



The involvement of inhibition in word and sentence reading

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Abstract

Individual differences in reading performance between children appear from the onset of literacy acquisition. One possible explanation for this variability is the influence of inhibition in reading ability, a topic that has received very little research attention. Nevertheless, children often make guessing errors characterized by replacing a word with an orthographic neighbor, possibly linked to failing inhibition. The present study aims to evaluate the role of inhibition during word and sentence reading and compare its effects in spoken and motor tasks. Participants comprised 25 children in Grades 2 and 3 ($M_{age}=8; 2$). The children performed five inhibition tasks in reading (words, sentences), spoken (words, sentences) and motor modalities. Within the two reading tasks, inhibition demands were assessed using pairs of orthographic neighbors for which the frequency was manipulated. Accuracy, types of errors, latency, and response times were measured. GLMM analyses demonstrated that children were sensitive to the inhibitory demands of both spoken tasks and of the sentence reading task regarding accuracy, latency, and response times. Indeed, children made more mistakes and were slower when inhibitory demands were augmented. They also made more guessing errors in the word reading task. No such inhibitory effect was found in the motor task. Moreover, correlational analyses revealed that children who showed better inhibitory skills were able to read words and texts more accurately. These findings suggest that children need to utilize inhibitory resources when processing words or sentences and that these inhibitory skills are involved in overall reading ability.

Keywords Inhibition · Word reading · Sentence reading · Executive functions · Reading assessment

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Introduction

Reading plays a fundamental role in one's academic, personal and social development. While reading is one of the foundations of academic achievement, individual differences are present in children from the beginning of the learning process. One important candidate process that may explain the individual variability in (a)typical reading performance and which has, to the best of our knowledge, only been reported in one recent study (Van Reybroeck & De Rom, 2020) is inhibition. Indeed, inhibition could explain the guessing errors that are among the most frequently committed reading errors by children with or without learning difficulties. Guessing errors are characterized by the replacement of a word by an orthographically close word, often an orthographic neighbor (e.g., *joie* [joy] is read *jolie* [pretty]). A plausible explanation for the guessing errors is that children fail to inhibit lexical orthographic neighbors, according to the lexical competition hypothesis (McClelland & Rumelhart, 1981).

To date, in the literature, most of the studies have focused on the link between inhibition and reading comprehension through correlational studies (Butterfuss & Kendeou, 2018; Johann et al., 2020), without addressing the question of inhibition processes within a reading task. Therefore, the present study aims to shed light on the role of inhibition in reading in school-aged children by assessing its effect during word and sentence reading and by comparing its effect in spoken and motor tasks.

Inhibition

Inhibition is part of the group of executive functions (EFs) that are defined as the underlying processes involved in cognitive functioning. EFs allow us to concentrate and pay attention and, more generally, regulate our behaviors (Booth et al., 2010; Varvara et al., 2014). While Miyake et al. (2000) initially put forward shifting, updating, and inhibition, Diamond (2013) more recently identified working memory, cognitive flexibility, and also inhibition as the three core EFs. Inhibition entails being able to control one's attention, behavior, thoughts, and/or emotions to act appropriately in a given situation (Diamond, 2013). While authors agree on the definition of inhibition, the question of whether it is a unitary process that serves multiple functions or a collection of separate processes remains open (Noël & Docquier, 2011). According to Altemeier et al. (2008), inhibition can occur at the behavioral level and/or at the cognitive level and it delays a prepotent automatic response to achieve a goal. However, as emphasized by the same authors, the boundaries between these two levels are blurred, as cognitive disinhibition (i.e., representational disinhibition) often leads to behavioral disinhibition. Friedman and Miyake (2004) and Diamond (2013) categorized three similar inhibition-related functions, although the functions were named differently. According to Friedman and Miyake (2004), the first function, called *prepotent response inhibition*, involves the blocking of dominant and prepotent cognitive responses that are automatically activated by stimuli (e.g., self-control, resisting temptations, and resisting acting impulsively). According to Diamond (2013), this function also includes behavioral responses in

addition to cognitive responses. The second function concerns the *resistance to distractor interference*, which involves focusing attention on relevant information by ignoring irrelevant items. This inhibitory control of attention can be either voluntary (e.g., we can choose to ignore particular stimuli to focus on others) or involuntary (e.g., when we talk to someone at a party, we ignore the noise around us; Diamond, 2013). The third function, *resistance to proactive interference*, concerns resisting memory intrusions by limiting the activation of thoughts that are no longer relevant (e.g., resisting extraneous thoughts to help our mental workspace from becoming too cluttered).

The most frequent inhibition tasks used in the literature (i.e., go-no-go, flanker, stop signal, antisaccade, and Stroop tasks) assess the prepotent response inhibition component (Luna, 2009). These tasks use different response modalities. Indeed, Censabella (2007) makes the distinction between motor inhibition tasks, where a motor response is asked (e.g., go-no-go), and verbal inhibition tasks, where a verbal response is needed (e.g., Stroop task). Altemeier et al. (2008) found that the development of inhibition increases steadily from Grade 1 to 6. Research has shown that young children are already able to generate some correct inhibitory responses (Luna, 2009). However, in order to do that, they have to engage many cognitive resources. Afterwards, their performance increases and becomes more consistent with age (Luna, 2009). This ability continues to improve during childhood and adolescence (Davidson et al., 2006). These results suggest that the neural components that support the ability to inhibit are available early in development but become more consistent in adulthood (Luna, 2009).

Inhibition in reading

Since reading is not automatic, at least during the early phases of its acquisition, children need their EFs to be concentrated, to pay attention, and to self-regulate their behavior when they read. Inhibition, amongst other EFs, could therefore be involved in the reading process (Christopher et al., 2012), more precisely to avoid guessing errors (i.e., replacing a word by an orthographic neighbor). However, the available evidence is not conclusive. Firstly, studies provide evidence of a correlation between reading and inhibition without directly demonstrating the involvement of inhibition processes within a reading task. Secondly, there are some indications of a possible involvement of inhibition in reading at the levels of word processing and sentence processing but without strong experimental evidence.

Among studies investigating the relation between EFs and reading, results are very diverse, probably because the authors focused on various EFs (e.g., inhibition, working memory, attention shifting) and different reading subskills (e.g., reading comprehension, letter recognition). Nevertheless, most of the studies investigating the relationship between inhibition and reading in school-aged children focused on reading comprehension and rarely on orthographic decoding skills (Cirino et al., 2019; Raudszus et al., 2018). For instance, Borella and de Ribaupierre (2014) found that inhibition, working memory, and processing speed predict reading comprehension in 10- to 12-year-old children. They used the Color Stroop and Hayling tasks

to assess inhibition and found that resistance to distractor interference (i.e., the ability to inhibit distractors) was specifically involved in reading comprehension. Kieffer and Christodoulou (2020) also demonstrated a relation between EFs and reading comprehension (inhibition, working memory, and attention shifting) in the same age population. However, they used motor-response inhibition tasks, such as the Simon task and the Flanker task (assessing the prepotent response inhibition). Meixner et al. (2019) even found reciprocal relations between EFs (inhibition, updating, and attention shifting) and reading comprehension in Grades 2 and 3 (using the Fruit Stroop Task, assessing prepotent response inhibition). In addition to reading comprehension, other studies have shown the impact of inhibition on letter recognition (discrimination between mirror letters such as *d* and *b*; Ahr et al., 2016) or the effect of inhibition in written text composition (Altemeier et al., 2006). On the whole, the tasks vary greatly between studies in terms of modality (e.g., Stroop and Hayling task in Borella & de Ribaupierre, 2014; Simon and Flanker task in Kieffer & Christodoulou, 2020) but also regarding the type of inhibition function being measured (Butterfuss & Kendeou, 2018).

Furthermore, the relation between inhibition and word-level reading (i.e., decoding) has received very little attention from the scientific community. Both Altemeier et al. (2008) and Messer et al. (2016) have suggested that verbal inhibition is a significant contributor to decoding (word reading), possibly because inhibition processes ensure complete word processing rather than hasty guessing based on incomplete information. However, no study has evaluated this relation directly. In addition, most of the studies were correlational and investigated participants' performance in inhibition tasks and reading tasks independently, while the occurrence of inhibitory demands during the reading process itself has been overlooked. Nevertheless, direct manipulation of orthographic suppression requirements within a reading task would allow understanding more precisely how inhibition governs the reading process. To the best of our knowledge, only one study has evaluated inhibition within a sentence reading task in 8- to 10-year-old French-speaking children with dyslexia compared to typically developing children (Van Reybroeck & De Rom, 2020). The authors used a sentence reading task in which semantically constrained words were replaced by orthographic neighbors. This task implies inhibition processes to suppress the semantically biased words to access the target word correctly (e.g., *A la mer, je m'amuse comme un fou dans les bagues*, instead of *vagues*; [At sea, I have a lot of fun in the *rings*, instead of *waves*]). Children's inhibition performance was compared between two modalities: reading inhibition and cognitive inhibition (Stroop task based on fruit colors). This experiment highlighted the importance of comparing different inhibition modalities. The results allowed to demonstrate that children with dyslexia have a domain-specific inhibition deficit in reading, while they do not show a marked deficit of inhibition in a cognitive task. However, this study did not evaluate the extent to which inhibition is also involved when younger typically developing children learn to read.

Indicators of a possible involvement of inhibition in reading at the level of word processing, or *lexical inhibition*, are as follows. When reading words, the reader has to activate or access the lexical orthographic representation of that word. Therefore, he/she has to select the correct orthographic representation from a set of

possible candidates (Davis & Lupker, 2006). According to Perea (2015) and based on McClelland and Rumelhart (1981)'s interactive activation model, when we recognize a word, several orthographic neighbors and similar lexical units are also activated. Orthographic neighbors are words that differ with only one letter from each other (e.g., porte [door]—poste [post office]), whereas similar lexical units differ with two or three letters. During word processing, these lexical candidates are gradually deactivated until only one lexical unit remains. For orthographic neighbors, the competition between words is very strong, particularly for highly frequent orthographic neighbors, making inhibition crucial for suppressing other words that have received almost the same amount of activation (Davis & Lupker, 2006). More precisely, it is assumed, based on McClelland and Rumelhart (1981)'s lexical competition hypothesis, that high-frequency words have a higher basic activation level than low-frequency words. Therefore, words that have higher-frequency competitors would be more difficult to identify than words with lower-frequency orthographic competitors. Consistent with this effect, Perea (2015) reported that within a visual lexical decision task, words with higher frequency neighbors required longer word identification times than words with no higher frequency neighbors. Moreover, this finding is not limited to word identification tasks, as it has also been replicated and generalized to sentence reading. Indeed, fixation times on words with higher frequency neighbors were demonstrated to be longer than those for control words with low-frequency neighbors (Johnson, 2009; Slattery, 2009). This hypothesis of lexical competition is one possible explanation for guessing errors, frequently observed in individuals learning to read, that are expected to occur when children have developed their lexicon.

Another possible explanation for the guessing errors and also an indicator of a possible involvement of inhibition in reading at the level of sentence processing arises from the influence of *contextual facilitation* in reading. Context is known to play an important role in reading. Indeed, context has been shown to facilitate the preactivation of upcoming words. Predictable words are read more quickly than unpredictable words (Johnson et al., 2018; Luke & Christianson, 2016; Tiffin-Richards & Schroeder, 2020). In this sense, sentence context seems to facilitate reading performance. This process of contextual facilitation was demonstrated to decrease with age, as word recognition becomes more automatic (Schustack et al., 1987; West & Stanovich, 1978). Knowing that, it is possible that guessing errors arise because young children tend to overuse context to the detriment of reading accuracy. This could be linked to the fact that children too quickly rely on context and fail to inhibit its influence. Therefore, there is a need to more precisely specify the role played by inhibition during reading at both word and sentence levels.

The present study

In summary, previous studies investigating inhibition in reading have mainly focused on the impact of inhibition on reading comprehension (Borella & de Ribaupierre, 2014; Kieffer & Christodoulou, 2020), while inhibition during decoding has received very little attention (Van Reybroeck & De Rom, 2020). In the meantime,

frequent errors made by children during decoding, guessing errors, could possibly be explained by two different hypotheses implying an inhibition process: lexical inhibition or contextual facilitation. To the best of our knowledge, no study has tried to demonstrate with solid experimental arguments whether inhibition is involved in word and sentence reading tasks.

Therefore, the present study aimed to better understand the role of inhibition during word reading (lexical inhibition) and sentence reading (contextual facilitation) in school-aged children and to compare the effect of inhibition in spoken and motor tasks. We wanted to investigate whether the inhibitory mechanisms possibly involved in reading tasks are specific to reading or whether they reflect the functioning of a broader, domain-general mechanism that subserves the suppression of either unwanted information or responses in the entire cognitive system. Participants were typically developing children from Grades 2 and 3. Children performed five inhibition tasks, all relying on the same inhibition function, prepotent response inhibition, but varying in terms of modality to shed new light on the impact of inhibition in reading compared to spoken and motor modalities. The three evaluated inhibition modalities were (i) *reading inhibition* at the word and sentence levels (operationalized by an experimental word reading task and an experimental sentence reading task), (ii) *spoken inhibition* at the word and sentence levels (operationalized by an experimental oral word production task and an experimental oral sentence production task), and (iii) *motor inhibition* Simon Task (Simon & Rudell, 1967). Within the two reading tasks, inhibition demands were assessed by using pairs of orthographic neighbors and compared to filler items. In the experimental word reading task, children had to read isolated words followed by their orthographic neighbors; neighbors varied in terms of lexical frequency (high vs. low). In the experimental sentence reading task, children had to read sentences in which, based on the context, expected words were replaced by orthographic neighbors, also varying in terms of frequency (low vs. high). This task was based on earlier work (Van Reybroeck & De Rom, 2020) but it has been further elaborated for the purpose of the current study. Indeed, some items were modified and filler sentences were added to the task. Moreover, Van Reybroeck & De Rom (2020) did not compare the sentence reading task with a word reading task and other response modalities (i.e., spoken and motor inhibition). The experimental oral word production task was based on a rapid automatized naming task (RAN) in which pictures were phonological neighbors that varied in terms of frequency (low vs. high). In the oral sentence production task, children had to complete sentences with expected and unexpected words based on the semantic context. Types of errors in the reading and the spoken tasks were also analyzed. This allowed investigating whether errors were linked to inhibition or not, more precisely to investigate guessing errors in the reading tasks. The motor task was based on the Simon Task (Simon & Rudell, 1967). In each task, measures of accuracy, latency, and response times were taken. In line with the aims of the study, we addressed the following research questions:

(1) Is inhibition involved in an experimental word reading task?

According to McClelland and Rumelhart (1981)'s model, we expected an inhibitory effect on the orthographic neighbor presented in the second position in the pair of words. Indeed, when reading a neighbor of a word that has been presented earlier in the task, children have to recall a word that was strongly inhibited before due to the competition between orthographically similar words. Therefore, we predict that children will make more reading errors or will be slower to read orthographic neighbors than filler words. More precisely, we expect children to make more guessing errors on orthographic neighbors (i.e., linked to inhibition). Additionally, we anticipate that children will make more reading errors or will be slower for low-frequency than for high-frequency words. If inhibition is not involved in word reading, we should not observe any differences between orthographic neighbors and fillers in accuracy and type of errors, latency, and response time.

(2) Is inhibition involved in an experimental sentence reading task?

Based on contextual facilitation and lexical inhibition (McClelland & Rumelhart, 1981), we expected children to make more reading errors and to be slower when reading the inhibition sentences than when reading the control sentences. More precisely, we expect children to make more guessing errors (i.e., errors linked to inhibition) in the inhibition condition compared to the control condition. Moreover, we expected the children to make more mistakes and to be slower when reading low-frequency words than when reading high-frequency words. If inhibition is not involved in sentence reading, we should not observe any differences between inhibition sentences and control sentences for any of the dependent variables, including type of errors.

(3) Are the inhibition mechanisms involved in a reading task specific to reading (domain-specific) or do they reflect the functioning of a broader mechanism, also observed in spoken and motor tasks (domain-general)?

If the inhibition mechanisms involved in a reading task are specific to reading (domain-specific), we should observe an impact of inhibition in the experimental reading tasks only. If the inhibition mechanisms are domain-general, we should observe an inhibitory effect in all three inhibition modalities: the reading (experimental word reading and experimental sentence reading tasks), spoken (experimental oral word production and experimental oral sentence production tasks), and motor modality (Simon task). More precisely, we should observe less accurate and slower responses in the inhibition conditions among the tasks as well as more error types linked to inhibition.

(4) To what extent is inhibition performance related to reading performance, as measured by classical reading achievement tests?

If the inhibition performance is related to reading performance, we should observe a correlation between the inhibitory effect found in the experimental tasks and the scores of the classical reading achievement tests (word and text reading scores). If inhibition performance is not associated with reading performance, we should not observe any correlation between the inhibitory effect noted in the experimental tasks and the classical reading achievement tests.

The aimed scientific contribution of the present study is threefold. Firstly, the study will allow investigating whether inhibition is involved in word reading, in which case it would bring evidence for the recruitment of lexical inhibition resources in the reading process. Secondly, it will allow to empirically verify whether inhibition is involved in sentence reading, in which case it would provide a better understanding of the underlying processes of contextual facilitation. Moreover, this experiment is, to the best of our knowledge, the first one to assess inhibition through different modalities and within word and sentence reading tasks in typically-developing children. The used method could therefore constitute a new approach to the study of inhibition in reading contexts and provide researchers with new and precise experimental paradigms to do so.

Method

Participants

Twenty-five French-speaking children took part in this experiment. They were all from one rural French-speaking school in Belgium and had an average socioeconomic status. The headmaster and teachers voluntarily took part in this experiment, the children's parents gave active written consent, and the children gave verbal consent. The Ethical Committee of the experimenter's institution approved the experiment (anonymous). Data were collected in March 2020. Among the participants, 16 were in Grade 2, and 9 were in Grade 3 ($M_{\text{age}}=97.84$ months, age range=89–110 months; 16 girls, 9 boys). All participants performed normally on nonverbal reasoning, receptive vocabulary, verbal short-term memory, selective attention, and RAN tasks. Table 1 provides the characteristics of the participants.

Measures

Control measures were used to describe the sample, while inhibition measures allowed us to answer our research questions.

Table 1 Characteristics of the participants: descriptive statistics

Measures		Participants	
		<i>M</i>	<i>SD</i>
Age in months		97.84	6.45
Word reading accuracy	Raw score	88.64	14.43
	Standardized score	−0.04	0.56
Word reading response time	Raw score	272.16	124.18
	Standardized score	0.10	0.70
Text reading (BALE) accuracy	Raw score	84.11	48.07
	Standardized score	0.25	1.55
Text reading (Alouette) reading time	Raw score	178.60	5.31
	Standardized score	−0.18	0.47
Text reading (Alouette) accuracy	Raw score	148.00	62.19
	Standardized score	0.19	0.80
Reading comprehension	Raw score	9.44	3.62
	Percentile	69.48	27.47
Vocabulary	Standardized score	0.90	0.70
RAN non-repeated matrices	Composite score	0.77	0.29
RAN repeated matrices	Composite score	1.17	0.28
Verbal short term memory	Subtest scaled score	11.68	2.46
Nonverbal IQ	Subtest scaled score	10.88	2.76
Selective visual attention accuracy	Percentile	73.80	31.32
Selective visual attention response time	Percentile	66.60	26.64

RAN Rapid Automatized Naming, *Composite score* correct answers/response time

Control measures

Word reading Word reading skill was assessed by the standardized subtest from the BALE (Batterie Analytique du Langage Ecrit [Analytical Battery of Written Language]; Jacquier-Roux et al., 2010). Children were asked to read isolated words aloud as quickly and as accurately as possible. The words were of three different types: regular, irregular, and pseudowords. Each type of word was evaluated using two lists composed of 20 high-frequency words and 20 low-frequency words. Concerning the pseudowords, the experimenter explained to the children that the words did not exist and that they did not have to try to understand them. Speech and accuracy were measured for each list by measuring reading time in seconds and by attributing one point for each item correctly read. Children's scores consisted of the number of items correctly read and the reading time for each column. Scores were then converted to scaled scores. The internal reliability (Cronbach's α) in a large sample of second graders from a previous study was .90 (Vander Stappen & Van Reybroeck, 2018).

Text reading Text reading skills were evaluated by two different tests. First, the standardized subtest "Monsieur Petit" from the BALE [Analytical Battery of Written

Language] (Jacquier-Roux et al., 2010) was administered. Children were asked to read text as accurately and as quickly as possible within a time limit of 1 min. Their score consisted of the number of words correctly read in 1 min. The score was converted to a scaled score. The second text reading test was the standardized “Alouette” test (Lefavrais, 2005). Children were asked to read text aloud the best they could within a time limit of 3 min. The text used in this test is peculiar because some sentences are meaningless, and the text is incoherent. The children’s scores consisted of the reading time and the number of words correctly read. Their scores were compared to the test’s norms.

Reading comprehension Reading comprehension skills were assessed by the standardized subtest from the BMT (Batterie Modulaire de Tests [Modular Test Battery]; Billard et al., 2019). Children were asked to read a text aloud knowing they would have to answer questions without having the text in front of them. After reading, they were asked six (Grade 2) or ten questions (Grade 3) about the text. Questions were rated 0, 1, or 2 based on their answers. The maximum accuracy score was 12 for 2nd graders and 20 for 3rd graders. Scores were converted to scaled scores.

Vocabulary The level of receptive vocabulary was measured by the standardized EVIP test (Echelle de Vocabulaire en Images Peabody [Peabody Picture Vocabulary Test]; Dunn et al., 1992). Children were asked to choose one image out of four until they made six mistakes among eight consecutive answers (considered the ceiling level). The maximum number of answers was 170. Depending on the age of the child, the test started at a lower or higher item. If they made a mistake within the first eight answers, the experimenter had to use items from a lower level until the children provided eight consecutive correct answers (considered the bottom level). The scores consisted of the number of images correctly designated while taking the words below the bottom level into account. The reported internal consistency coefficient of this test is .81 (Cronbach’s α).

Rapid automatized naming (RAN) RAN skills were assessed by using a subtest of the BEPHO (Batterie d’Evaluation des compétences Phonologiques [Battery for the Assessment of Phonological Skills]; Van Reybroeck, 2003). Four matrices of objects were presented to the participants. All the items were highly familiar French words with an age of acquisition lower than 60 months (Chalard et al., 2003). They were represented by colored pictures arranged in four rows of six. Two matrices were composed of three items that were repeated eight times, and two other matrices were composed of 24 nonrepeated items. For each type of matrix, one of the two matrices was made up of short words (one-syllable words), and the other was made up of long words (two- and three-syllable words). The test was preceded by the presentation of two training matrices. The participants were asked to name all the items as quickly as possible. For each matrix, the number of errors and the naming time were recorded. Two composite scores were computed by dividing the number of items correctly named by the total naming time (one global score for repeated items and one global score for nonrepeated items). A high score, therefore, indicated good performance.

The internal reliability score in a larger sample, from a previous study, was .83 (Cronbach's α).

Verbal short-term memory Verbal short-term memory was assessed by a digit span memory task from the fifth edition of the WISC [Wechsler Intelligence Scale for Children] (Wechsler et al., 2015). Children were asked to repeat a sequence of numbers that the experimenter presented orally. The task was composed of three sections: forward repetition, reverse repetition, and ascending repetition. The further the children progressed, the longer the sequence became. The children's scores consisted of the total number of correctly repeated sequences (including the three sections). The maximum accuracy score was 54. This score was converted to a scaled score.

Nonverbal IQ Nonverbal reasoning was assessed by the French version of the Matrix Reasoning subtest from the fifth edition of the WISC (Wechsler et al., 2015). A series of 35 incomplete figure matrices containing abstract patterns and designs were presented to the participants. Participants were required to complete the matrices by choosing one of the five response options. The total number of correct responses (maximum 35) was converted to a subtest scaled score.

Selective visual attention Visual attention was assessed to exclude visual attention difficulties. The subtest "Search in the sky" from the TEA-ch (Test d'Evaluation de l'Attention chez l'Enfant [Test of Assessment of Attention in children]; Manly et al., 2006) was administered to the children. The children had to find and circle pairs of identical spacecrafts on a sheet of paper with 88 pairs of spacecrafts. Speed and accuracy were scored by measuring response time in seconds and by attributing one point for each correctly identified pair. The scores were converted to scaled scores.

Inhibition measures

Inhibition was measured through three modalities: the reading modality (two tasks: word reading and sentence reading), spoken modality (two tasks: word production and sentence production), and motor modality (one task: Simon Task). The tasks were selected or created to be as similar as possible between modalities.

Word reading To assess the implication of inhibition in word reading, an isolated-word reading task was created. The participants were asked to read 50 isolated words on a computer screen. Of these words, 20 were orthographic neighbors (10 pairs of words), and 30 were fillers (not orthographic neighbors). The word frequency was manipulated in the task with the Manulex Standard Frequency Index for Grade 2 children (Lété et al., 2004). Within the pairs of orthographic neighbors, one word was of high frequency (frequency above 60, which corresponds to a score above P75), and one was of low frequency (frequency between 45 and 59, which corresponds to a score between the 50th and 75th percentiles). The pairs of neighbors were presented both ways: first, the high-frequency word was presented and then the low-frequency word was presented for one half and the opposite order was used for the other half.

Within the fillers, one half of the words were of high frequency, and the other half of the words were of low frequency. To prevent a facilitating effect related to the similarity between items, the pairs of neighbors also varied by the position of the changing letter, either at the beginning of the word (e.g., *venir-tenir*; [come—hold]) or in the middle of the word (e.g., *couler-couper*; [sink—cut]). “Appendix 1” presents the list of inhibition words and their frequency. The children were asked to read the words as accurately and as quickly as possible. Two sample items were presented to ensure a clear understanding of the instructions and the process of the exercise. Task performance was recorded. The scores were accuracy, response time, and latency. We also examined the type of errors made by the children to investigate potential inhibitory difficulties between orthographic neighbors and more precisely, to observe whether guessing errors were made by children or not. The answers were classified as follows, based on the “Alouette” reading test (Lefavrais, 2005) but modified according to the context of our task: (a) correct answer; (b) inhibition error which consisted of replacing the target with its orthographic neighbor (e.g., *couper* [cut] was read *couler* [sink]); (c) guessing error which consisted of reading another orthographically close word instead of the target word (e.g., *plage* [beach] was read *planche* [plank]); (d) segmentation error which consisted of adding, omitting or reversing a phoneme (e.g., *abri* [shelter] was read *abir*); (e) confusion error which consisted of an auditory (e.g., *b/p* or *v/f* confusion) or visual confusion (e.g., *b/d* or *m/n* confusion); and (f) autocorrection which consisted of correcting one’s error with the target word. The internal reliability score of this test was .47 (Cronbach’s α).

Sentence reading A sentence reading task was created. The participants were asked to read 50 sentences on a computer screen to complete task. The task was divided into two sessions of 25 sentences. Out of the 50 sentences, 20 were inhibition sentences (with orthographic neighbors), and 30 were filler sentences (without orthographic neighbors). In each inhibition sentence, an expected word based on the context was replaced by an orthographic neighbor (e.g., *pour rentrer dans la maison, je dois ouvrir la poste* (instead of *porte*); [to get into the house, I have to open the *post office*]). The participants thus had to inhibit the automatic, prepotent response to read the correct word. The word frequency was manipulated with the Manulex Standard Frequency Index (Lété et al., 2004). Each orthographic neighbor pair was composed of one low-frequency word and one high-frequency word. The pairs of neighbors were presented both ways: first, the high-frequency word was presented and then the low-frequency word was presented for one half of the pairs and the opposite order of presentation was used for the other half. Regarding the fillers, half of them were of low frequency, and the other half were of high frequency. The pairs of neighbors also varied by the position of the changed letter; the changed letter either at the beginning of the word (e.g., *moucher-coucher*; [to blow your nose—to lie down]) or in the middle of the word (e.g., *livre-liter*; [book—liter]). “Appendix 2” presents the list of sentences and the characteristics of the target words. The children were asked to read the sentences as quickly and as accurately as possible, even if the sentence had a strange meaning. Task performance was recorded. Accuracy, response time, and latency were scored. We also examined the type of errors made by the children to investigate potential inhibitory difficulties between orthographic neighbors and more precisely,

to observe whether guessing errors were made by children or not. The answers were classified as follows, based on the “Alouette” reading test and modified according to the context of the task (Lefavrais, 2005): (a) correct answer; (b) inhibition error which consisted of replacing the target with its expected orthographic neighbor (e.g., *liter* [liter] was read *livre* [book]); (c) guessing error which consisted of reading another orthographically close word instead of the target word (e.g., *caisse* [box] was read *cuisine* [kitchen]); (d) segmentation error which consisted of adding, omitting or reversing a phoneme; (e) confusion error which consisted of an auditory confusion (e.g., *b/p* or *v/f* confusion) or a visual confusion (e.g., *b/d* or *m/n* confusions); (f) context error when the context of the sentence was so poorly read that it could not activate the target word (e.g., in the sentence *mes mains sont sales, je vais devoir les laver* [my hands are dirty, I have to wash them], both hands and dirty were misread); (g) autocorrection which consisted of correcting the orthographic neighbor with the target word (e.g., the target was *poste*, first read *porte* [door] and then corrected with *poste* [post office]); (h) autocorrection neighbor which consisted of correcting the target word with the orthographic neighbor (e.g., the target was *poste*, first read *poste* but then corrected with the expected neighbor *porte*); and (i) other autocorrection which consisted of correcting another error (apart from orthographic neighbor errors) with the target word. The internal reliability of this test was .65 (Cronbach’s α).

Oral word production Oral word inhibition was assessed by a RAN task that we created. One matrix of 50 objects was presented to the participants. They were represented by colored pictures arranged in five rows of ten. The participants were asked to name the items as accurately and as quickly as possible. Out of the 50 words, 20 were pairs of orthographic neighbors, and 30 were fillers (no orthographic neighbors). The word frequency was manipulated in the task with the Manulex Standard Frequency Index for Grade 2 children (Lété et al., 2004). Within the word pairs, one neighbor was of low frequency (frequency between 45 and 59, which corresponds to a score between the 50th and 75th percentile), and one neighbor was of high frequency (frequency above 60, which corresponds to a score above P75). The pairs of neighbors were presented both ways: first, the high-frequency word was presented and then the low-frequency word was presented for one half and the words were presented in the opposite order for the other half. Within the fillers, one half of the words were of low frequency, and the other half were of high frequency. The images were selected via the “langageoral.com” (<https://www.langageoral.com/>) tool and were pretested with six typically-developing children to ensure that children recognize the images. However, a precaution was taken regarding the analysis of the task. Four pairs of phonological neighbors had to be removed from the analysis. Indeed, some pictures were poorly illustrated, and/or the target words were not familiar enough to the children, despite the frequency control and the pretest. Out of the 1000 items, 800 were selected and 200 were removed due to the high proportion of errors (under 16/25, i.e., 64% success rate). The participants’ responses were recorded. The scores were the number of errors, the naming time, and the latency before naming. A composite score was computed by dividing the number of items named correctly by the total naming time. A high score, therefore, indicated good performance. We also examined the type of errors made by the children to investigate possible inhibition difficulties originating

from phonological neighbors. The answers were classified as follows, based on the RAN task from BEPHO (Van Reybroeck, 2003): (a) correct answer, (b) nonresponse which consisted of giving no answer, (c) inhibition error which consisted of replacing the target with its orthographic neighbor (e.g., *corde* [rope] instead of *corne* [horn]), (d) visual error which consisted of replacing the target with a visually close picture (e.g., *boule* [ball] instead of *bouton* [button]), (e) semantic error which consisted of replacing the target with a word of the same semantic category (e.g., *verre* [glass] instead of *bouteille* [bottle]), (f) visuo-semantic error which consisted of replacing the target with a visually and semantically close word (e.g., *manteau* [coat] instead of *cape* [cape]), (g) phonological error which consisted of replacing the target with a phonologically close word (e.g., *raseau* instead of *râteau* [rake]), (h) autocorrection which consisted of correcting one's error by replacing it with the target word, and (i) autocorrection neighbor which consisted of making an inhibition error and then correcting it (e.g., *corne* [horn] was first read as *corde* [rope] but then was corrected). The reliability score for accuracy is .79 (Cronbach's α). This reliability score was based on a larger sample.

Oral sentence production Oral sentence inhibition was assessed by an adaptation of the Hayling task (Burgess & Shallice, 1996). The task consists of two parts: one training session and one inhibition session. In the training session, children were asked to complete 10 sentences orally with the most appropriate word. In the inhibition session, they were asked to complete 10 sentences with a nonrelated word that required inhibiting the expected word. The experimenter insisted on the fact that the word should not be linked to the expected word, the sentence, or previous answers. The words to be completed were obvious and automatic (e.g., *Je ne vois pas bien de loin, je dois porter des [lunettes]*; I cannot see well from a distance, I will have to wear [glasses]). In this case, the prepotent automatic response (i.e., glasses) has to be inhibited to think of a nonrelated word. The sentences were presented on a computer. Participants were asked to answer as quickly and as accurately as possible. The participants' outcomes were recorded. After each answer, feedback was given to improve the following answers. We also examined the type of errors made by the children to investigate whether errors were linked to inhibition difficulties or not. The answers were classified as follows, based on the classification of Burgess and Shallice (1996): (a) correct answer when the given word complied with the instructions; (b) nonresponse, when the participant gave no answer; (c) target word when the expected word was given instead of a nonrelated word; (d) semantic response when the given word was semantically related to the target word or was from the same semantic category (e.g., the answer was *feuilles* [leaves] when the target word was *fleurs* [flowers]); (e) syntaxico-semantic response when the completed sentence was absurd but that the verb-noun association was familiar or corresponds to an expression (e.g., *je ne vois pas bien de loin, je vais devoir porter des chaussettes* [I cannot see well from a distance, I will have to wear socks]); (f) semantic sentence response when the given answer word was semantically related to the sentence (e.g., *quand je vais à la plage, j'adore faire des châteaux d'eau* [when I go to the beach, I love to make water castles]); (g) phonological response when the given word was phonologically related to the target word (e.g., the answer *chaussette* [sock] for *fourchette* [fork]); (h) gram-

matically incorrect response when the given word led to an agrammatic sentence (e.g., nonrespect of the gender or number of the name); (i) repetition of a response when the given word was already said before, when the word was a phonological neighbor of a previous answer or when the given word was a previous target word; (j) autocorrection when the given answer was corrected by the participant. Response types were coded 1 or 0. In addition to the accuracy score, the response time and latency between the end of the sentence and the child's answer were also recorded. The internal reliability score of the test was .50.

Motor inhibition Motor inhibition skill was assessed by the Simon task, adapted from Simon and Rudell (1967). The task was administered on a computer. Participants saw colored squares on the left or the right side of the screen. They were asked to respond as quickly and as accurately as possible whether the square was blue or red by pressing the left key or the right key on the keyboard. Position and color were either the same (congruent trials) or different (incongruent trials). According to Simon and Rudell (1967), congruent trials are supposed to be processed faster and more accurately than incongruent trials, which is called the Simon effect. At the beginning of each trial, a central fixation cross was shown for 800 ms, followed by a 250 ms blank interval. Then, a blue or red square was presented on the left or right side of the screen for 1000 ms or until a response was given. There was a 500 ms interval between the trials. Matching between the color and the response key changed across participants. Before the experimental trials, a central task was administered to the participants. Squares were presented at the center of the screen, which allowed the children to familiarize themselves with the exercise and to remember the color-key correspondence. Reaction time and accuracy were scored.

Procedure

Data collection took place in a quiet room at the school. Participants were assessed by one experimenter. Children were seen individually during two sessions of approximately 40 min. All tasks were administered in the same order. The children's assessment took place in March 2020 and was interrupted due to the COVID-19 pandemic. Indeed, data collection was interrupted sooner than expected, as a consequence of which the results of 25 children could be included in the study. The participants knew their data were recorded for certain tasks. The inhibition tasks, apart from the RAN inhibition task, were administered on a computer and were preceded by training items to allow the participants to familiarize themselves with the task and the instructions.

Results

Data analysis

Statistical analyses were performed using SPSS 26. In a set of preliminary analyses, we observed the degree of skewness and kurtosis to ensure that the data met the normality assumption of parametric procedures. Their values revealed no distributional problems (skewness $<|2|$ and kurtosis $<|7|$ Kim, 2013), except for latency and response time in the reading inhibition and spoken inhibition tasks. Therefore, latencies and response times were transformed (LN transformation) to reach distributions within acceptable levels of symmetry and peakedness. Generalized linear mixed models (GLMMs) were used to answer our research question. These analyses allow us to take both the variability induced by children and that induced by the items into account in the same analysis. In the GLMM, participants ($N=25$) were entered as random factors. Inhibition condition (two levels: inhibition and filler) and frequency (two levels: low and high frequency) were entered as fixed factors. Interactions between inhibition condition $\times$ frequency were also analyzed. When interactions were significant, simple effects were examined with repeated-measures ANOVAs, which allowed us to compare the within-group performance between the conditions (inhibition vs. filler and low frequency vs. high frequency). To report effect sizes, partial eta squared values were reported from the ANOVA models for main effects and interactions and additional Cohen's d were calculated in the case of pairwise comparisons. Error analyses were also conducted on the reading and spoken tasks, comparing the control and inhibition conditions. Sums of error types are presented in "Appendix 3". Fisher's exact tests were performed to investigate whether the error types had a relationship with the condition (i.e., filler or inhibition). Error analyses allowed us to investigate more precisely if inhibition errors were made by the children (e.g., guessing errors in the reading tasks). Analyses were conducted on 1000 items (25 participants $\times$ 40 words) for both the word reading task and the sentence reading task, on 800 items for the oral word production task, on 500 items for the sentence oral production task and 4000 items for the motor task. The three target variables were accuracy, latency, and response time for word reading, sentence reading, oral word production, and oral sentence production. For the oral sentence production task and the motor inhibition task, the same analyses were conducted without the frequency factor. The total time including the latency (time between the item and the participant's response) and the response time was automatically recorded via the computerized task using the Psychopy software. Then, the Audacity software was used to calculate the response time by hand from the total time. Finally, response time was subtracted from the total time to get the latency. Latency and response times are reported in seconds while reading accuracy is a success rate expressed in percentage (e.g., a mean of 0.80 indicates that 80% of the words were accurately read). The α level was set at 0.05 for all the analyses. Descriptive statistics for the dependent variables are presented in Table 2.

GLMMs were run for each dependent variable, leading to five models: word reading inhibition, sentence reading inhibition, oral word production inhibition, oral

Table 2 Descriptive statistics of the dependent variables

	Accuracy				Latency				Response time			
	M		SD		M		SD		M		SD	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
<i>Word reading</i>												
Inhibition words												
Low fre-quency	0.93	0.67	0.80	1	0.82	0.50	0.38	2.34	0.70	0.28	0.37	1.67
High fre-quency	0.97	0.07	0.70	1	0.73	0.39	0.38	2.04	0.64	0.19	0.41	1.43
Filler words												
Low fre-quency	0.94	0.08	0.70	1	0.85	0.50	0.38	2.20	0.73	0.29	0.41	1.79
High fre-quency	0.97	0.04	0.90	1	0.97	0.30	0.33	1.48	0.62	0.23	0.38	1.54
<i>Sentence reading</i>												
Inhibition words												
Low fre-quency	0.65	0.14	0.30	0.90	0.28	0.28	0.03	1.25	0.82	0.34	0.47	1.87
High fre-quency	0.65	0.19	0.20	0.90	0.27	0.32	0.02	1.42	0.80	0.31	0.48	1.68
Filler words												
Low fre-quency	0.95	0.06	0.78	1	0.23	0.41	0.02	1.98	0.69	0.23	0.36	1.19
High fre-quency	0.98	0.04	0.82	1	0.10	0.21	0.00	0.93	0.58	0.19	0.37	1.07
<i>Oral word production</i>												
Inhibition words												
Low fre-quency	0.84	0.15	0.50	1	1.02	0.49	0.18	1.76	0.78	0.26	0.49	1.53

Table 2 (continued)

	Accuracy				Latency				Response time			
	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
High frequency	0.96	0.08	0.67	1	0.57	0.28	0.12	1.20	0.71	0.21	0.50	1.47
Filler words												
Low frequency	0.94	0.65	0.80	1	0.87	0.37	0.18	1.76	0.73	0.12	0.56	0.98
High frequency	0.99	0.02	0.90	1	0.57	0.28	0.12	1.20	0.54	0.89	0.69	0.09
Oral sentence production												
Inhibition words	0.60	0.492	0	1	4.54	5.31	0.193	40.48	0.81	0.74	0.27	8.38
Filler words	0.98	0.15	0	1	0.65	1.31	0.01	15.54	0.47	0.16	0.17	1.98
Motor inhibition												
Inhibition words	0.82	0.38	0	1	N/A				0.60	0.24	0	0.99
Filler words	0.84	0.36	0	1	N/A				0.60	0.35	0	0.99

Latency and response times are reported in seconds while reading accuracy is a success rate expressed in percentage

sentence production inhibition, and motor inhibition. Correlational analyses were carried out, revealing the associations between the inhibition sensitivity in the different experimental tasks and the control reading tasks used to assess the reading achievement level.

Reading inhibition

To confirm the implication of inhibition in reading, participants must have a lower accuracy score, and/or higher latency and response time in the inhibition conditions (with orthographic neighbors) than in the control conditions.

Word reading

In the word reading task, a 2×2 GLMM with inhibition condition [inhibition, filler] $\times$ frequency [low, high] was conducted. Regarding accuracy, the results did not demonstrate an inhibitory effect. The children did read the words with the same accuracy, whether in the inhibition condition or in the control condition. Analyses did not show a frequency effect on accuracy. The children did not present significantly more accurate reading outcomes for high-frequency words than for low-frequency words. The interaction inhibition $\times$ frequency was not significant. For latency, the analyses did not show an inhibitory effect. The latency time between the presentation of the word and the point at which the child began to read did not differ significantly in the inhibition condition compared to the control condition. The results showed a frequency effect [$F(1,984) = 20.218$, $p < .001$, $\eta p^2 = .51$]. The latency time was significantly longer before reading low-frequency words than before reading high-frequency words. The interaction inhibition $\times$ frequency was not significant. Regarding response times, the analyses did not reveal an inhibitory effect. The children read the words with the same speed, whether in the inhibition condition or in the control condition. Analyses revealed a frequency effect [$F(1,996) = 19.108$, $p < .001$, $\eta p^2 = .45$]. High-frequency words were read more quickly than low-frequency words. The interaction inhibition $\times$ frequency was significant [$F(1,996) = 6.975$, $p = .008$, $\eta p^2 = .37$]. The simple effect analyses revealed a significant difference between high-frequency fillers and inhibition words [$t(24) = -3.711$, $p = .001$, $d = .22$]. Children had significantly faster reading for high-frequency fillers than for high-frequency inhibition words.

Error analyses were conducted on the word reading task, comparing the error types in the control and inhibition conditions. A Fisher's exact test was performed and demonstrated an association between the condition and the error types (Fisher's Exact Test = 6.048, $p = .044$). Indeed, the frequency of the guessing errors was higher in the inhibition condition ($n = 8$ out of the 500 inhibition items, 1.6%) compared to the control condition ($n = 1$ out of the 500 filler items, 0.2%).

Sentence reading

For the sentence reading task, a 2×2 GLMM with inhibition condition [inhibition, filler] $\times$ frequency [low, high] was conducted. For accuracy, analyses demonstrated an inhibitory effect [$F(1,996)=99.003$, $p < .001$, $\eta^2=.81$]. The success rate was higher in the control condition than in the inhibition condition. The results revealed no significant frequency effect. The children read both high-frequency words or low-frequency words with the same accuracy. The inhibition $\times$ frequency interaction was not significant. Regarding latency, analyses revealed an inhibitory effect [$F(1,996)=9.598$, $p=.002$, $\eta^2=.40$]. Latency was significantly longer in the inhibition condition than in the control condition. The results showed a frequency effect [$F(1,996)=3.975$, $p=.046$, $\eta^2=.21$]. Latency was significantly longer before reading low-frequency words than before reading high-frequency words. The inhibition $\times$ frequency interaction was not significant. For response times, the results showed an inhibitory effect [$F(1,996)=22.690$, $p < .001$, $\eta^2=.42$]. The words were read faster in the control condition than in the inhibition condition. Analyses did not demonstrate a significant frequency effect. The target words, whether low-frequency or high-frequency, were read with the same speed. The inhibition $\times$ frequency interaction was not significant.

Error analyses were conducted for the sentence reading task, comparing the error types in the control and inhibition conditions. A Fisher's exact test was performed and demonstrated an association between the condition and the error types (Fisher's Exact Test = 236.153, $p < .001$). Indeed, the children made more mistakes in which they replaced an orthographic neighbor in the inhibition condition ($n=122$ out of the 500 inhibition sentences, 24.4%) than in the control condition ($n=0$).

Spoken inhibition

Oral word production

For the oral word production task, a 2×2 GLMM with inhibition condition [inhibition, filler] $\times$ frequency [low, high] was conducted. Regarding accuracy, analyses revealed an inhibitory effect [$F(1,796)=5.165$, $p=.023$, $\eta^2=.34$]. The children named the images more accurately in the control condition than in the inhibition condition. The results also demonstrated a significant frequency effect [$F(1,796)=10.680$, $p < .001$, $\eta^2=.50$]. High-frequency words were named more accurately than low-frequency words. The inhibition $\times$ frequency interaction was not significant. For latency, the results revealed no inhibitory effect. Latency was similar, whether in the inhibition condition or in the control condition. The GLMM analyses revealed a frequency effect [$F(1,601)=25.257$, $p < .001$, $\eta^2=.052$]. Latency was significantly longer for low-frequency words than for high-frequency words. The inhibition $\times$ frequency interaction was not significant. Regarding response time, the results revealed no inhibitory effect. The images were identified with the same speed, whether in the control condition or in the inhibition condition. Analyses demonstrated a frequency effect [$F(1,778)=5.452$, $p=.020$, $\eta^2=.18$]. High-frequency

words were identified faster than low-frequency words. The inhibition $\times$ frequency interaction was not significant. Error analyses were conducted for the word production task, comparing the error types in the control and inhibition conditions. A Fisher's exact test was performed and demonstrated an association between the condition and the error types (Fisher's Exact Test = 18.963, $p = .001$). Within the inhibition condition, the most frequent errors were visually related errors ($n = 9$ out of the 300 inhibition items, 3%). Nonresponses ($n = 7$ out of 300 inhibition items, 2.33%) and visuosemantic errors ($n = 6$ out of 300 inhibition items, 2%) were also frequent errors.

Oral sentence production

For the oral sentence production task, a GLMM with inhibition condition [inhibition and filler] as a fixed factor was conducted. For accuracy, the results revealed an inhibitory effect [$F(1,498) = 59.961$, $p < .001$, $\eta p^2 = .77$]. The sentences were completed more accurately in the control condition than in the inhibition condition. Regarding latency, the results revealed an inhibitory effect [$F(1,498) = 145.593$, $p < .001$, $\eta p^2 = .65$]. Latency was significantly longer in the inhibition condition than in the control condition. For response times, analyses also revealed an inhibitory effect [$F(1,498) = 53.707$, $p < .001$, $\eta p^2 = .55$]. The children completed the sentences faster in the control condition than in the inhibition condition. Error analyses were conducted for the word production task, comparing the error types in the control and inhibition conditions. A Fisher's exact test was performed and demonstrated an association between the condition and the error types (Fisher's Exact Test = 125.349, $p < .001$). Within the inhibition condition, the most frequent errors were semantic errors ($n = 26$ out of 250 inhibition items, 10.4%), which consisted of giving a semantically related answer. Syntaxico-semantic responses ($n = 21$ out of 250 inhibition items, 8.4%) and grammatically incorrect responses ($n = 20$ out of 250 inhibition items, 8%) were also frequent.

Motor inhibition

For the motor inhibition task, a GLMM with inhibition condition [inhibition and filler] as a fixed factor was conducted. In this task, only accuracy and response time were considered dependent variables. Latency was not provided in the data. For accuracy, the results did not demonstrate a significant difference between the control condition and inhibition condition. The children answered with the same accuracy, whether in the congruent trials or in the incongruent trials. Regarding response times, analyses did not reveal an inhibitory effect. The children answered with the same speed, whether in the congruent trials or in the incongruent trials.

Correlations

Correlational analyses were carried out to investigate the associations between the inhibitory effect in the experimental tasks and the children's performance in classical

Table 3 Correlation coefficients between experimental measures and reading measures

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Inhibition performance																			
1. Word reading ACC	–																		
2. Word reading LS	–.236	–																	
3. Word reading RT	.046	–.449*	–																
4. Sentence reading ACC	–.302	.072	.369	–															
5. Sentence reading LS	.365	.168	–.139	–.435*	–														
6. Sentence reading RT	–.037	.169	–.658**	–.355	.254	–													
7. Oral word production ACC	.159	.005	.004	–.060	.328	.041	–												
8. Oral word production LS	.040	–.165	.039	.053	.002	–.085	–.029	–											
9. Oral word production RT	–.114	–.017	–.086	–.151	–.013	.044	–.408	.428*	–										

Table 3 (continued)

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
10. Oral sentence production ACC	.015	-.010	.271	.243	.085	-.204	.219	.443*	.020	-									
11. Oral sentence production LS	-.042	.216	.427*	.089	.166	-.242	-.130	.045	-.219	.273	-								
12. Oral sentence production RT	.111	.141	.012	-.039	.306	-.123	.196	-.051	.237	.029	-.073	-							
13. Motor ACC	.220	-.138	-.011	-.010	.058	-.140	-.115	-.092	.439*	-.351	-.371	.233	-						
14. Motor RT	.143	-.245	.104	-.233	-.250	-.042	-.140	-.086	.056	-.075	.196	-.248	.061	-					
Reading performance																			
15. Word reading ACC	.122	.093	-.202	-.529**	.010	.234	-.616**	-.252	.238	-.415*	.060	-.002	.193	.175	-				
16. Word reading RT	-.129	.165	-.041	.378	-.078	-.234	.494*	.330	.090	.374	-.157	.036	.013	-.193	-.778**	-			
17. Text reading—BALE-ACC	.202	.148	-.217	-.410*	.231	.300	-.367	.002	.131	-.326	.205	.181	.088	.189	.711**	-.728**	-		

Table 3 (continued)

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
18. Text read- ing- Alou- ette- ACC	.208	.059	-.218	-.520**	.273	.211	-.550**	-.092	.245	-.428*	.096	.171	.195	.153	.833**	-.822**	.906**	-	-
19. Text read- ing- Alou- ette-RT	-.225	.194	.091	.316	-.089	-.115	.249	-.320	-.351	.363	.030	-.129	-.168	-.161	-.322	.349	-.383	-.469*	-

Significant results are presented in bold

ACC accuracy, *LS* latency score, *RT* response time* $p < .05$, ** $p < .01$

word and text reading achievement tests. For each experimental task (experimental word and sentence reading tasks, experimental oral word and sentence production tasks, and the Simon task), the inhibitory effect was computed by calculating the difference between the filler condition and the inhibition condition. The results revealed negative correlations between word reading accuracy and the inhibitory effect and between text reading (meaningless text) accuracy and the inhibitory effect; these correlations were observed on accuracy in the experimental sentence reading, oral word production, and oral sentence production tasks. A high reading accuracy score was correlated with a smaller inhibitory effect, meaning that children with higher reading accuracy (both in word and text reading) were less sensitive to the inhibitory trials. The second text (text with meaning) accuracy score was negatively correlated with inhibition accuracy in the experimental sentence reading task, meaning that children with higher reading accuracy showed better inhibition performance in sentence reading inhibition. Moreover, the word reading response time was positively correlated with oral word inhibition accuracy, meaning that children with slower word reading showed a lower inhibition performance (i.e., larger inhibitory effect) in the oral word production task. Finally, no correlation was found between inhibition performance in the motor tasks and reading performance. Pearson's correlation coefficients are provided in Table 3.

Discussion

Although the impact of inhibition in reading seems undeniable, the involvement of inhibition in word and sentence reading has received very little attention. This study aimed to better understand the role of inhibition in reading and its specificity compared to other inhibition modalities. Therefore, typically developing children completed five experimental inhibition tasks of word reading, sentence reading, oral word production, oral sentence production, and motor level. For each dependent variable, accuracy, latency, and response time, we analyzed whether there was an inhibitory effect and/or a frequency effect within each experimental task. We also conducted correlational analyses between inhibition performance in the experimental tasks and reading performance in the classical reading tests. The results are discussed below each research question.

(1) Is inhibition involved in an experimental word reading task?

Our hypothesis was partially confirmed. Indeed, within the experimental word reading task, no inhibitory effect was found, in the sense that children did not read orthographic neighbors less accurately or more slowly than control words. Regarding accuracy, latency, and response time, children seemed to read the words without being influenced by the manipulation of orthographic neighbors at first glance. However, by taking a closer look at the error analysis, we noted that children made more guessing errors in the inhibition condition, which indicates some influence of inhibition when reading words. According to these results, the previous activation of an

orthographic neighbor seems to partially influence access to the target word. These results were expected based on the interactive activation model of McClelland and Rumelhart (1981). However, the lack of differences between these two conditions in accuracy, latency, or response time could be related to the fact that the children were too familiar with the words. Indeed, we observed a ceiling effect (95% success rate) in the task, and the items seemed to be well established in their lexicon. The effect might have been greater if the words had been more complicated and an inhibitory effect might have been observed. On the other hand, the results showed a frequency effect on all three dependent variables, which is consistent with McClelland and Rumelhart (1981)'s and Sprenger-Charolles et al. (1998)'s findings in French-speaking children. Children showed a greater latency time and were slower when reading low-frequency words than when reading high-frequency words. However, reading accuracy was the same for both low- or high-frequency words. Again, this is probably linked to the ceiling effect observed in the task. Overall, these results are in line with the well-known frequency effect in reading; frequent words seem to be read more quickly than less frequent words (McClelland & Rumelhart, 1981), observed on both accuracy and latency (Sprenger-Charolles et al., 1998). These outcomes are also in agreement with priming effects observed by Davis and Lupker (2006). Indeed, the larger the frequency advantage the prime has over the target, the stronger the likelihood of obtaining inhibition. When word targets are primed by masked, higher frequency neighbor primes, target latencies are longer. Moreover, regarding response time, an interaction was found between inhibition and frequency. More precisely, children were able to read high-frequency fillers faster than they were able to read high-frequency orthographic neighbors. With the observation of the guessing errors, these outcomes seem to support the fact that children are impacted by previous neighbor activation and revealed a moderate involvement of inhibition during word reading.

(2) Is inhibition involved in an experimental sentence reading task?

Our results clearly supported our hypothesis regarding this research question. A significant inhibitory effect was observed during the sentence reading task, marked on the different stages of reading, whether in terms of accuracy, latency, or response time. Children made more mistakes, presented greater latency times, and were slower when an expected word was replaced by an orthographic neighbor in a sentence compared to control sentences. These results led us to believe that the expected word could be preactivated when the children were reading the context that preceded the target. This could explain why these expected words would be more difficult to inhibit and thus lead to more reading errors related to the context and a greater latency and response time. These outcomes are consistent with the findings of Johnson et al. (2018) and Tiffin-Richards and Schroeder (2020) regarding contextual facilitation. Indeed, by analyzing eye movements, the authors also demonstrated contextual facilitation in children during sentence reading (Johnson et al., 2018) and text reading (Tiffin-Richards & Schroeder, 2020). Johnson et al. (2018) added that the efficiency of contextual facilitation increases with reading experience.

Our results are also in line with these of Van Reybroeck & De Rom (2020), who highlighted the involvement of inhibition in a sentence reading task in fourth Grade children with dyslexia. This supports the idea that contextual facilitation could be overused by less experienced readers, for example children with dyslexia or younger typically developing readers, as is the case in the current sample. Moreover, we observed a frequency effect on the latency variable. Indeed, latency was greater before a low-frequency word than before a high-frequency word, whether in the control condition or the inhibition condition. This result is consistent with the findings of Perea (2015) and McClelland and Rumelhart (1981)'s model. Indeed, according to the interactive activation model (McClelland & Rumelhart, 1981), in the absence of input, all words return to an inactive state, or a resting level. This resting level is assumed to be higher for high-frequency words than for low-frequency words. This would explain why high-frequency words are read more accurately and faster than low-frequency words. However, we expected the frequency effect to be generalized to all three dependent variables. In contrast to word reading, where the frequency effect was stronger, these results could suggest that contextual facilitation overrides the frequency effect.

(3) Are the inhibition mechanisms involved in a reading task specific to reading (domain-specific) or do they reflect the functioning of a broader mechanism, also observed in spoken and motor tasks (domain-general)?

Our results support neither the first nor the second hypothesis. Indeed, inhibitory effects were found in the experimental word and sentence reading tasks and in both experimental spoken inhibition tasks, oral word production and oral sentence production. Thus, the implication of inhibition does not seem to be domain-specific to reading in children from Grades 2 and 3 but rather generalizable to language production either in reading or spoken modalities.

Regarding spoken inhibition, an inhibitory effect was found in both oral word and sentence production tasks. For oral word production, an inhibitory effect was observed on the accuracy variable. Indeed, children made more errors in naming the phonological neighbors in contrast to the control words. These findings suggest that phonologically similar words compete in the mental lexicon. These results are consistent with the outcomes of Fox et al. (2015), who reported that accessing the phonological form of a target word results in the automatic and obligatory coactivation of the target's neighborhood. These outcomes are also in line with the lexical inhibition processes in word perception (Dell, 1986; McClelland & Elman, 1986). These recognition theories assume that similar words are coactivated together with the target word and compete for selection, thereby slowing down the recognition process. On the other hand, a frequency effect was found in the oral word production task on the three variables (i.e., accuracy, latency, and response time). Indeed, high-frequency words were named more accurately and more quickly than low-frequency words.

In the sentence production task, an inhibitory effect was observed on all three dependent variables. Children were less accurate and presented greater latency and

response times when they had to inhibit an expected word and complete an oral sentence with an unexpected word compared to the control condition. These results are in line with the findings concerning sentence reading. The importance of contextual facilitation also seems to be highlighted in an oral task.

In the motor task, no inhibitory effects were observed. Children from Grades 2 and 3 were not less accurate or slower in the incongruent trials compared to congruent trials in the Simon task. This finding is surprising if we consider the developmental trajectory of response inhibition presented by Luna (2009). According to this author, children in Grades 2 and 3 should be sensitive to inhibitory demands in a Simon task. This suggests that children at that age seem to be less affected by inhibition in a motor task compared to reading and speaking tasks. Indeed, inhibition seems to have a particular influence on language-related tasks in children at the beginning of primary school.

(4) To what extent is inhibition performance related to reading performance in classical reading achievement tests?

Our results support the assumption that inhibition performance is related to reading achievement tests, given that some inhibition scores were correlated to reading scores. Indeed, word and text reading accuracy (Alouette, meaningless text) was negatively correlated with the inhibitory effect on accuracy in the experimental sentence reading, oral word production, and oral sentence production tasks. Children with more accurate word and text reading abilities seemed less impacted by inhibitory demands. Hence, children who had poorer inhibition skills seemed to be poorer readers. Moreover, word reading response time was positively correlated with the inhibitory effect on accuracy in the oral word production task. Children who showed slower word reading skills seemed to have poorer inhibition skills in the oral word production task (i.e., the RAN task). However, no correlation was found between word reading scores and inhibition performance and between text reading scores and inhibition performance in the experimental word reading task. This could be related to a potential ceiling effect (95% success rate) in this task. Finally, it is important to note that no relation was found between reading performance and inhibition performance in the motor task. Indeed, only the inhibition mechanisms of the language tasks were correlated with reading performance. Interestingly, this seems to indicate that the inhibition mechanisms found in the experimental reading and spoken tasks were different from those involved in the motor task.

Overall, our study provides new pieces of evidence for the influence of inhibition in word and sentence reading tasks and in oral word and sentence production tasks among children from Grades 2 and 3. To the best of our knowledge, this experiment is the first to evaluate inhibition in both word reading and sentence reading tasks. By doing so, our study also has the distinction of providing future researchers with new and precise experimental paradigms aimed at measuring inhibition in reading contexts. It might be useful to replicate this study with a larger sample to see if the same results are confirmed in a broader population. Similarly, our results shed light on the

impact of inhibition in reading, and it seems important to analyze this process more precisely in the future to better understand the observed reading errors.

Limitations

This study has a few limitations that should be noted to guide future research. First, because of the pandemic context, we had a small sample size that could limit the extent to which the results can be generalized. However, the inclusion of a large number of items and the use of item-based analysis ensured good statistical power. Second, regarding the oral sentence production task (the Hayling task), we know that children rely on their visual environment to complete the sentence with a non-related word. As the experiments could not always be conducted in the exact same room, we chose the most similar rooms possible within the school for the test taking, in order to avoid any bias. Third, we were not able to compare children's outcomes between Grades. It could have been the case that we observed differences between second and third graders, in particular we could expect older children to be less influenced by inhibition than younger children. However, it is also known that there are important interindividual differences between children, with some children showing the same reading level as others 1 year above or below. We should also mention that a large number of tests were run, which may have increased the probability of Type 1 errors. We could have performed a MANOVA to reduce this risk of error, but we chose to use GLMMs because they are statistically powerful in incorporating both the variability induced by children and that induced by the items.

Conclusion

In summary, these findings bring new insights regarding the implication of inhibition in reading in typically developing children. While other studies focused on the relationship between inhibition and reading comprehension, this study is innovative in that it assessed inhibition in a reading task at the word and sentence levels. The results showed that inhibition is involved in word and sentence reading. In that sense, inhibition seems to be difficult when the word to inhibit is activated by contextual facilitation or by an orthographic neighbor. Regarding the question of inhibition in spoken and motor modalities, inhibition seems to impact oral tasks in addition to reading tasks but not motor tasks. At this age, the motor modality does not seem to involve inhibition demands that are difficult for children. Moreover, the correlational analyses revealed that children who showed better inhibitory skills read words and texts more accurately. Overall, these findings may have practical implications. Indeed, these findings open up new perspectives on the understanding of guessing errors. The manipulation of orthographic neighbors, in both word and sentence reading, could be an interesting lead for therapeutic and pedagogical approaches, if confirmed by an interventional approach. Indeed, including exercises with orthographic neighbors encourage children to slow down reading in favor of a more accurate decoding. Ultimately, this type of exercises should allow them to be

more attentive to possible traps and avoid guessing errors. Our results also support the benefits of an analytical reading learning method over and above a holistic reading approach. Learning to read in a global way could indeed induce guessing errors given that it encourages children to guess the word based on its global form. Given that children, at the beginning of primary school, seem to be impacted by inhibition during reading, it might be interesting to investigate this issue more specifically to better identify the source of reading errors.

Appendix 1

List of words used in the word reading inhibition task and frequency

Words	Frequency
1. couler (flow)	51,01
couper (cut)	59,72
2. bol (bowl)	54,95
sol (floor)	62,71
3. matin (morning)	67,64
malin (smart)	50,78
4. sauter (jump)	60,18
sauver (save)	54,4
5. tenir (hold)	55,88
venir (come)	61,07
6. liste (list)	63,21
piste (slope)	56,2
7. vie (life)	64,35
vue (sight)	54,49
8. carte (map)	61,71
tarte (pie)	54,85
9. four (oven)	56,93
tour (tower)	66,78
10. bac (tray)	47,07
bec (beak)	59,22

The frequency is based on the Manulex Standard Frequency Index
Frequency > 60 = P75; frequency 45–60 = P50–P75

Appendix 2

List of the sentences used in the sentence reading inhibition task and frequency of the orthographic neighbors

Sentences	Orthographic neighbors (frequency)
1. Mes mains sont remplies de boue, avant de manger je vais devoir les <i>lever</i> My hands are full of mud, before I eat I will have to <i>raise</i> them	Lever (60,35)—laver (55,39)
2. En classe, quand je veux poser une question, je dois <i>laver</i> le doigt During class, when I want to ask a question, I have to <i>wash</i> my finger	
3. J'ai fait des ratures au crayon, heureusement j'ai pu les effacer avec ma <i>pomme</i> I made pencil scratches, fortunately I was able to erase them with my <i>apple</i>	Pomme (61,79)—gomme (50,98)
4. Blanche Neige a croqué dans une mauvaise <i>gomme</i> Snow White bit into a bad <i>eraser</i>	
5. Pour rentrer dans la maison, je dois ouvrir la <i>poste</i> To enter the house, I have to open the <i>post office</i>	Poste (54,26)—porte (66,81)
6. Je dois acheter des timbres, je vais devoir aller à la <i>porte</i> I need to buy stamps, I will have to go to the <i>door</i>	
7. J'aime lire, c'est déjà la troisième fois que je lis ce <i>litre</i> I like to read, it is already the third time I read this <i>liter</i>	Litre (48,06)—livre (65,21)
8. Pour faire ce gâteau, on n'a pas besoin de beaucoup de lait, seulement un demi- <i>livre</i> You don't need a lot of milk to bake this cake, only half a <i>book</i>	
9. Il est tard, il est l'heure d'aller se <i>moucher</i> It's late, it's time to <i>blow your nose</i>	Moucher (44,11)—coucher (60,08)
10. J'ai un rhume, j'éternue et je n'arrête pas de me <i>coucher</i> I have a cold, I sneeze and I can't stop <i>going to bed</i>	
11. Avant d'allumer le feu de camp, je dois ramasser du <i>pois</i> Before lighting the fire, I have to collect some <i>peas</i>	Pois (58,71)—bois (66,86)
12. Hier on a mangé des carottes et des petits <i>bois</i> Yesterday we ate carrots and <i>wood</i>	
13. On va déménager donc j'ai mis toutes mes affaires dans des <i>cuisses</i> We are going to move so I put all my stuff in <i>thighs</i>	Cuisse (42,87)—caisse (55,74)
14. Ce soir on mange du poulet mais je n'aime pas trop le blanc, je préfère une <i>caisse</i> Tonight we are eating chicken but I don't like breast too much, I prefer a <i>box</i>	
15. Ma chambre est en désordre, maman m'a dit de la <i>manger</i> tout de suite My room is a mess, mom told me to <i>eat</i> it up right now	Manger (65,82)—ranger (57,36)
16. Il est l'heure de passer à table, on va <i>ranger</i> des pâtes It is time to eat, we are going to <i>tidy up</i> some pasta	
17. Quand je suis sorti, mon chapeau s'est envolé car il y avait beaucoup de <i>dent</i> When I went out, my hat flew off because there was a lot of <i>tooth</i>	Dent (57,16)—vent (68,72)

Sentences	Orthographic neighbors (frequency)
18. Je pense que j'ai une carie parce que j'ai très mal à une <i>vent</i> I think I have a cavity because I have a <i>wind</i> that hurts a lot	
19. Ma sœur a découvert mon mot de passe, je vais devoir le <i>chanter</i> My sister found out my password so I will have to <i>sing</i> it	Chanter (61,65)—changer (57,57)
20. Depuis que mon frère a reçu un micro pour Noël, il n'arrête pas de <i>changer</i> Since my brother got a microphone for Christmas, he hasn't stopped <i>changing</i>	

The frequency is based on the Manulex Standard Frequency Index. Frequency > 60 = P75; frequency 45–60 = P50–P75

Appendix 3

Sum of error types by inhibition task

Type of errors—word reading	Condition			
	Filler	Inhibition	Total	Example
Correct answer	479	475	954	
Inhibition error	0	0	0	
Guessing error	1	8	9	<i>Clouer</i> instead of couler [sink]
Segmentation error	6	9	15	<i>Carde</i> instead cadre [frame]
Confusion error	5	2	7	<i>Pleu</i> instead of bleu [blue]
Auto-correction	9	4	90	<i>Plague</i> is corrected plage [beach]
Type of errors—sentence reading	Condition			
	Filler	Inhibition	Total	Example
Correct answers	484	326	810	
Inhibition error	0	122	122	Il est tard je vais aller me <i>coucher</i> instead of moucher [It's late, I'm going to blow my nose, instead of go to bed]
Guessing error	10	8	18	C'est déjà la 3ème fois que je lis ce <i>titre</i> instead of litre [It's already the third time that I read this title instead of liter]
Segmentation error	1	3	4	<i>Cuises</i> instead of cuisses [thighs]
Confusion error	0	1	1	<i>Bomme</i> instead of pomme [apple]
Auto-correction 1	0	24	24	Porte [door] corrected poste [post office] (target word = poste)
Auto-correction 2	0	4	4	Poste [post office] corrected with porte [door] (target word = poste)
Auto-correction 3	6	6	12	Pule is corrected poule [chicken] (target word = poule)

Auto-correction 1 correcting the orthographic neighbor with the target word, *auto-correction 2* correcting the target word with the orthographic neighbour, *auto-correction 3* correcting another error with the target word

Type of errors—RAN task	Condition			
	Filler	Inhibition	Total	Example
Correct answer	484	271	755	
Nonresponse	11	7	18	
Inhibition error	0	0	0	
Visual error	1	9	10	<i>Siège</i> [seat] instead of luge [sled]
Semantic error	1	1	2	<i>Chèvre</i> [goat] instead of mouton [sheep]
Visuosemantic error	3	6	9	<i>Doigt</i> [finger] pour pouce [thumb]
Phonological error	0	2	2	<i>Cordre</i> instead of corde [rope]
Auto-correction	0	4	4	Cordre corrected by corde [rope]
Auto-correction 2	0	1	1	Corde [rope] corrected by corne [horn]

Auto-correction correcting one's error with the target word, *auto-correction 2* = correcting the phonological neighbor with the target word

Type of errors—Hayling task	Condition			
	Filler	Inhibition	Total	Example
Correct answers	244	149	393	
Nonresponses	1	0	1	
Target word	0	1	1	I watched the time on my <i>watch</i> (target word = watch)
Semantic	3	26	29	To wash myself, I use <i>bath</i> (target word = soap)
Syntaxico-semantic	0	21	21	I have eaten to much and my <i>back</i> hurts (target word = stomach)
Semantic sentence	0	15	15	I eat with a knife and a <i>table</i> (target word = fork)
Phonological	0	1	1	cerveau [brain] and cerceau [hoop] as consecutive answers
Agrammatical	1	20	21	I will look at the time on my <i>microwave</i> (non-respect of the gender in French)
Repetition	0	13	13	Repeating a previous answer
Auto-correction	1	4	5	I eat with a knife and a <i>fork</i> corrected by <i>girl</i>

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