It is also worth noting that some of these studies lack clear selection criteria for dyslexia (Booth et al., 2010). It might be interesting to address this question by assessing the impact of the modality by proposing inhibition tasks that are as similar as possible while modifying the modality.

Inhibition difficulties amongst children with dyslexia may explain the occurrence of global errors or guessing errors in an isolated word context or in a text reading context. Indeed, children with dyslexia would be less able or would not be able to inhibit an orthographic neighbour more frequent than the target word to be read. This supports the hypothesis of lexical competition between the orthographic representations assumed by McClelland and Rumelhart's connectionist model (1981). This hypothesis is partly supported by the fact that dyslexic children read less accurately, but also supported by the type of reading mistakes they make. Indeed, it is worth noting that children with dyslexia, when they have made reading mistakes, have more often than control children, replaced the word to be read with a more frequent word, different from the orthographic neighbour word expected. This interesting observation seems to shed light on the fact that they have more difficulty in inhibiting words that are more frequent in their lexicon. Future studies should provide a better understanding of these frequency effects on inhibition processes.

The comparison with the two groups of typically developing children is also informative. Given that the children with dyslexia made more errors than younger children of the same reading level, it can be assumed that these reading inhibition difficulties are a deviant profile and do not fall within a developmental delay profile. These difficulties can therefore be described as a specific disorder. The fact that the difficulties are specific tells us that it is probably useful to work specifically on these difficulties with children with dyslexia rather than waiting for them to disappear in the developmental decade.

With regard to word frequency and the distance between orthographic neighbours in the reading inhibition task, the results showed on the one hand that all children read frequent words more accurately than less frequent words. This observation is in line with McClelland and Rumelhart's lexical competition hypothesis (1981). Indeed, high-frequency words have a higher basic activation level, which would make it more complex to inhibit them when reading a less frequent word in the task. On the other hand, the results showed that all the children read words less accurately when the distance between the orthographic neighbours was shorter (one sentence) than when the distance was longer (three sentences). This pattern of results is consistent with Vandierendonck's (2013) study, according to which residual inhibition is greater when the distance between orthographic neighbours is short. The orthographic neighbour has just been activated in the lexicon beforehand, which makes its inhibition more complex or slower. Finally, our results indicate that word frequency and distance between orthographic neighbours interact because it is when distance is short that less frequent words are less well read than frequent words.

Our study in favour of a domain-specific inhibition deficit in reading is, to our knowledge, the first to investigate inhibition skills in a reading task amongst children with dyslexia. Previous studies assessed inhibition skills in tasks that did not involve reading (Brosnan et al., 2002; Varvara et al., 2014). It is worth noting that in several studies, the classic Stroop task was used (Protopapas, Archonti, & Skaloumbakas, 2007). However, in this classic task, the process of inhibition is different because the task requires precisely the ability to not read the word (but to say the ink colour of the written word instead of reading it). Being able to demonstrate an inhibition deficit within the reading task allows us to better relate this explanatory hypothesis to reading difficulty than if we evaluate inhibition in a purely cognitive task. With this in mind, it seems to us that the ecological validity of the study is greater because it allows a better understanding of the reading processes themselves in dyslexic children (see Van Reybroeck, Schelstraete, Hupet, & Szmalec, 2014 for the same approach in spelling and switching).

Limitations

This study has several limitations that should guide future research. First, our group of dyslexic children was small, which could limit the extent to which the results can be generalised. It may be interesting to replicate this first experiment attempt with a higher number of dyslexic participants. Second, among the 18 dyslexic children, four were children who had not had a clear diagnosis of dyslexia by a professional. However, we kept these children because they had at least a score of—4 standard deviations, which was significantly more severe than the diagnostic criteria and therefore gave some assurance about the severity of their disorder. In Belgium, some children are not diagnosed through their parents' choice. However, it would have been preferable to have had a diagnosis for the whole group. Third, with regard to time measurement in the inhibition reading task, we only had the total time measurement for all sentences. It would be interesting to have the reading time of each sentence and each target word, in order to better understand the inhibition mechanisms involved, at the precise moment when the inhibition process must take place. Fourth, as explained above, our study was based on the comparison of the Stroop fruit and the sentence reading inhibition task. Between the two tasks, other processes may be involved in addition to inhibition. Therefore, it may be relevant to test children with the most similar tasks possible by modifying the modalities. In the same vein, it might be interesting to compare children's performance to the sentence reading task and the traditional Word-Colour Stroop task. Indeed, in both tasks, the source of the prepotent response is different. In the Word-Colour Stroop task, the word to be inhibited is activated by the automatic decoding, whereas in the sentence reading task, the word to be inhibited is activated by the semantic context of the sentence. This experience should probably be conducted with older children to ensure that their reading is automatized.

Educational implications

This study opens up new perspectives on the understanding of guessing reading errors often made by children with dyslexia. More research should be conducted to have concrete educational implications. However, the present study, by precisely assessing the mechanisms of inhibition during reading, allows us to consider new potential avenues for treatment. Considering that the guessing errors reflect a difficulty in inhibiting the logographic strategy of reading, it could be interesting to offer them an intervention that would allow them to increase their ability to inhibit and lead them to use the alphabetic strategy (see McCandliss, Beck, Sandak, & Perfetti, 2003 intervention; Van Reybroeck, Cumbo, & Gosse, in press). Finally, the current study, by providing strong experimental evidence in favour of a reading inhibition deficit, affirms the importance of better understanding this deficit and being able to find effective ways to help dyslexic children, specifically at the inhibition level.

Conclusion

In conclusion, the present study shows that children with dyslexia do have a domain-specific inhibition deficit in reading, while they do not have a marked deficit of inhibition in a purely cognitive task. While previous studies focused on inhibition in cognitive tasks, this study emphasised the reading mechanisms themselves. In doing so, the study provides explanations for the reading guessing errors often made by children with dyslexia. The study also highlights the presence of inhibition processes within the task of reading. Finally, it opens up new avenues for the understanding of reading mechanisms in dyslexic children, which in turn should allow new perspectives for their treatment.

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