



How do French students in primary grades process past participle inflections and their N-1 and N+1 in sentence dictation tasks? An analysis of the effects of verb frequency and verb consistency

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Abstract

The research presented in this paper aimed to serve two purposes. First, the objective was to understand the relationship between lexical and grammatical spelling. In this way, we studied how the frequency and consistency of verb interacted with the application of grammatical rules. Second, we investigated the dynamics of spelling during the writing of simple sentences to evaluate the impact of spelling one word on another; that is, to determine anticipatory and delayed spelling treatments in a sentence. Second- to fifth-grade students from primary schools completed a spelling-to-dictation task using sentences of the following type: Subject noun + Verb conjugated in the perfect tense + Object noun (e.g. *Mon frère a habité cette ville* [My brother lived in this city]). Verbs have been selected according to their lemma frequency and spelling consistency, while subject and object nouns were both frequent and consistent. Analyses of the proportions of errors on past participle inflections (*N*), subject nouns (*N-1*), and object nouns (*N+1*) showed an evolution of the impact of verb frequency or consistency during primary school. Depending on the position of the three types of words in the sentence and the grade of the writer, we noted classical or reversed effects of frequency or consistency. We discuss the results in light of statistical learning and Van Galen's cascading model of writing (Human Movement Sci 10(2-3):165-191, 1991).

Keywords Lexical spelling · Grammatical spelling · Statistical learning · Cascading model

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Introduction

In most alphabetic languages, spelling words in sentences requires both lexical knowledge of each word and grammatical knowledge to link the words together (Fayol & Jaffré, 2014). Lexical spelling consists of understanding how written language represents oral language. Grammatical spelling determines the relationships between words with inflectional marks. Some languages are more transparent, such as Spanish or Italian, than English, Danish, Portuguese, or French, which take longer to learn (Bahr et al., 2009; Caravolas, 2006; Fayol, 2020; Morin et al., 2018; Seymour et al., 2003; Sprenger-Charolles, 2003). In English, the most opaque language, for example, the sound [i:] can take different spellings (bead, weed, zebra), and the past verbal form is written -ed but pronounced either [tʃ], as in watched, or [ɪd] as in succeeded. French spelling also has a deep orthography, even if it is less than English spelling, at both the lexical and grammatical levels (Fayol & Jaffré, 2008). In French, many phonemes can be transcribed differently (*motō, pot, peau*/motorcycle, pot, skin), silent letters are frequent, especially at the end of a word (*souris, prix*/mouse, price), and double consonants are not audible (*panne, malle*/breakdown, trunk). Furthermore, French morphology is particularly rich and redundant in writing, with many non-audible endings (*amies, chantent*/friends, sing) or homophones (*chantai, chanté, chanter, chantez*/sang, sung, to sing, sing). This opacity leads to many lexical and grammatical errors, even if the syllabic structure in French or Portuguese is simpler than in English or in Danish.

Today, a great deal of experimental data concerns lexical spelling processes on the one hand, and grammatical spelling processes on the other, as if they were entirely separate and independent processes. Few studies, however, have analysed both dimensions and their development simultaneously (Bosse et al., 2021; de Bree et al., 2018; Morin et al., 2018). To write each word in a sentence, the writer uses at least three types of information: graphophonological, orthographical, and morphological. Our aim was to determine whether students in primary school process lexical orthography independently of grammatical orthography, or whether the processing of a morphological characteristic in the sentence is disrupted by lexical constraints. Moreover, spelling research has mostly reported data on isolated words, even in recent studies about the dynamics of writing, which examined the time course of spelling and handwriting processes in adults (Delattre et al., 2006; Palmis et al., 2019; Roux et al., 2013) or in children (Afonso et al., 2018; Kandel & Perret, 2015; Pontart et al., 2013). Few studies have elucidated the dynamics of writing more than one word (Lambert et al., 2011; Maggio et al., 2015) or one sentence (Chanquoy et al., 1990; Maggio et al., 2012). Writing latencies and durations have been used to investigate the dynamics of writing and spelling. The objective here was to cross these online measurements with off-line results, such as spelling errors, which are real open windows on the processes involved. This question would lead to a better understanding of how primary school writers process the spelling of an entire sentence. It would also have pedagogical implications, particularly in the dictation task, a commonly used school exercise.

Literature review

The characteristics of lexical and grammatical spelling in French

One of the most well-known, frequently studied effects in the lexical spelling literature is the interaction between consistency and frequency effects. Phonographic consistency corresponds to the variability of assignments from one spelling code to one phonological code (i.e. the consistency effect). If shallow systems, such as Spanish or Italian, represent language in a relatively consistent manner at the phonological level, deep systems, such as French and English, are highly inconsistent; that is, the set of phoneme-grapheme correspondence rules is insufficient to spell all words (in French, only 50% of monosyllabic words; Véronis, 1988). In terms of learning, this uncertainty in the choice of a given grapheme among alternative graphemes is a major challenge for students (Bahr et al., 2012; Bonin et al., 2008; Lété, 2008; Sénéchal et al., 2016). In English, the consistency of vowels influences the accuracy of their spelling at the end of the first year of schooling and remains the strongest predictor six months later (Caravolas et al., 2005). In French, consistency affects spelling (*table* vs. *neige/table* vs. *snow*) from first to fifth grader (Lété et al., 2008), and difficulties persevere significantly among ninth graders (Hazard et al., 2020). Lexical frequency corresponds to the quality of the orthographic representations in the mental lexicon (*papa* vs. *miell* vs. *dad* vs. *honey*). Sprenger-Charolles and Serniclaes (2003) and Sprenger-Charolles et al., (1998, 2003) found a low-frequency effect only at the end of first grade. Moreover, young writers are sensitive to this frequency effect, particularly for monosyllabic words (Lété, 2008; Martinet et al., 2004) from the first grade to the end of primary school. The higher a word's frequency, the better it is spelled (i.e. the lexical frequency effect). More interestingly, consistency and frequency interact with grade. The consistency effect (more errors with inconsistent words) is significant for frequent and rare words for second to seventh graders, whereas it disappears for frequent words in ninth graders but not for rare words, which leads to more errors when they are inconsistent (31%) rather than consistent (9%) (Hazard et al., 2020). Lexical frequency attests to the direct recovery of the entire form of a word, while orthographic consistency reveals the indirect processing of a word via graphophonological conversion (Lété, 2008).

Grammatical spelling implies using morphological marks. Morphography is the third source of linguistic information involved in word spelling in context and is particularly important in deep orthography, such as English (past tense inflection *-ed*; Treiman, 1993; Nunes et al., 1997) or French. In the latter language, most morphemes are not pronounced, such as plural nouns (*le chien/les chiens*; the dog/the dogs) and plural verb inflection (*il chante/ils chantent*; he sings/they sing), or they are audible but inconsistent (past participle inflection *chanté* and infinitive form *chanter*). With inconsistent forms, writers tend to use the most frequent inflection encountered in writing and reading. Brissaud and Chevrot (2011) provided a developmental view of the inflection mastery in French regarding [e] verb endings. In grade 1, *-é* is the most frequent spelling used by children to write

the sound [e]. Beginning in grade 3, children tend to use the most frequent ending encountered in writing; that is, the infinitive form *-er* (see also Negro et al., 2014). Nonetheless, how can lexical and morphological learning be reconciled?

The development of spelling

The frequency and consistency effects, which appear quite early in children, do not account for a dual-route model of spelling (Ehri, 1987) in either lexical or grammatical spelling. Conversely, the self-teaching model (Share, 1995, 1999) assumes that word spelling is learned incidentally during reading by phonological recoding. However, this hypothesis needs to be verified because other types of knowledge, such as infralexical knowledge, would also be learned implicitly as exposure to the written code progresses. The statistical-based learning framework states that infants, children, and adults abstract the statistical relationships between orthographic inputs and phonological outputs to read and produce written words (Ellis, 2002; Lété, 2008; Lété et al., 2008; Sénéchal et al., 2016; Wells et al., 2009). From this perspective, spelling results from the use of probabilistic knowledge specific to each written and spoken alphabetic system (Boulware-Gooden et al., 2015). Statistical-based learning also makes it possible to reconcile both lexical and grammatical learning.

Treiman and Kessler (2014) proposed an integrated multiple patterns (IMP) model. Children are supposed to learn the spelling of words from all cues that written symbols maintain with language units, such as phonologic features, as well as graphotactic, morphographemic, semantic, and any other linguistic features (see also Treiman, 2017). In the same way, Sénéchal et al. (2016) proposed a fuzzy representation model. To support this model, they presented children in grades 1 to 3 with a spelling-to-dictation task of monomorphemic words in French ending with an equally silent letter (*-t* or *-d*, 87% and 90% of cases, respectively), but the letter *-t* is twelve times more frequent than the letter *-d* at the end of words. As postulated, children added the frequent ending more often than the rarer ending in the first grade, whereas this effect disappeared by the third grade. The fuzzy model assumes that the acquisition of silent-letter endings in words is sensitive to the statistical properties of the language. Word representation would be initially incomplete, explaining frequent omission errors among first graders, depending on statistical regularities in language, until a more precise representation is elaborated (see also Jubenville et al., 2014; Commissaire & Besse, 2019). The high frequency of some double consonants in French spelling (*-ll*) and conversely the illegal nature of other double consonants (*-hh*), which are rarely used by children, constitute other examples of linguistic knowledge implicitly acquired by children (Borchardt et al., 2012; Pacton et al., 2008). In summary, when a word is inconsistent, the writer-learner tends to use the most frequent sequence of graphemes encountered in writing to spell a given sound while taking into account the previous and following sequences of graphemes into the word; that is, graphotactic constraints (for English, see Hayes et al., 2006; for French, see Pacton et al., 2005; Pacton et al., 2001).

A large amount of experimental data also supports this model in morphology. Even though in pedagogical interventions, derivational and mostly inflectional

morphology is traditionally described as depending on rules to memorize, retrieve and apply in relevant contexts, several results suggest that both children and adults are sensitive to the frequency of linguistic cues. For example, Pacton and Fayol (2003) asked 8- and 10-year-old children to write adverbs or present participles, both ending phonologically with the sound [ã] (*lentement, marchant*/slowly, walking), pronounced either in isolation or embedded into a syntactic construction, and manipulated in frequency. Better performance was observed in the sentence context than with isolated words, and spelling of the most frequent word was preferentially used, even in the sentence context, at both levels. In another experiment (Pacton et al., 2005), children were asked to write nonwords expressing the diminutive meaning of objects (*-ette* or *-eau*). From the second grade, children added the appropriate diminutive morpheme to nonwords based on the letters preceding the diminutive suffix relative to other plausible phonological candidates, regardless of the task (a nonword embedded in a syntactic construction or in isolation). Recently, Negro et al. (2014) investigated, in children from the second to the eighth grades and young adults, the ability to inflect a verb in a spelling-to-dictation task using simple sentences that included past participle inflections (PPIs). Two frequency indicators were manipulated: past participle inflection frequency (the frequent inflection *-é* as in *chanté*/sung, and the rare inflection *-i* as in *fini*/finished) to index the use of rule-based procedures, and orthographic form frequency to index the use of frequency-based procedures. Younger children made more errors on the frequent PPI (*-é*) when the verb's orthographic form was frequent (*terminé*/finished) rather than rare (*capturé*/captured). A reversed effect was noted with the rare PPI (*-i*): Errors were higher with rare orthographic forms (*servi*/served) than among frequent forms (*subi*/endured). The experiment was replicated among children with low- and mid-level literacy achievements, specifically sixth and eighth graders. They performed similarly to the younger writers from the second and third grades. The authors suggested that younger writers and low readers are sensitive to probabilistic cues of language. Frequent orthographic forms have a great number of spelling competitors compared to rare orthographic forms. In addition, the difference of spelling competitors is all the more important with frequent PPI (*-é*) than rare PPI (*-i*). Regarding the frequent PPI (*-é*), lower-level readers and younger writers would activate all morphological forms that are phonologically plausible and associated with a verb. Thus, it would be easier to select the correct inflection when the verb is rare rather than frequent. These data imply that the development of orthographic representations is shaped from the first stages by properties acquired implicitly with written input (Caravolas et al., 2005; Lété, 2008; Pacton & Deacon, 2008). Younger writers in any language would be able to learn implicitly new orthographic forms with regular print exposure (Boulware-Gooden et al., 2015). From the fourth grade, the interaction between PPIs and the frequency of the orthographic form gradually disappears, as in high-level readers and adults. With written expertise, writers seem able to select a grammatical rule to avoid errors due to spelling competitors. The effect of spelling competitors with frequent PPI (*-é*) has been achieved with various verbs, whereas younger writers are sensitive to the consistency of lexical items (Lété, 2008; Lété et al., 2008). While

all lexical spelling studies attest to a major consistency effect on spelling performance, morphology research ignores this factor as if the root verb and suffix are processed independently without affecting each other.

The dynamics of spelling

Another question concerns the dynamics of spelling. Spelling is a complex cognitive task that requires retrieving the orthographic representation of words and then writing them correctly on paper. This task involves coordinating peripheral motor processes (motor control movements indexed by writing durations) and central processes (linguistic processes such as spelling). Cascading model of writing (Van Galen, 1991) supposes that central processes are activated simultaneously to peripheral processes; at one time, each module processes a particular aspect of the message. For instance, while word n is executed, the handwriting module processes the unit $N+1$, while the spelling module addresses the orthographic representation of the word $N+2$.

This impact of one unit to another was investigated with online studies. It has been assumed that if spelling is not fully recovered before initiating handwriting, then latencies and word-writing duration—operations that reflect peripheral processes—would be affected by manipulated factors designed to tap into spelling, such as frequency and consistency. Studies in adults indicated an effect of word frequency, primarily on writing latencies (Delattre et al., 2006; Lambert et al., 2011; Maggio et al., 2015; Palmis et al., 2019; Roux et al., 2013), whereas consistency affects writing duration (Delattre et al., 2006; Maggio et al., 2015; Palmis et al., 2019; Roux et al., 2013). Furthermore, frequency and consistency interact: Adults take longer to write an inconsistent word, especially if it is rare (Delattre et al., 2006; Lambert et al., 2011; Palmis, 2019; Roux et al., 2013). These results signal that spelling is anticipated before handwriting, but continues during the writing of the determinant and the noun.

Research conducted in primary and secondary grades with copying and dictation task showed that writing duration was longer for rare words than for frequent words among second graders, while this effect was marginally significant among fourth graders and not apparent in sixth graders (Afonso et al., 2018), as already shown in adults (Delattre et al., 2006; Lambert et al., 2011). Consistency affects latencies and writing duration, but differently by grade. Whereas in the third grade, consistency strongly affects latencies and the writing duration of the last letters, execution is slower by fourth and sixth grade at the start and end of a word (Kandel & Perret, 2015). These data suggest that third graders partially resolve the conflict generated by inconsistent words before handwriting is started to avoid cognitive overload since motor movements are not yet fully automated.

These studies on the dynamics of writing suggest that a word is orthographically processed before and during writing. However, online studies measured writing duration and latencies on a direct copy tasks or a spelling-to-dictation task of isolated words, but rarely with sentences (Maggio et al., 2012) and they did not report the impact of parallel processing on spelling accuracy. These experiments analysed

writing duration in terms of correct responses, excluding spelling errors, while there is a strong and systematic correlation between pen movements and spelling performances in the primary grades, as in the secondary grades (Pontart et al., 2013).

The present study

Aim

We aimed to address two main questions about spelling processing. The first concerns the interactions between lexical and grammatical cues in a word. Few studies have investigated the interactions between linguistic cues (length, graphotactic characteristics, lexical unit) and morphology, such as derivational morphology (Kandel et al., 2012; Pacton et al., 2001, 2005; Quémart & Lambert, 2019) and inflectional morphology (Negro et al., 2014). Morin et al. (2018) compared the relationship between lexical and grammatical spelling accuracy, asking third and fifth graders to complete a series of tasks evaluating lexical and grammatical spelling. Lexical and grammatical performances are more closely associated with fifth graders than third graders. Grammatical spelling may involve computing inflectional morphology compared to lexical spelling in younger writers. The gradual automaticity of morphology by grade would lead to the integration of these two types of spelling in memory, thus reducing the dissociated profiles at the end of primary school (see also Alamargot et al., 2015). A longitudinal study from the sixth to ninth grade confirmed that lexical and grammatical performances do not evolve independently and are highly correlated (Bosse et al., 2021). It can be expected that grammatical spelling should disrupt lexical spelling in younger writers, while competition between grammatical and lexical processing should decrease by the end of primary school.

Our second purpose was to enhance our understanding of the dynamics of spelling in sentences. To our knowledge, the impact of one spelling difficulty from one word to previous or later words in a sentence has never been explored. Everything happens as if we considered each word to be spelled independently. We thus designed our empirical study to test whether the spelling of words that vary in complexity, embedded in a sentence, may have anticipatory and delayed effects on preceding and following words. We examined the spelling of the subject and object nouns to assess the impact of the characteristics of the verb, manipulated for consistency and frequency. Based on studies with chronometric data, we might expect both anticipatory and delayed effects to occur at the end of the primary grades as evidence of handwriting and spelling processed in a cascading model. In the first grades, there would be no anticipatory or delayed effects of word-to-word spelling due to sequential processing.

To answer these questions, we asked children from the second to fifth grades to write dictated sentences. The sentences were of the form subject noun phrase + verb + object noun phrase. The singular subject and object nouns were both consistent and frequent. Conversely, we manipulated the verb—which was always regular (*-er* infinitive form)—in frequency and consistency, and conjugated it in the perfect tense (i.e. *passé composé*: *a* + verb + PPI *-é*; e.g. *Mon frère a habité cette*

ville [My brother lived in this city]). We analysed spelling errors on the past participle inflection (PPI) and on both the subject and object nouns.

We first hypothesised that the increase in spelling automation at the end of the primary grades would lead children to make few errors on PPI, regardless of the verb linguistic characteristics. Conversely, second and third graders would be particularly sensitive to the frequency of the verb (Negro et al., 2014). We expected to replicate the reversed frequency effect on PPI in younger writers, with more spelling errors on PPI when the verb was frequent versus rare (Negro et al., 2014). Our purpose here was to identify whether the reversed frequency effect is maintained when the consistency of the verb is manipulated. Negro et al. (2014) did not take this factor into account, whereas the literature suggests that younger children are particularly sensitive to consistency in spelling words (Hazard et al., 2020; Lété, 2008; Lété et al., 2008). Second, we postulated a relationship between the lexical and morphological cues; regardless of grade, writers should make more errors on PPI when the verb is inconsistent. Third, a cascading model of writing assumes that the spelling of all words in a sentence is not fully completed before handwriting starts. Verb unit spelling should be processed during the transcription of the subject noun. Thus, spelling a complex verb (rare and inconsistent) should affect the spelling accuracy of the subject noun. Furthermore, intraword pauses measured in adults revealed that spelling is resolved during the writing of that word (Maggio et al., 2012, 2015). This late processing is all the more important because the verb is inconsistent and rare, preventing the planning of the next word. That is to say, spelling errors of object nouns should also increase when they are preceded by a complex verb.

Method

Participants

One-hundred-and-fifty-four native French speakers in Nice (southern France) completed the task. The students were divided into four grades: 20 s graders (mean age: 7.97, ranging from 7.58 to 8.25), 45 third graders (mean age: 8.94, ranging from 8.33 to 9.42), 44 fourth graders (mean age: 9.99, ranging from 9.5 to 10.5), and 45 fifth graders (mean age: 10.99, ranging from 10.58 to 11.42), among whom 74 were female and 80 were male. None of the children had repeated a grade or had language difficulties.

In France, the government supervises school programmes and teaching practices. The primary grades are organized into three cycles (i.e. Cycle 1 from 3 to 5 to 6 years old depending on the child's birthday; Cycle 2 from the first to third grades; and Cycle 3 from the fourth to sixth grades, with the last grade belonging to secondary school). Concerning verb morphology, the French national programs specify that, as soon as Cycle 2 begins, children gradually develop the conjugation of the verb in the present, future, imperfect, and perfect (i.e. *passé composé*) tenses. Formal instruction of the perfect tense, which associates the auxiliary 'to have' or 'to be' in the present tense with the past participle form, begins in the middle of Cycle 2 with verbs of the first group (verb endings in *-é* such as *chanté/sung*) and

other frequent verbs of the second and third groups (with different endings, *m-is*, *sent-i*, *mord-u/put*, smelled, bitten). The teaching continues throughout Cycle 3 with all the other verbs. Past participle inflection is particularly complex for children with the [e] ending because various spellings may be associated with this phonologically plausible verb ending, including ‘*donner*’ in the infinitive form (to give), ‘*vous donnez*’ in the present tense (you give), ‘*donn-é, -ée, -és, -ées*’ in the past participle form (given) according to the agreement with the subject, as well as close phonological forms, such as ‘*je/tu donnais*’ (I/you gave), ‘*il/elle donnait*, and *ils/elles donnaient*’ (he/she/they gave) in the imperfect tense (see Brissaud et al., 2012).

Stimuli

The stimuli were composed of 40 sentences with the following syntactic structure: subject (always singular) + perfect verb (*a* + verb + PPI *-é*) + object (always singular) (e.g. *Le camion a heurté un lièvre*/The truck hit a hare; see Appendix 1).

The material was constructed with the Manulex (Lété et al., 2004) and Manulex-infra (Peereman et al., 2007) databases. The Manulex databases provide lists of the frequencies of non-lemmatised (48,886 entries) and lemmatised words (23,812 entries) compiled from the 1.9 million words obtained from 54 reading books used in French primary schools between the first and fifth grades. Word frequencies are given for four levels: first, second, and third to fifth grades (because frequency counts vary little across these grades), and all the grades combined. The first-grade Manulex lexicon served as the basis for verb selection because all participants were beyond this grade. However, verbs were retained only if their lemma frequencies were maintained across the five primary grades. Manulex-infra was used to select consistent or inconsistent words. Unlike frequency, this index varies little by grade.

Descriptive statistics of the experimental verbs are presented in Table 1 and were selected to fill the four conditions created by crossing verb lemma frequency (frequent verbs vs. rare verbs; Manulex: Lété et al., 2004) with verb total consistency (consistent verbs vs. inconsistent verbs; Manulex infra: Peereman et al., 2007). There were 10 verbs in each category. Verb lemma frequencies (per million words=U) were extracted from the Manulex database and indicated how many times a verb occurred in the entire Manulex corpus (first-to-fifth grades). Compared to the F index (occurrences of the word), the U index was preferred because it takes into account the total frequency of occurrences of words and the number of different books in which the words are encountered. Phonology-to-orthography consistency refers to the level of variability in the orthographic codes that can be assigned to a particular phonological unit. In this research, verbs were selected from Manulex-Infra (Peereman et al., 2007) according to the mean phoneme-to-grapheme consistency of the verbs in the PPI, which was constant (verb + *-é*). The verbs were not selected from Manulex-Morpho database, which consists of a smaller number of lexical entries than Manulex-Infra, especially for the rare verbs we needed to construct the experimental material (Peereman et al., 2013). However, to avoid a graphotactic effect of the letters preceding the verb ending past-participle *-é*, we controlled the final bigrams and trigrams bearing the verb endings. As in French

Table 1 Characteristics of the selected verbs

	Frequent and Consistent Verbs	Rare and Consistent Verbs	Frequent and Inconsistent Verbs	Rare and Inconsistent Verbs
Number of items	10	10	10	10
Mean number of letters	5.90	6.00	5.40	6.60
Mean number of syllables	2.40	2.50	2.20	2.70
Mean number of graphemes	5.50	5.50	4.30	4.90
Mean lemma verb frequency (U) and (standard errors) (min-max)	236.6 (124.3) (97.95–458.14)	17.5 (11.6) (5.13–37.94)	308.2 (228.9) (95.14–778.92)	13.9 (11.8) (1.57–32.45)
Mean verb consistency and (standard errors) (min-max)	82.53 (2.9) (75.65–86.73)	83.79 (1.2) (82.19–86.40)	46.93 (5.05) (39.41–53.72)	49.87 (4.2) (40.83–54.34)
Mean number of orthographic competitors (by token)	132.20	30.50	125.90	3.20
Mean number of phonographic competitors (by token)	82.80	6.40	18.90	0.10

Lemma verb frequency and verb consistency are calculated among the first to fifth grades of the Manulex and Manulex-Infra databases

the verb ending *-er* is on average more frequent than the verb ending *-é* (both corresponding to the sound [e]), consonants preceding endings were equally represented in each experimental condition (e.g., *-her* is more frequent than *-hé* regardless of the verb category; Frequent-Consistent: *touc-her*/to hit > *touc-hé*/hit; Rare-Consistent: *mouc-her*/to blow > *mouc-hé*/blew; Frequent-Inconsistent: *empêc-her*/to prevent > *empêc-hé*/prevented; Rare-Inconsistent: *embauc-her*/to hire > *embauc-hé*/hired). Manulex-Infra provided also positional consistency of words. Consistent verbs were such that the initial (I) and medial (M) phoneme-grapheme (PG) consistencies were both consistent (mean IPG=98.23 from 81.58 to 100; mean MPG=97.19 from 79.32 to 99.56 for medial). Inconsistent verbs selected were such that inconsistency concerned either the initial (mean IPG=43.46 from 0.8 to 100) or the medial (MPG=58.60 from 31.95 to 99.90) phoneme-grapheme consistency. And the final phoneme-grapheme consistency was the same for all verbs (past participle verb ending *-é*).

To construct sentences, subject and object nouns were also selected in the Manulex database. To ensure that participants would recognize subject and object nouns, highly frequent nouns (respectively, for subjects, $M=250.05$, and for objects, $M=248.82$), which were also highly consistent words (respectively, for subjects, $M=77.37$, and for objects, $M=75.30$), were selected in the lists for the first through fifth grades.

Four examples are listed below:

Frequent and consistent verb: *L'ours a rapporté un poisson* [The bear brought back a fish].

Rare and consistent verb: *L'avion a survolé la route* [The plane flew over the road].

Frequent and inconsistent verb: *L'homme a aidé son village* [The man helped his village].

Rare and inconsistent verb: *Le pompier a scié une branche* [The fireman sawed a branch].

Two practice sentences and ten filler sentences, all with a present verb and varying syntactic constructions, were added to the experimental sentences.

Procedure

The task required the participants to write 52 sentences that were provided orally. It was completed in two sessions due to the large number of sentences to be transcribed. The 40 experimental sentences and the ten fillers were pseudorandomly divided into two equal blocks in two sessions on separate days within the same week in spring. The first session began with the two practice sentences to ensure that the children understood the spelling task. Then, they were provided with a 27-page booklet during the first session and a 25-page booklet during the second session. The experimenter read each sentence aloud twice and provided a 'top' signal at the end. This 'top' signal cued the participants to transcribe the sentence on one page

of the booklet as quickly as possible. Then, the writers had to turn the page immediately after transcription and wait for the following sentence. Neither revisions nor corrections were allowed.

Results

The proportions of spelling errors were analysed for three dependent measures: (1) past participle inflection (PPI) spelling errors (verb ending errors independent of the spelling of the verb) (N); (2) subject noun spelling errors ($N-I$); and (3) object noun spelling errors ($N+I$).

When the verb was changed or absent in a sentence, the subject and object nouns of this sentence were also removed from the analyses. When the subject or object nouns were changed compared to those dictated, they were deleted from the analyses, such as a lack of responses. Then, the analyses of PPI (N) included 5917 data points (243 excluded), the analyses of subject noun spellings ($N-I$) focused on 5883 responses (277 deleted), and 5813 responses were included (347 excluded) in the analyses of object noun spellings ($N+I$).

The data were analysed with SPSS 25. A general linear mixed model (GENLIN-MIXED) was fitted for each dependent variable with verb frequency (frequent vs. rare), verb consistency (consistent vs. inconsistent), and grade (second, third, fourth, and fifth) as fixed main effects. The model also included interactions between various factors. A logit link function was chosen since our dependent variables were binary.

One random factor for participants was included in the model because of its significant contribution to the variance tested by the likelihood ratio test. This factor allowed us to take into account the dependence between our observations due to repeated measures. The random intercept for participants enabled the intercept to vary between participants. Furthermore, introducing random slopes (allowed to vary across participants) would have led us to consider seven mixed effects (one for each main effect, one for each dual interaction, and one for the triple interaction), which we did not consider relevant for our study. The absence of variability between items led us to not consider a random factor for the sentences.

In all analyses, only the significant effects are described in the text, and when necessary, completed with Bonferroni pairwise contrasts.

Analyses of past participle inflections (N)

The predictions of the general linear mixed model of spelling errors on PPI (see Appendix 2) are reported in Table 2 below.

There was an effect of grade ($p < 0.001$). Pairwise contrasts showed a difference, $t(5901) = 3.35$, $p < 0.01$, between third and fourth graders ($M = 0.386$, $SE = 0.073$, and $M = 0.116$, $SE = 0.034$, respectively). There were no differences between second and third graders (respectively, $M = 0.553$, $SE = 0.114$, and $M = 0.386$, $SE = 0.073$), $t(5901) = 1.23$, $p = 0.44$, or between fourth and fifth graders (respectively, $M = 0.116$,

Table 2 General linear mixed model results for spelling errors on past participle inflections according to grade, verb frequency, and verb consistency

Source	df_1	df_2	F	p
Grade	3	5901	7.699	.000
Verb Frequency	1	5901	4.357	.037
Verb Consistency	1	5901	6.324	.012
Grade * Frequency	3	5901	.604	.612
Grade * Consistency	3	5901	1.956	.118
Frequency * Consistency	1	5901	.552	.457
Grade * Frequency * Consistency	3	5901	1.573	.194

$SE=0.034$, and $M=0.163$, $SE=0.044$), $t(5901) < 1$. There was also an effect of verb lemma frequency ($p < 0.05$), with more errors on frequent verbs than on rare verbs ($M=0.289$, $SE=0.038$, and $M=0.257$, $SE=0.035$, respectively). Finally, an effect of verb consistency was highlighted ($p < 0.05$), with fewer errors on consistent verbs than on inconsistent verbs ($M=0.254$, $SE=0.035$, and $M=0.292$, $SE=0.038$, respectively).

Analyses of subject nouns (N-1)

The predictions of the general linear mixed model of spelling errors on the subject nouns (see Appendix 3) are reported in Table 3 below.

There was an effect of grade ($p < 0.001$). Pairwise contrasts showed higher proportions of errors in second graders ($M=0.464$, $SE=0.047$) than in third graders ($M=0.191$, $SE=0.02$), $t(5867)=5.39$, $p < 0.01$. Errors also decreased, $t(5867)=3.41$, $p < 0.01$, between third and fourth graders ($M=0.108$, $SE=0.014$), whereas there was no difference, $t(5867) < 1$, between fourth and fifth graders ($M=0.097$, $SE=0.013$). The proportions of errors on subject nouns varied with verb consistency ($p < 0.001$), with fewer errors on nouns followed by consistent verbs than inconsistent verbs (respectively, $M=0.129$, $SE=0.01$, and $M=0.257$, $SE=0.015$).

In addition, the Verb Frequency x Verb Consistency interaction (Fig. 1) was significant ($p < 0.001$), with a marginal reversed frequency effect, $t(5867)=1.838$,

Table 3 General linear mixed model results for spelling errors on subject nouns according to grade, verb frequency, and verb consistency

Source	df_1	df_2	F	p
Grade	3	5867	31.464	.000
Verb Frequency	1	5867	.737	.391
Verb Consistency	1	5867	120.740	.000
Grade * Frequency	3	5867	1.241	.293
Grade * Consistency	3	5867	2.219	.084
Frequency * Consistency	1	5867	13.932	.000
Grade * Frequency * Consistency	3	5867	1.356	.254

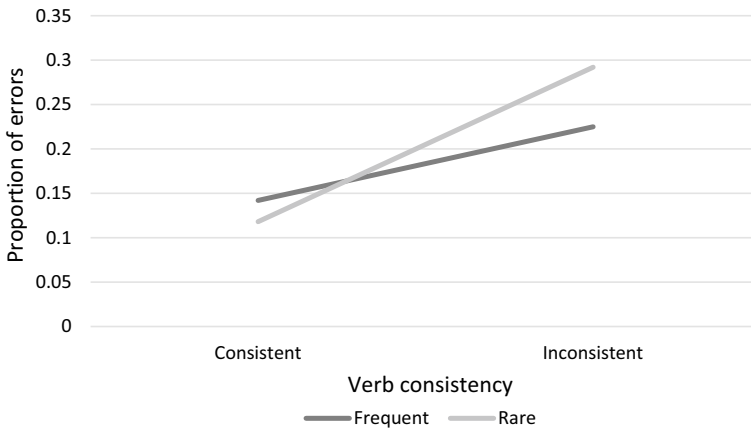


Fig. 1 Interaction between Verb Frequency and Verb Consistency on spelling errors on subject nouns

$p=0.066$, when verbs were consistent (frequent and consistent verbs: $M=0.142$, $SE=0.013$; rare and consistent verbs: $M=0.118$, $SE=0.011$) and a classical frequency effect, $t(5867)=3.67$, $p<0.01$, when verbs were inconsistent (frequent and inconsistent verbs: $M=0.225$, $SE=0.017$; rare and inconsistent verbs: $M=0.292$, $SE=0.019$). In summary, rarity and inconsistency of verbs were two difficulties leading to more errors on subject nouns.

Analyses of object nouns (N+1)

The general linear mixed model predicted spelling errors on object nouns (see Appendix 4) that are presented in Table 4.

There was an effect of grade ($p<0.001$). Pairwise contrasts showed that second graders ($M=0.449$, $SE=0.043$) made more spelling errors than third graders ($M=0.197$, $SE=0.019$), $t(5797)=5.32$, $p<0.01$, who in turn made more errors than fourth graders ($M=0.118$, $SE=0.014$), $t(5797)=3.35$, $p<0.01$. In contrast, no differences appeared between fourth and fifth graders ($M=0.134$, $SE=0.015$), $t(5797)<1$. There was also an effect of verb lemma frequency ($p<0.001$), with

Table 4 General linear mixed model results for spelling errors on object nouns according to grade, verb frequency, and verb consistency

Source	df_1	df_2	F	p
Grade	3	5797	26.263	.000
Verb Frequency	1	5797	28.532	.000
Verb Consistency	1	5797	.526	.468
Grade * Frequency	3	5797	.106	.957
Grade * Consistency	3	5797	3.235	.021
Frequency * Consistency	1	5797	3.142	.076
Grade * Frequency * Consistency	3	5797	3.770	.010

more errors on object nouns preceded by frequent verbs than by rare verbs ($M=0.235$, $SE=0.014$, and $M=0.173$, $SE=0.012$, respectively).

In addition, the Grade \times Verb Consistency interaction (Fig. 2) was significant ($p<0.05$). The effect of consistency appeared only in fifth graders: More errors appeared on object nouns when the preceding verb was consistent ($M=0.159$, $SE=0.019$) versus inconsistent ($M=0.113$, $SE=0.015$), $t(5797)=2.81$, $p<0.01$.

Finally, the critical Grade \times Verb Frequency \times Verb Consistency interaction (Appendix D) was significant ($p=0.01$). Indeed, the reversed frequency effect was registered in all grades, with more errors on object nouns preceded by frequent verbs versus rare verbs, but this effect was modulated by verb consistency and grade. In second graders, the reversed frequency effect emerged with consistent verbs (frequent and consistent verbs: $M=0.497$, $SE=0.055$; rare and consistent verbs: $M=0.349$, $SE=0.051$), $t(5797)=2.75$, $p<0.01$, but not with inconsistent verbs (frequent and inconsistent verbs: $M=0.49$, $SE=0.057$; rare and inconsistent verbs: $M=0.465$, $SE=0.056$), $t(5797)<1$. In third graders, it was only marginally significant with consistent verbs (frequent and consistent verbs: $M=0.221$, $SE=0.027$; rare and consistent verbs: $M=0.169$, $SE=0.023$), $t(5797)=1.894$, $p=0.058$, and significant with inconsistent verbs (frequent and inconsistent verbs: $M=0.241$, $SE=0.028$; rare and inconsistent verbs: $M=0.165$, $SE=0.023$), $t(5797)=2.69$, $p<0.01$. In fourth graders, it was not apparent with consistent verbs (frequent and consistent verbs: $M=0.121$, $SE=0.019$; rare and consistent verbs: $M=0.123$, $SE=0.019$), $t(5797)<1$, but significant with inconsistent verbs (frequent and inconsistent verbs: $M=0.169$, $SE=0.024$; rare and inconsistent verbs: $M=0.076$, $SE=0.014$), $t(5797)=3.98$, $p<0.01$. In fifth graders, as in fourth graders, the reversed frequency effect did not occur with consistent verbs (frequent and consistent verbs: $M=0.166$, $SE=0.023$; rare and consistent verbs: $M=0.152$, $SE=0.022$), $t(5797)<1$, but it was significant with inconsistent verbs (frequent and inconsistent verbs: $M=0.145$, $SE=0.021$; rare and inconsistent verbs: $M=0.087$, $SE=0.015$), $t(5797)=2.68$, $p<0.01$.

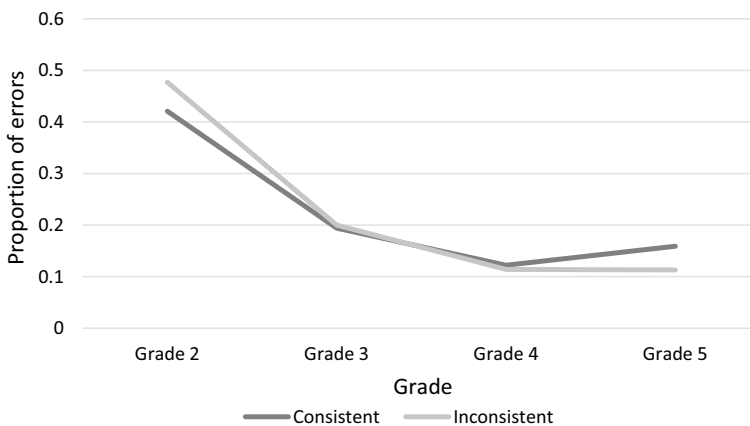


Fig. 2 Interaction between Grade and Verb Consistency on spelling errors on object nouns

In summary, the reversed frequency effect was registered in second graders only when verbs were consistent. For students in other grades, this effect disappeared with consistent verbs and emerged with inconsistent verbs.

Discussion

The experiment reported in this paper was designed to developmentally study the interactions between both lexical and grammatical cues in the spelling of words embedded in one sentence. Children from the second to fifth grades were asked to write orally dictated sentences in which PPI had to be added to a verb varying in frequency and consistency. All dictated sentences were of the form ‘singular subject + perfect verb (*a* + verb + PPI -*é*) + singular object’ (e.g. *Mon frère a habité cette ville* [My brother lived in this city]). The subject and object nouns were all frequent and consistent nouns to evaluate both the proactive and retroactive effects of verb orthographic complexity on the spelling of subject and object nouns. The proportions of spelling errors on PPI, on subject and object nouns were analysed according to the verb lemma frequency (U frequency from Manulex database) and consistency (mean phoneme-grapheme consistency selected from Manulex-Infra).

First, we postulated an effect of the grade on PPI errors and, most importantly, one interaction between the grade and the verb characteristics. As expected, errors on PPI decreased between third and fourth graders. These data replicated Negro et al.’s results (2014). Learning of the past participle inflections formally begins at school in the third grade. The grammatical rule in French implies adding the inflection -*é* to all verbs with the -*er* infinitive form (i.e. *chanter* [to sing]) and the auxiliary ‘*avoir*’ (have/has) conjugated in the present tense (when the object is positioned after the verb as in our experimental sentences). We anticipated that until the third grade, children would not use the grammatical rule governing the past participle inflection using a plausible phonological orthographic form to spell the end of the verb (Alamargot et al., 2015; Morin et al., 2018). From the fourth grade, the grammatical rule should be more regularly used, leading to fewer errors on PPI without any differences between fourth and fifth graders. However, the analysis of errors on PPI showed no interaction between the grade, frequency, and consistency of the verb but a principal effect of the frequency and consistency factors appeared regardless of grade. Children made more verb ending errors when the verb was inconsistent or frequent.

The impact of the consistency factor was predictable since inconsistent spelling was associated in the literature with an important proportion of errors. Lexical spelling studies have regularly shown that unit inconsistency affects word spelling from the first grade (Lété et al., 2008) to the ninth grade for rare words (Hazard et al., 2020). One possible explanation is that an inconsistent verb disrupts the PPI grammatical rule (has/have + verb + PPI -*é*). However, this inconsistency effect seems to persist from the second to fifth grade, while the grammatical rule is learned starting in second grade and would be mastered by fourth or fifth grade. It is possible that the use of the grammatical rule competes with an implicit strategy of verb form retrieval.

The hypothesis of an implicit verb form retrieval strategy was confirmed with the reversed lemma frequency effect; children made more errors on PPI when verb lemmas were frequent rather than rare. This effect replicated Negro et al.'s results (2014), who found that frequent PPI *-é* was associated with more errors when the verb was frequent rather than rare. No such effect was apparent with the rare PPI *-i*. The reversed frequency effect with the PPI *-é* replicated in our experiment highlights its robustness. It seems difficult to account for this pattern of results in the morphologically based framework of spelling rules because the implementation of rules implies that there is no orthographic-form frequency effect. In contrast, a statistically based learning framework may easily explain these results. We supposed that frequent verb lemmas should be associated with various phonologically plausible inflections rather than rare verb lemmas. The Manulex database provides the number of orthographic neighbours and phonographic neighbours associated with each word. Table 1 outlines these spelling competitors by token. The orthographic neighbourhood of a word corresponds to the number of words that are similar with one letter substitution compared to the target unit. The phonographic competitors are both orthographically and phonologically similar to the target word. The French language is such that, as reported in our experiment or in that of Negro et al. (2014), frequent lemmas are associated with a higher number of orthographic forms ($M = 129.05$), $F(1,36) = 10.288$, $p = 0.003$, and marginally with a higher number of phonographic competitors ($M = 50.85$), $F(1,36) = 3.79$, $p = 0.059$, than rare lemmas (respectively $M = 16.85$ and $M = 3.25$). The number of competitors tends to decrease with rare verbs because the variety and the frequency of endings for these verbs are lower. For example, in Manulex, the verb lemma '*scier/to saw*', which is rare, is associated with only three competitor forms, *sci-él/sawed*, *sci-er/to saw*, *sci-ait/sawed*, which rarely occur. Conversely, the frequent verb lemma '*porter/to carry*' has various competitor forms that are phonologically plausible—such as *port-él/carried*, *port-éel/carried*, *port-és/carried*, *port-ez/carry*, *port-er/to carry*, *port-ais/carried*, *port-ait/carried*—and orthographic competitors in nominal (*la portée/the scope*) or adjectival forms (*le regard porté sur l'horizon/the gaze on the horizon*). Furthermore, this verb '*porter/to carry*' may be associated with prefixes to form other verbs (*em-porter/to take away*, *im-porter/to import*, etc.).

A qualitative analysis of verb ending errors revealed that the main error consisted of adding the ending *-er* (74%) to the verb. This verb ending corresponds in French to the infinitive form, which is orthographically incorrect but phonologically plausible for the PPI *-é*. The *-er* pattern of errors was dominant in all grades (second grade = 69%, third grade = 79%, fourth grade = 80%, fifth grade = 74%). The more frequently the verb appears in French writing, the greater the probability of encountering the *-er* ending increases. For example, in Manulex, the U index frequency in grades 1 to 5 indicates that the infinitive *-er* is a much stronger competitor for the past participle *-é* when the writer has to write the past participle of a frequent verb ('*porter/to carry*' = 85.32 vs. '*porté/carried*' = 12.94) rather than a rare verb ('*scier/to saw*' = 7.61 vs. '*scié/sawed*' = 1.05). Children from primary grades tend to use this erroneous but plausible orthographic ending

to inflect a verb with the past participle. This implicit processing competes with grammatical rule learning.

Frequent ending errors could also result from spatial agency bias (SAB), reflecting the spatial position of nouns in a single sentence (Carnaghi et al., 2014). Regarding SAB, people apply a spatial schema of action, which is culturally determined: A more agentic group (men, masculine noun, or the more active or competent group) is to the left of a less agentic group (women, feminine noun, or the less active or competent group). In our experimental sentences, this was the case in all sentences, except for two (*La pluie a limité le feu*/The rain limited the fire; *La mère a mouché sa fille*/The mother blew her daughter). We could anticipate that a feminine subject noun leads to more errors in PPIs, such as *-ée*, than a masculine subject noun. However, errors with the ending *-ée* remained rare regardless of the gender of the subject nouns (5.52% with a feminine subject noun and 1.56% with a masculine subject noun), whereas ending errors *-er* were the most frequent (23.38% and 24.58%, respectively, for feminine and masculine subject nouns). Furthermore, the impact of verb lemma frequency was replicated here with different experimental sentences (different nouns and verbs) than those used in the experiment conducted by Negro et al. (2014). If SAB cannot explain the verb frequency effect, the place, and above all, the gender of the agentic group could affect the diversity of ending errors. A future study could investigate the weight of SAB in grammatical errors.

The second purpose of our research concerned the dynamics of spelling in sentences by studying the impact of verb frequency and consistency on the mean proportions of spelling errors on the nouns preceding and following the verbs according to grade.

As reported in the literature, the mean proportions of errors on nouns decreased progressively by grade (Hazard et al., 2020). For frequent and consistent words in isolated condition, Hazard et al. found that children from the second grade made more errors than third graders, who made significantly more errors than fourth graders, whereas there was no difference in the proportion of errors on nouns between fourth and fifth graders. The same results were replicated here in dictated sentences for both noun types (see Table 5), subject and object nouns (both frequent and consistent). These data confirmed a progressive acquisition of lexical spelling of frequent and consistent words. With words dictated in isolated condition, second graders successfully spelled 76% of frequent and consistent words, and proportions of correct responses reached a ceiling effect at the end of

Table 5 Comparison of correct responses (%) for frequent and consistent words between isolated condition (Hazard et al., 2020) and sentence conditions (this experiment)

	Isolated condition	Sentence condition (subject noun)	Sentence condition (object noun)
Grade 2	76	54	55
Grade 3	83	81	80
Grade 4	94	89	88
Grade 5	95	90	87

the primary grade (93–94%; see Hazard et al., 2020). The evolution of performance by grade was the same in the sentence conditions (see Table 5).

However, the percentage of correct responses was higher in the isolated condition than in the sentence conditions due to the impact of one word on the other in one sentence, particularly for second graders, and weaker for fourth and fifth graders. There was no difference between the conditions in third graders, who seemed to recover word spelling in the same way in both conditions. In second graders, word spelling is disrupted as soon as a word is embedded in a sentence because lexical spelling is not yet automated, which makes processing very costly when words are embedded in a sentence. In fourth and fifth graders, lexical processing is in the course of automation, but is sometimes disrupted in sentence conditions. The increase in the proportion of lexical spelling errors in the sentence conditions compared to the isolated condition suggests anticipatory and delayed effects on the words processed in sentences. Notwithstanding, the results showed that spelling errors of the noun preceding the verb (subject noun) do not depend on the same psycholinguistic characteristics of the verb as the noun following the verb (object noun). Spelling errors of the subject noun increased when the following verb was inconsistent, especially when it was rare. In contrast, the proportion of errors of the object noun was higher when the verb was frequent (reversed frequency effect) than when it was rare, regardless of grade, and when it was consistent in fifth grade only (reversed consistency effect). Frequency and consistency also interacted with grade, exhibiting a reversed frequency effect with consistent verb in second graders, a general reversed frequency effect in third graders, and a reversed frequency effect with inconsistent verb in fourth- and fifth-graders.

These findings imply that when children are writing the subject noun, they already anticipate the spelling of the verb. Then, they are more likely to make spelling errors on the subject noun when the verb is inconsistent rather than consistent, particularly when it is rare. These data are consistent with online measurements of latencies and writing duration. Kandel and Perret (2015) found that consistency strongly affected latencies and writing duration at least from the third grade, signaling that children resolve the conflict generated by an inconsistent word before writing it down. There was no such conflict with a consistent verb. In this condition, the percentage of correct spelling of the subject noun (Grade 2=60%; Grade 3=87%; Grade 4=93%; Grade 5=94%) approximated those in the isolated word condition (see Table 5), except in the case of second graders, for whom spelling recovery was disrupted by the sentence writing condition. The conflict generated by the inconsistency became all the more important as the verb was rare. Difficulty lexically (rare verb) and orthographically (inconsistent verb), in anticipation of the following word, affects the spelling of the subject noun. According to the EOLE database (Pothier & Pothier, 2002), the age of acquisition of our selected rare and inconsistent verbs in their infinitive form (lexical form) is later (mean percentage of correct spellings in grade 5=47%) than that of the other verbs (mean percentage of correct spelling in grade 5 for frequent consistent=87.80%; rare consistent=89.70%; frequent inconsistent=73.90%).

In contrast, and more surprisingly, the object noun was associated with more spelling errors when a frequent verb preceded it. As already mentioned for PPI, the frequency of the verb indexed the number of orthographic and phonographic neighbours. Then, the number of competitors previously activated during the writing of the verb (N) inhibited the possibility of anticipating the writing of the next noun ($N+1$). Furthermore, spelling errors of the object nouns increased among fifth graders when the previous verb was consistent, suggesting a reversed consistency effect. Such surprising outcomes have already been reported in online measurement studies from fifth to ninth graders (Maggio et al., 2012, 2015). Maggio et al. (2015) noted ‘a reversed consistency effect on noun writing rate and on intranoun pause’ without any clear explanation of this effect. Even if it is difficult to compare our data about spelling errors with online measurements of correct responses, this reversed consistency effect is robust in sentence production, whereas it has never been reported so far in word-isolated conditions. The analysis of the interaction between the frequency and the consistency factors according to grade helped us to better understand the processing of the object noun following the verb. Second graders made fewer errors on the object noun when the previous verb was rare and consistent, whereas the proportions of errors varied little in the other conditions. Hence, the younger writers were sensitive to the consistency of the verb and the frequency of competitors. When the verb was consistent and rare, there was little conflict. Furthermore, when the verb lemma was rare, the number of inflected verb forms activated simultaneously was lower than when the verb was frequent. In this condition, the younger participants were more able to plan for object noun spelling. In third graders, the spelling errors of the object noun increased when the previous verb was frequent, regardless of its consistency. The diversity of the written words encountered increased the number and frequency of the inflected verb forms that were phonologically similar but orthographically different (possible verb endings: *-é*, *-er*, *-ez*, etc.). The great number of plausible inflected forms activated would prevent planning the object noun spelling, leading to a higher proportion of errors for that noun. In other words, the number of spelling competitors always inhibited the possibility of correctly anticipating the spelling of the next noun ($N+1$). Finally, in fourth and fifth graders, the lowest proportion of errors on object nouns appeared when the preceding verb was rare and inconsistent, whereas the proportions of errors varied little in the other conditions. With rare and inconsistent verb, the mean frequency (U) of orthographic and phonographic competitors was lower (3.20 and 0.10, respectively) than with rare consistent verb (30.50 and 6.40, respectively). This implies that rare and inconsistent verb forms are stored as entire forms with few and rare orthographic and phonographic neighbours. This should allow writers to anticipate the spelling of the object noun. Conversely, the number and frequency of spelling competitors should inhibit the possibility of correctly anticipating the spelling of the next noun ($N+1$). These data address an important topic for research on spelling in sentences. To better specify the impact of the characteristics of one word on another within a sentence, it would be necessary to consider a study in which all words would be kept constant except for one.

Probabilistic models for knowledge spelling, such as the Integrative Multiple Patterns (IMP) model (Treiman & Kessler, 2014) or the fuzzy representation model

(Sénéchal et al., 2016), are currently used to account for spelling acquisition. The statistical-based learning framework states that alphabetic systems in each language are based on certain regularities. Our learning system would be such that it could process the language system according to the frequency of the data encountered (Ellis, 2002; Lété, 2008; Lété et al., 2008; Wells et al., 2009). For orthography acquisition, the statistical learning conception assumes that writers store the spelling of words according to probabilistic cues based on print exposure (Deacon et al., 2008; Lété, 2008; Pacton et al., 2005; Treiman & Kessler, 2006). This approach accounts for lexical spelling errors (Hazard et al., 2020) or grammatical errors on PPIs (Negro et al., 2014), demonstrating an impact of the frequency and consistency of words encountered in writing.

However, studying the dynamics of spelling in sentences shows that a word is not orthographically encoded as an isolated unit, which can be recovered regardless of the condition (Hazard et al., 2020). If so, the spelling of one unit would not depend on the others in a sentence. However, the probability of producing spelling errors of frequent and consistent nouns varied according to the spelling context (i.e. isolated words versus words in sentences), except in third grade. The higher proportion of errors in sentences suggests an impact of the relationship between the words. Analyses of online measurements, such as writing rates, pauses, and latencies to write different letters of one noun or noun phrase, have reported on correct responses and given some support to the cascading model (Van Galen, 1991). This model assumes that while word N is executed, the handwriting module processes unit $N+1$, while the spelling module addresses the orthographic representation of word $N+2$. Our purpose was to investigate the impact of one word on another by examining spelling errors. The fact that both nouns preceding and following the verb were affected by the psycholinguistic characteristics of the verb demonstrates the anticipatory and delayed effects in sentence writing. When the writer is executing the subject noun, he or she anticipates verb writing. This anticipation disrupts the subject noun spelling when the next verb to plan is inconsistent, especially if it is rare. Then, the PPI is planned during the execution of the verb, leading to higher errors with inconsistent or frequent verb, which activates different ending competitors. Finally, competition between orthographic and phonologic neighbours has a delayed effect on object noun spelling. The management of verb endings in competition prevents planning of the object noun spelling. This explains why errors on object nouns increase when the previous verb is frequent. Furthermore, while younger writers were sensitive to a consistent verb and easier to deal with, children at the end of the primary grades were more efficient in planning the object noun spelling when the verb was rare and inconsistent; that is, an orthographic form stored as a block without competitors. These data suggest that when composing texts, the writer processes several words in parallel and several dimensions of these words simultaneously. In written production, the diversity of the words used that vary in frequency and consistency adds a considerable amount of variance, which may be explained by grades and by the different psycholinguistic cues of the words used. This interpretation needs further investigation with online measurements.

These data have experimental and educational implications. First, they suppose that a dictation task of isolated words differs from a dictation task of words

embedded in clauses, sentences, or texts. To spell one word, the writer may recover the orthography of the word encoded in memory according to probabilistic cues encountered in written language. However, spelling words embedded in sentences implies recovering the orthography of each word while planning the next words of the sentence. As such, we cannot extend the results in isolated word tasks to more complex spelling tasks. Second, regarding educational methods, the findings signal that spelling acquisition at school needs to be planned progressively. For first and second graders, teachers can evaluate spelling abilities in the isolated condition only and first with consistent words (even if these words may be contextualized in a single oral sentence for meaning). This does not mean that younger children should not write dictated sentences or produce written text. Indeed, these tasks help to develop other abilities (such as working memory, planning ideas, selecting lexical units to express ideas, etc.), but spelling should not be evaluated, and it remains important for teachers to correct the spelling of words produced by children to prevent them from memorizing incorrect spelling. From third to fifth graders, teachers can evaluate spelling in sentence conditions with inconsistent words, which are first rare, to limit orthographic-form competitors and then more frequent words. In dictation and written production tasks, it is critical not to add supplementary difficulties such as lexical (e.g. rare and inconsistent words) and grammatical spelling complexities (e.g. forms with frequent competitors) until the end of the primary grades. Teachers cannot assume that children, when writing one sentence, will process the lexical spelling of each word and then apply the appropriate grammatical rules. Grammatical and lexical treatments are broadly interconnected (Bosse et al., 2021; Morin et al., 2018).

Appendix 1

Forty experimental sentences according to verb frequency and verb consistency.

Frequent and consistent verbs	1. <i>Mon frère a habité cette ville</i> /My brother lived in this city
	2. <i>Le papa a porté son bébé</i> /The dad carried his baby
	3. <i>L'ours a rapporté un poisson</i> /The bear brought back a fish
	4. <i>Le loup a hurlé une heure</i> /The wolf howled for an hour
	5. <i>Le corbeau a protégé son nid</i> /The raven protected its nest
	6. <i>Le danseur a tourné la tête</i> /The dancer turned his head
	7. <i>Le maître a préparé sa classe</i> /The teacher prepared his class
	8. <i>Le garde a levé la barrière</i> /The guard raised the barrier
	9. <i>Le ballon a touché le poteau</i> /The ball hit the pole
	10. <i>Le fermier a gardé son troupeau</i> /The farmer kept his flock

Rare and consistent verbs	<ol style="list-style-type: none"> 1. <i>Le camion a heurté un lièvre</i>/The truck hit a hare 2. <i>La pluie a limité le feu</i>/The rain limited the fire 3. <i>Le cheval a redouté le tonnerre</i>/The horse dreaded the thunder 4. <i>Le chef a varié le repas</i>/The chef varied the meal 5. <i>L'avion a survolé la route</i>/The plane flew over the road 6. <i>Le gendarme a détourné la voiture</i>/The gendarme diverted the car 7. <i>Le pirate a libéré la famille</i>/The pirate released the family 8. <i>Le robot a gravé un numéro</i>/The robot engraved a number 9. <i>La mère a mouché sa fille</i>/The mother blew her daughter's nose 10. <i>Mon père a vidé le poisson</i>/My father cleaned the fish
Frequent and inconsistent verbs	<ol style="list-style-type: none"> 1. <i>Le clown a arrêté le disque</i>/The clown stopped the disc 2. <i>Mon copain a compté son argent</i>/My friend counted his money 3. <i>Le fantôme a quitté le château</i>/The ghost left the castle 4. <i>Le gamin a crié son nom</i>/The kid shouted his name 5. <i>Le docteur a appelé la dame</i>/The doctor called the lady 6. <i>Le facteur a collé le timbre</i>/The postman stuck the stamp 7. <i>Le petit a serré sa maman</i>/The kid hugged his mom 8. <i>L'orage a empêché son départ</i>/The storm prevented his departure 9. <i>L'homme a aidé son village</i>/The man helped his village 10. <i>Le pêcheur a lancé son filet</i>/The fisherman launched his net
Rare and inconsistent verbs	<ol style="list-style-type: none"> 1. <i>Le chien a embêté le chasseur</i>/The dog annoyed the hunter 2. <i>Le garçon a égoutté la salade</i>/The boy drained the salad 3. <i>Le marchand a augmenté le café</i>/The merchant increased the coffee 4. <i>Le pompier a scié une branche</i>/The fireman sawed a branch 5. <i>Le soldat a emballé son fusil</i>/The soldier packed his gun 6. <i>Le bonhomme a arrangé sa chemise</i>/The guy arranged his shirt 7. <i>Le chat a déterré une souris</i>/The cat unearthed a mouse 8. <i>Mon cousin a embauché un jeune</i>/My cousin hired a young person 9. <i>Le professeur a effacé la faute</i>/The professor erased the mistake 10. <i>Le gardien a coincé le voleur</i>/The guardian caught the thief

Appendix 2

Error proportions (with standard errors) on the past participle from 2nd to 5th grade according to verb frequency (frequent vs. rare) and verb consistency (consistent vs. inconsistent).

	2nd Grade		3rd Grade		4th Grade		5th Grade	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Frequent	0.540 (0.121)	0.596 (0.118)	0.410 (0.079)	0.431 (0.080)	0.106 (0.034)	0.147 (0.045)	0.177 (0.050)	0.156 (0.045)

	2nd Grade		3rd Grade		4th Grade		5th Grade	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Rare	0.512 (0.121)	0.562 (0.120)	0.281 (0.066)	0.430 (0.080)	0.100 (0.033)	0.114 (0.036)	0.160 (0.046)	0.160 (0.046)

Appendix 3

Error proportions (with standard errors) on the subject noun from 2nd to 5th grade according to verb frequency (frequent vs. rare) and verb consistency (consistent vs. inconsistent).

	2nd Grade		3rd Grade		4th Grade		5th Grade	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Frequent	0.440 (0.057)	0.528 (0.059)	0.136 (0.021)	0.241 (0.029)	0.072 (0.014)	0.125 (0.020)	0.073 (0.014)	0.123 (0.020)
Rare	0.357 (0.054)	0.536 (0.058)	0.129 (0.021)	0.292 (0.033)	0.075 (0.015)	0.191 (0.026)	0.045 (0.011)	0.205 (0.027)

Appendix 4

Error proportions (with standard errors) on the object noun from 2nd to 5th grade according to verb frequency (frequent vs. rare) and verb consistency (consistent vs. inconsistent).

	2 nd Grade		3 rd Grade		4 th Grade		5 th Grade	
	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent	Consistent	Inconsistent
Frequent	0.497 (0.055)	0.490 (0.057)	0.221 (0.027)	0.241 (0.028)	0.121 (0.019)	0.169 (0.024)	0.166 (0.023)	0.145 (0.021)
Rare	0.349 (0.051)	0.465 (0.056)	0.169 (0.023)	0.165 (0.023)	0.123 (0.019)	0.076 (0.014)	0.152 (0.022)	0.087 (0.015)

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