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The development of children's sensitivity to bigram frequencies when spelling in Spanish, a transparent writing system

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Abstract The aim of this study was to collect data concerning the sensitivity of 2nd–6th grade Spanish-speaking children towards orthographic regularities. In a first experiment, children were asked to spell words that begin with /b/, a sound that is inconsistently spelled *b* or *v*, depending on the lexeme. Low frequency words were used to reduce the use of lexical information in spelling. In Spanish, the frequency of graphemes *b* and *v* depends on the following vowel; for example, in initial position, the bigram *vi* is more frequent than *bi* while *vu* is less frequent than *bu*. Evidence concerning the use of sublexical regularities in English and French—opaque orthographic systems—is already available. The question was whether such knowledge also applies in a more transparent system like Spanish, in which a phonologically based strategy is quite efficient. The main finding was that participants' spelling strongly depended on the relative frequency of bigrams. This was already evident in second graders' spelling and increased with schooling. In Experiment 2 these results were confirmed using pseudo-words. The results exclude a functional view of spelling, which supposes that orthographic resources are not used to spell in consistent orthographic systems, since phonologically based mechanisms are sufficient to override any others.

Keywords Implicit learning · Orthographic regularities · Self-teaching · Spelling acquisition · Spelling mechanisms · Transparent–opaque orthographic systems

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Introduction

Alphabetic orthographic systems differ considerably as regards the consistency with which they fulfil the ideal principle of one grapheme for each phoneme and vice versa. Relatively transparent orthographic systems such as Spanish, Italian, and some others are relatively consistent compared with more opaque systems like English and French. Interest in comparing systems has increased because previous models of reading and spelling were mainly based on studies carried out in English, the most opaque system of all European languages (Seymour, Aro, & Erskine, 2003). For this reason, doubts might be formulated about the advisability of generalizing English-based models to other systems (Share, 2008). The "orthographic depth hypothesis", in its strongest version, explicitly supposes that written word processing does indeed differ in opaque and transparent systems. In transparent, but not in opaque systems, written word processing is exclusively based on phonological prelexical computation (Frost, 2005; Katz & Frost, 1992, 2001; Ziegler & Goswami, 2005). This is probably because most of the words in transparent systems can be read and spelled using a limited set of fairly consistent rules. In languages like English and French, the relationship between spoken and written language is more complex so that reading and especially spelling (see below) is not possible using phonologically based mechanisms, and, in order to spell most words in these languages, huge doses of orthographic knowledge are required. Such knowledge has two dimensions. One is lexical, e.g. knowing that the French word *enfance* (chilhood) is spelled with *en* in the first syllable and with *an* in the second syllable cannot be derived from the pronunciation: /ã f ã s/. Correctly spelling *enfance* might result from possessing a completely specified orthographic representation of this word. The second source of orthographic knowledge is sub-lexical; for example, in French, the nasal vowel /ã/ is more probably spelled *en* than *an*, at the beginning of words. Using this sub-lexical orthographic information can help to correctly spell the word *enfance* without a lexical representation of it.

The aim of the present study was to explore the development of sub-lexical orthographic knowledge in Spanish-speaking children. For example, one important inconsistency in Spanish spelling is the phoneme /b/ which can be spelled *b* or *v*. A Spanish speller who correctly writes the word *vestíbulo* (hall) might be believed to have a lexical representation of it specifying the graphemes *v* and *b* in first and sixth position respectively. However a second source of orthographic knowledge might be considered. The examination of the relative frequencies of the bigrams formed by *b* and *v* followed by one of the five Spanish vowels: *a*, *e*, *i*, *o*, *u*, shows that *ve* is more frequent than *be*, while *bu* is more frequent than *vu*. So that, correctly spelling the word *vestíbulo*, might result from sub-lexical statistical knowledge. The question of interest is whether Spanish-speaking children do exploit this sub-lexical orthographic information. It has been argued that in consistent orthographic systems, readers and spellers do not exploit those sub-lexical orthographic resources because phonologically based mechanisms permit most words to be read and spelled (Katz & Frost, 1992, 2001). An alternative hypothesis is that the statistical properties of the orthographic system are passively acquired thought simple exposure to written material and do not depend on the degree of transparency of the system. The aim of the present study was to explore the development of sub-lexical orthographic knowledge in Spanish-speaking children.

Most of the comparative data available are confined to reading, not to spelling acquisition, see for example, Turkish with English (Öney & Goldman, 1984), German with English (Wimmer & Goswami, 1994), Dutch with English (Patel, Snowling, & de Jong, 2004), Spanish with Portuguese (Defior, Martos, & Cary, 2002), Spanish with French and English (Goswami, Gombert, & Barrera, 1998), English, Hungarian, Dutch, Portuguese and French (Ziegler et al., 2010), and Welsh with English (Spencer & Hanley, 2003). The main finding of this work might be summarized by the study made by Seymour et al. (2003), who compared thirteen European languages. The authors conclude that important differences in the rate of reading acquisition exist. In most of the languages considered the children became fluent and accurate at the foundation reading level by the end of the first school year. However, in English, and to a lesser extent in French, Portuguese and Danish, a similar level of reading ability was reached considerably later. The differences between European languages in the rate of reading acquisition depend on their degree of opacity.

Concerning spelling development, experimental studies are less numerous than they are in the case of reading (but see compilations by Brown & Ellis, 1994; Hulme & Joshi, 1998; Joshi & Aaron, 2006; Nunes & Bryant, 2004, for some contributions on this matter). Frith (1985) proposed a model whose basic feature was that orthographic knowledge develops following an alphabetic stage in which children grasp the notion that graphemes represent speech sounds. During the alphabetic stage, word spelling is exclusively based on phoneme-to-grapheme translation rules. Progressively, reading activity allows children to store orthographic representations of words successfully decoded. The "self-teaching hypothesis" proposed by Share (1995, 1999, 2004) captures a similar view. According to this author, orthographic representations of words are gradually stored in memory through the repeated identification of words using phonological decoding mechanisms. This hypothesis has been successfully tested in opaque orthographic system like English (Bowey & Muller, 2005; Caravolas, Hulme, & Snowling, 2001; Cunningham, 2006; Cunningham, Perry, Stanovich, & Share, 2002; Kyte & Johnson, 2006; Nation, Angell, & Castles, 2007), as well as in Hebrew, a transparent system (Share & Shalev, 2004). In more general terms, correlations between reading and spelling during the first years of school hold well in this theoretical context. More precisely, the "self-teaching hypothesis" has predicted significant correlations between phonological decoding and self-teaching related abilities. In the longitudinal study conducted by Caravolas et al. (2001) with English speaking first to third graders, regression analysis showed that skilled spelling was founded on decoding ability, which, in turn, enables the formation of orthographic representations. A similar conclusion was drawn in a longitudinal study conducted with French speaking children from first to fourth grade (Sprenger-Charolles, Siegel, Bechennec, & Serniclaes, 2003).

The "self-teaching hypothesis" also predicts that spelling development, and more specifically the spelling of words containing graphemes which cannot be derived from their phonology, is more rapid in transparent than in opaque systems. That is because word decoding is easier in the former than in the latter, so that specific representations of words will be more rapidly stored. Caravolas (2004) has examined this prediction comparing several studies conducted in two opaque systems, English and French, and one more transparent, Czech. She carefully examined factors determining the spelling of vowels, and concluded that the same underlying abilities, namely phonological awareness and letter knowledge, determined spelling development in all cases, but that the transparency-opacity dimension played an important role in determining the rate of learning to spell.

A recent study compared the development of orthographic representations of words in French, an opaque system, and Spanish, a more transparent system (Carrillo, Alegría, & Marín, 2013). The authors examined spelling abilities of high and low frequency words in primary school children. The result showed significant word frequency effects in Spanish as early as the beginning of the second grade, the youngest children examined. Similar effects appeared only at the end of second grade in the French group. The authors speculate that Spanish-speaking children learn to read words sooner than French children because Spanish words are easier to decode. This does not mean that French speaking children as young as first graders do not have orthographic representations of words. Martinet, Valdois and Fayol (2004) found word frequency effects in a dictation task involving high frequency words carefully chosen from the classroom books used by the children. Both studies are compatible with the notion that repeated exposure to words enables children to progressively elaborate orthographic representations in transparent as well as in opaque systems.

The experiments examined above were mainly concerned with two basic aspects of spelling development, one phonological, i.e. the ability to translate speech units into the corresponding orthographic units, and the other orthographic, i.e. the gradual elaboration of a lexicon containing complete information about word spelling. As mentioned above, the focus of the present work is a third level, i.e. the development of sub-lexical orthographic knowledge. This question is relatively well documented in opaque systems like English and French. For example, Treiman (1993) has shown that English-speaking children as young as first graders are sensitive to graphotactic regularities. Children sometimes erroneously use the grapheme *ck* for the phoneme /k/, although this almost never happens in initial position since no English word begins with this grapheme. These findings have been extended to other graphotactic regularities in English (Cassar & Treiman, 1997; Hayes, Treiman, & Kessler, 2006; Treiman, Kessler & Bick, 2002). In French, Pacton, Fayol, and Perruchet (2002) used a dictation task exploiting the fact that the phoneme /o/ admits several graphemes—*eau*, *au*, *o*, and several others—depending on its position in the word and on the consonantal context. They found that *eau* was more often used in final position than in the beginning or the middle of words. In addition, *eau* in final position was more frequently used after *v* than after *f*. Similarly, using a pseudo-word dictation task with primary school French-speaking children, Alegría and Mousty (1996) found that /s/ was sometimes incorrectly spelled *ss* in inner word position but almost never in initial position, reflecting the fact that /s/ → *ss* is a relatively frequent phoneme-to-grapheme pair but double consonants never occur in initial word position. Using a wordness task (*Tell me* *which one of these two pseudo-words looks more like a real French word*), Pacton, Perruchet, Fayol and Cleeremans (2001) demonstrated that children from first grade onwards show sensitivity to positional and frequency regularities for all of the graphemes composed of double letters. All of these findings match the graphotactic regularities of French orthography.

In a study run in Finnish, one of the most consistent alphabetic systems existing according to Seymour et al. (2003), Lehtonen and Bryant (2005) examined the sensitivity to formal aspects of orthography of primary school children. Their results showed that first graders correctly prefer double consonants in medial word position in order to spell long consonants. However, they do not adopt this strategy in initial word position in conformity with the formal principle, which prohibits double consonants in this position. The authors state that formal properties of the orthographic system are acquired before its functional rules. According to this notion, young Spanish-speaking children might be expected to show sensitivity to orthographic regularities in spelling.

Data concerning the sensitivity to orthographic regularities in Spanish spelling are not available. In the present study, spelling was used to this end because spelling requires the use of orthographic information. Spanish, despite being totally reliable at reading level, presents some spelling inconsistencies. For example:

- the phoneme /b/ can be spelled either *b* or *v* in every word position, except the consonantal clusters /bl/ and /br/, which are always spelled *b*;
- the phoneme /x/ followed by *e* or *i* can be spelled *g* or *j*;
- the phoneme /ɟ/ can be spelled *ll* or *y*;
- the vowel /i/ in word endings is sometimes spelled *y* instead of the usual *i*;
- the phoneme /θ/ followed by *e* or *i* is usually spelled *c,* but exceptionally spelled *z;*
- finally, the unsounded letter *h*, which cannot be derived from a phoneme.[1]

While any of these inconsistencies might be exploited to explore the development of orthographic knowledge, the phoneme /b/ in initial word position was adopted. As just mentioned, /b/ can be spelled either *b* or *v*. These phoneme-grapheme correspondences are quite frequent and typically give rise to problems for Spanish spellers. More importantly, the proportion of words beginning with *v*/*b* depends on the following vowel; with *e* and *i*, *v* is more frequent than *b* (*ve*/*vi* > *be*/bi), with *u*, it is *b* which is the more frequent (*bu* > vu), while in the case of *a* and *o*, *v* and *b* have similar frequencies.

The aim of this study was to determine whether primary school children demonstrate sensitivity to these graphotactic regularities. If this was the case, the participants' spelling would depend on the relative frequency of bigrams; i.e. *v* would be preferred to *b* before *e* and *i*, *b* would be preferred to *v* before *u*, and no difference would be found between *b* and *v* before *a* and *o*. In Experiment 1, words of very low frequency were used in order to minimize the impact of lexical knowledge for choosing between *v* and *b*, and so facilitate the emergence of the

[1] In Latin America and in some regions in Spain (notably the Canary Islands), the phoneme /s/ can be spelled *s*, *c* or *z*. This was not the case in the Spanish region where this experiment took place.

effects of sub-lexical regularities. A second experiment was carried out using pseudo-words.

Experiment 1

Method

Participants

The sample consisted of 220 Spanish-speaking monolingual children attending classes for normally developing students in two elementary schools in the province of Murcia (Spain). The schools recruited middle class children from the neighbourhood. The group included 65 students in grade 2 (mean age 7.7 years; range 7.3–8.2), 84 in grade 4 (mean age 9.6 years; range 9.3–10.2), and 71 in grade 6 (mean age 11.7 years; range 11.3–12). Parental and child informed assents were obtained.

Materials and procedure

Spelling task Infrequent words were used in the spelling task in order to minimize the influence of the orthographic lexicon. It would obviously have been possible to use pseudo-words to this end, but we felt that this might induce a simplistic spelling tendency consisting of adopting a default strategy, i.e. systematically using *b* or *v*, instead of exploiting all of the subject's orthographic knowledge to spell. However, taking some methodological precautions, pseudo-words were used in Experiment 2 in order to eliminate all possible lexical effect. The experimental words began with the phoneme /b/ followed by one of the five Spanish vowels: /a e i o u/. So that the target bigrams were: *ba, be, bi, bo, bu* and *va, ve, vi, vo, vu*. The words were chosen from two available lexical counts: Martínez and García's (2004) dictionary of frequencies of written words in 6- to 12-year-old children's books, and Lexesp (Sebastián, Cuetos, Martí, & Carreiras, 2000). Forty-nine words were chosen among the least frequent, five per bigram (except *vu* for which only 4 appropriate words were available in both dictionaries). Appendix 1 presents the list of words with their corresponding frequency in both the Martínez and García, and Lexesp counts (incidentally, it is reassuring that the correlations between the mean frequency of words beginning with each bigram in both dictionaries were high, $r = .67$ with *v-words* and $r = .71$ with *b-words*). In this experiment we considered the frequency of bigrams in initial word position exclusively. Appendix 2 represents the absolute frequency of the words (tokens) found in the children's and in the adults' dictionary, per bigram. Also included are the relative frequencies per bigram calculated as the ratio between the absolute frequency of a particular bigram (e.g. *vi*) and the addition of this frequency to the frequency of the alternative spelling (*vi* plus *bi*). In the discussions, only the values of the adults' dictionary will be considered. It can be seen, however, that the differences in bigram frequencies in both dictionaries are relatively small (the correlation between the relative frequencies of bigrams in both dictionaries was $r = .98$). The decision to use the initial position was motivated by data showing that participants are more sensitive to orthographic regularities appearing in word beginnings (Alegría & Mousty, 1996; Treiman & Kessler, 2005; Pacton et al., 2002). It was expected that if orthographic regularity effects did exist, they would first appear in initial word position. Appendix 2 also represents their relative frequency regardless of the position in the word (columns All Positions). The few differences between initial and all positions were relatively weak. Besides, in all counts *v* showed the strongest association with *e* (*ve* > *be*) and *b* the strongest with *u* (*bu* > *vu*). Finally, the frequency of word types appears in Appendix 3. Note first that differences between the relative frequencies of types and tokens are relatively weak. The main question of interest was whether a small number of very frequent types beginning with a particular bigram might spuriously increase the relative frequency of the tokens sharing the same bigram. For example, the rather frequent verb *vivir* (to live) might be responsible for the high relative frequency of *vi*. This risk can be strayed; the most frequent word beginning by /bi/ was *bien* (well, goodness) which begins with *b*. At the other end of the scale of relative frequencies of bigrams, the most frequent words beginning by /bo/ and /bu/ were *vosotros* (you) and *vuestro* (your), spelled with *v*, not with *b*.

The experimental words were mixed in a fixed random order with 50 other words which do not begin with /b/, and split into three lists of 33 words. The six possible orders of presentation of these three lists were given to groups of participants in three separate sessions of 10–15 min. The tests took place in the participants' classroom. The words, experimental as well as fillers were included in sentences. The experimenter read the whole sentence aloud, and then repeated the word to be spelled in isolation. Participants were given an answer sheet on which they were asked to spell the dictated words in numbered places prepared for this purpose.

Reading ability test The global reading ability of each participant was assessed using TECLE, a forced choice sentence completion test (Marín & Carrillo, 1999). The test consisted of 64 sentences with a missing word. Four alternatives were proposed for each sentence and the participant had to choose the correct one. All of the incorrect alternatives were orthographically similar to the target; two were pseudo-words and the third one was a real word (e.g. for the correct response *problema* the pseudo-word foils were *probrema* and *proglema*, and the word foil was *protesta*). Subjects read silently and completed as many sentences as they could in 5 min. The subject's score was the number of correct responses. As the participants progressed from the first sentence, the complexity of the task increased; sentences became longer, words less frequent, and syntactic, cognitive and pragmatic aspects of the sentences more complex. For example, the first sentence was: *Tu pelota es de color… rogo, roco, robo, rojo* (The colour of your ball is… *red)*, and the last one: *Ten mucho cuidado para que la máquina no caiga al agua, ya que no es… sumergible, sumengible, sunergible, sustituirle* (Be very careful the machine doesn't fall into the water, because it is not… *submersible*). Before the test began, two examples were shown to the participant. The reliability of this test was evaluated using the test–retest technique on 376 primary school children with an interval of about one month between tests (Cuadro, Costa, Trias, & Ponce de León, 2009). The correlation was strong and significant ($r = .88$, $p < .001$).

Results

The results will first be examined considering the tendency to use the grapheme *v* to spell the bigrams being examined included in words beginning with *v* or *b*. The alternative spelling *b* will not be considered because it was the exact complement of *v* (no other responses were observed). Two covariates will then be introduced in the main analysis: the reading level of the participants and the relative frequency of the bigrams. The former aimed to ascertain whether individual differences in reading determine differences in spelling. The latter was aimed at considering the possibility that the differences observed between bigrams can be totally or partially explained in terms of the relative frequency of the bigrams.

Table 1 presents the mean percentage of *v* responses (spelling *v*) per bigram and grade. The columns headed *v-words* represent the percentages obtained with words beginning with the grapheme *v*. Similarly, the mean percentages of *v* responses for *b-words* appear in the columns *b-words*. The most striking fact coming out from Table 1 is that the use of *v* depended much more on the following vowel than on the target word to be spelled, whether *v-* or *b-word*. It must be remembered that, in accordance with the conventional spelling, *v* responses were correct for *v-words*, while they were spelling errors in the case of *b-word*. The relative ordering of bigrams (*vu* less than *vo* − *va* less than *ve* − *vi*), which is mostly the same in *v* and *b-words*, fairly closely corresponded to the relative frequencies of the bigrams, as shown in Appendix 2. Moreover, the trend to use the grapheme *v* increased with grade for *v-words* (28, 37, and 52 % in 2nd, 4th and 6th grades, respectively) but remained globally unchanged with *b-words* (26, 23 and 27 % in 2nd, 4th and 6th grades, respectively). This is probably due to an enhancement in lexical knowledge from second to sixth grade, which made that *v* was progressively more used in *v-words* and less in *b-words*. Finally, it is worth noting that the use of the grapheme *b*, the complement of *v*, to spell /b/ was largely dominant. In second grade, *b* reached about 75 % of spellings for *v-words* as well as for *b-words*. The grapheme *b* was still used in about 50 % of the cases by sixth graders to spell *v-words*, which was an error according to conventional spelling.

A preliminary global 2 × 5 × 3 (Type of word × Bigram × Grade) ANOVA was carried out with repeated measures in Type of word (*v-words* and *b-words*) and Bigram, taking the percentage of *v* spellings as dependent variable. The main effects of Type of word and Grade were highly significant in both analyses, by participants as well as by items: $F_1(1, 217) = 177.70, p < .001, \eta^2 = .45$, and $F_2(1, 39) = 30.66$, $p < .001, \eta^2 = .44$ for Type of word, and $F_1(2, 217) = 8.52; p < .001, \eta^2 = .07$, and $F_2(2, 78) = 47.08; p < .001, \eta^2 = .55$, for Grade. The Bigram effect was strong and highly significant in both analyses: $F_1(4, 868) = 147.72, p < .001, \eta^2 = .41$, and $F_2(4, 39) = 20.25, p < .001, \eta^2 = .68$. The pattern of results differed between *b-* and *v-words*, the Type of word by Bigram interaction being significant in the

Table 1 Mean proportions of v-spelling (and standard deviations in parentheses) per grade for *v-words*, *b-words* (Experiment 1) and pseudowords (Experiment 2) as a function of bigrams

	2nd grade			4th grade			6th grade		
	v-words	b-words	ps-words	v-words	b-words	ps-words	v-words	b-words	ps-words
/bu/	.20 (.28)	.18 (.26)	.14 (.21)	.23 (.24)	.08 (.15)	.15 (.17)	.31 (.27)	.06 (.17)	.26 (.20)
/ba/	.24 (.28)	.24 (.30)	.23 (.26)	.26 (.25)	.19 (.21)	.23 (.18)	.43 (.31)	.19 (.26)	.45 (.31)
/bo/	.25 (.29)	.22 (.27)	.18 (.25)	.34 (.30)	.16 (.20)	.24 (.21)	.54 (.26)	.21 (.20)	.46 (.26)
/be/	.31 (.34)	.30 (.32)	.35 (.30)	.48 (.26)	.29 (.25)	.37 (.28)	.58 (.26)	.35 (.27)	.53 (.21)
/bi/	.38 (.35)	.34 (.32)	.33 (.28)	.54 (.30)	.44 (.28)	.48 (.25)	.73 (.26)	.55 (.29)	.59 (.25)
Total	.28 (.28)	.26 (.23)	.25 (.10)	.37 (.24)	.23 (.21)	.29 (.15)	.52 (.27)	.27 (.22)	.46 (.16)

participants analysis, $F_1(4, 868) = 3.88$, $p = .004$, $\eta^2 = .02$, but not by items $F_2(4, 39) < 1$, $\eta^2 = .04$.

In order to provide a clearer account of the results, two new 5 × 3 (Bigram × Grade) ANOVAs were run, one for *v-words* and the other for *b-words*, with repeated measures in Bigram, and taking the percentage of *v* spellings as dependent variable.

Analysis of v-words

In the case of *v-words*, ANOVA by participants showed that both main effects were highly significant, as was their interaction: $F_1(4, 868) = 82.83$, $p < .001$, $\eta^2 = .27$, for Bigrams; $F_1(2, 217) = 20.46$; $p < .001$, $\eta^2 = .16$, for Grade; and $F_{1(8,\ 868)} = 5.51$, $p < .001$, $\eta^2 = .05$, for Bigrams x Grade interaction. Similar results were obtained in the ANOVA for items: $F_2(4, 19) = 6.72$, $p < .002$, $\eta^2 = .59$, for Bigrams; $F_2(2, 38) = 57.38$, $p < .001$, $\eta^2 = .75$, for Grade; and $F_2(8, 38) = 2.23$, $p = .047$, $\eta^2 = .32$, for their interaction. In post hoc comparisons of by participants' data (Tukey's HSD test), comparisons between grades showed that second and fourth differ at a significance level of $p = .011$, while the other two comparisons (2nd–6th and 4th–6th) reached $p < .001$. In post hoc comparisons of by items' data (Tukey's HSD test), comparisons between bigrams showed significant differences between *va* and *vi* ($p = .009$), *va* and *vu* ($p = .040$) and between *vi* and *vu* ($p = .002$), so that bigrams could be grouped into three homogeneous sets which differed significantly from each other: $vu - va - vo < va - vo - ve < vo - ve - vi$.

A separate ANOVA considering exclusively second grade data showed that the Bigram effect was already significant at this school level, $F_1(4, 256) = 9.44$; $p < .001$.

Analysis of b-words

This analysis showed the highly significant effects of Bigram and its interaction with Grade in the ANOVA by participants, $F_1(4, 868) = 104.63$, $p < .001$, $\eta^2 = .32$, for Bigram, and $F_1(8, 868) = 7.31$, $p < .001$, $\eta^2 = .06$, for Bigram x Grade interaction, but failed to reach the significance effect for Grade ($F < 1$). As is clearly apparent in Table 1 (columns *b-words*), the percentage of responses *v* with *b-words* remained globally unchanged across grades at about 25 %. Importantly, different bigrams evolved differently: *bu* items, for example, presented the lowest score in second graders but still decreased slightly with schooling, while *bi* items had the highest level but increased from second grade onwards.

The ANOVA by items basically confirms the analysis by participants: $F_2(4, 20) = 17.22$, $p < .001$, $\eta^2 = .77$, for Bigram; $F_2(2, 40) = 3.30$, $p = .047$, $\eta^2 = .14$, for Grade; and $F_2(8, 40) = 5.49$, $p < .001$, $\eta^2 = .52$, for Bigram x Grade interaction. Post-hoc comparisons between grades (Tukey's HSD test) showed that none of the differences was significant. Post-hoc comparisons between bigrams (Tukey's HSD test) showed significant differences ($p < .001$) for five of the ten comparisons: *bi* differed significantly from *be*, *bo*, *ba* and *bu*, and *be* differed significantly from *bu*.

A separate ANOVA of second grade data showed the Bigram effect was already significant at this school level, $F_1(4, 256) = 8.84$; $p < .001$.

Analysis of covariates

In both ANOVAS by participants (*v-words* and *b-words*), the reading level of the participants was introduced as covariate. The effects of Grade disappeared, $F_1(2, 216) = 2.78$, $p = .065$, $\eta^2 = .02$, for *v-words*; and $F_1(2, 216) = 1.02$, *n.s.*, $\eta^2 = .009$, for *b-words*, but not the effects of Bigram, $F_1(4, 864) = 4.20$, $p = .002$, $\eta^2 = .02$ for *v-words* and $F_1(4, 864) = 2.35$, $p = .052$, $\eta^2 = .01$ for *b-words*, indicating that reading level and schooling are confounded, whereas sensitivity to orthographic regularities, as revealed by the bigram effect, was not totally explained by reading level.

Similarly, in both ANOVAs by items (*v-words* and *b-words*), the relative frequency of *v* bigrams in initial position (see Appendix 2) was introduced as covariate. For *v-words* the effect of Bigram disappeared, $F_2(3, 19) = 1.51$, *n.s.*, $\eta^2 = .19$, suggesting that the differences between them were totally due to differences in relative frequency. For *b-words* the effect of Bigram diminished but remained significant, $F_2(3, 20) = 5.65$, $p < .006$, $\eta^2 = .46$.

Discussion

The aim of this study was to collect data concerning the sensitivity to orthographic regularities in Spanish-speaking children. The participants were asked to spell low frequency words beginning with graphemes *b/v* followed by vowels *a, e, i, o*, or *u*. The question was whether primary school children would demonstrate sensitivity to these graphotactic regularities. The main finding was that participants' spelling depended on the relative frequency of bigrams. The grapheme *v* was more frequent than *b* with *e* and *i*, while *b* was the more frequent with *o* and *u*. The effect of bigram frequency was already evident in 2nd graders and increased with schooling. It might be argued that the results were obtained using words as stimuli, and so the contribution, at least partial, of lexical resources to spelling cannot be excluded. Besides it is reasonable to assume that the use of lexical information increased with grade. In order to control for this factor a second study was carried out, similar to Experiment 1, but using pseudo-words in place of low frequency words.

Experiment 2

Method

Participants

The sample consisted of 104 Spanish-speaking monolingual children attending classes for normally developing students in an elementary school in the province of Murcia (Spain). The school recruited middle class children from the neighbourhood. The group included 40 students in grade 2 (mean age 7.6 years; range 7.0–8.1), 31 in grade 4 (mean age 9.7 years; range 9.2–10.1), and 33 in grade 6 (mean age 11.7 years; range 11.2–12.3). Parental and child informed assents were obtained.

Materials and procedure

Spelling task The experimental pseudo-words began with the phoneme /b/ followed by one of the five vowels: /a, e, i, o, u/. Forty pseudo-words beginning with /b/ were constructed, four per each vowel: /ba − be − bi − bo − bu/. The pseudo-words were of 2 or 3 syllables with 5–7 phonemes (i.e. /ber-ko/, /bi-su-ko/, /bo-ren/). The experimental pseudo-words were mixed in a fixed random order with 74 words without any restriction concerning their frequency, and split into three lists of 38 items. The six possible orders of presentation of these three lists were given to groups of participants in three separate sessions of 10–15 min. The tests took place in the participants' classroom. The pseudo-words, as well as the word fillers were included in sentences. The fact that some items were not Spanish words was not mentioned. The experimenter told the children that some of the "words" to spell might be unknown but that they must spell them as correctly as they could. At each trial the experimenter read the whole sentence aloud, and then repeated the word or the pseudo-word to be spelled in isolation. Participants were given an answer sheet on which they were asked to spell the dictated items in numbered places prepared for this purpose. The sentences containing pseudo-words had been constructed in a way that these items became plausible words (e.g. Los esquimales untan el pan con *boren*, [Eskimos put *boren* on their bread]).

Reading ability test As it was done in the first study, the global reading ability of each participant was assessed using the TECLE test.

Results

The results will first be examined looking at the use the grapheme *v* to spell the five bigrams now included in pseudo-words. Then, as it was done in Experiment 1, the reading level of the participants and the relative frequency of bigrams will be used as covariates in the statistical analysis. The former was aimed at determining which part of the individual differences in spelling could be explained by the reading level, while the latter was aimed at examining whether the differences between bigrams could be explained in terms of bigram relative frequency.

Table 1 (columns of pseudo-words) presents the mean percentage of *v* responses for experimental pseudo-words per bigram and school year (response *b* was not considered because it was the exact complement of *v*). The inspection of data shows that the tendency to use the grapheme *v* to spell /b/ increases from /bu/ to /bi-be/. This is exactly what was expected if the participants tended to adapt their spelling to the bigram's frequency. Besides, the use of *v* increases with school grade (25, 29, and 46 % in 2nd, 4th and 6th grade respectively).

Two 5 × 3 (Bigram × Grade) ANOVAs were carried out, by participants and by items, with repeated measures in Bigram, taking the percentage of *v* spellings as dependent variable. The ANOVA by participants showed that both main effects were highly significant, as was their interaction: $F_1(4, 404) = 44.09$, $p < .001$, $\eta^2 = .30$, for Bigrams; $F_1(2, 101) = 11.13$; $p < .001$, $\eta^2 = .18$, for Grade; and $F_1(8, 404) = 2.231$, $p = .025$, $\eta^2 = .04$, for Bigrams x Grade interaction. In the ANOVA by items only the main effects were significant: $F_2(4, 35) = 29.53$, $p < .001$, $\eta^2 = .77$, for Bigrams; $F_2(2, 70) = 55.31$, $p < .001$, $\eta^2 = .61$, for Grade; the Bigram by Grade interaction was not significant: $F_2(8, 70) = 1.69$, *n.s.*, $\eta^2 = .16$. Post-hoc comparisons between grades (Tukey's HSD test) showed that second and fourth grades did not differ significantly but both differed from sixth grade ($p < .001$ for 2nd–6th, and $p = .003$ for 4th–6th comparisons). Post-hoc comparisons between bigrams (Tukey's HSD test) showed that all of the pairs of bigrams differed significantly (at least at $p < .01$) except *va* − *vo* and *ve* − *vi* which were not significantly different, so that bigrams can be grouped into three sets which differed significantly from each other: *vu* < *vo* − *va* < *ve* − *vi*.

In the ANOVA by participants the reading level of the participants was introduced as covariate. The main effect of Grade diminished but remained significant, F_1 (2, 100) = 4.77, $p = .011$, $\eta^2 = .09$, while the effects of Bigram and its interaction with Grade were not significant, $F_1(4, 400) = 1.55$, *n.s.*, $\eta^2 = .02$, and $F_2(8, 400) = 1.51$, *n.s.*, $\eta^2 = .03$ for Bigram and Bigram by Grade interaction, respectively.

Similarly, in the ANOVA by items the relative frequency of bigrams with *v* in initial position (see Appendix 2) was introduced as covariate. Both main effects, Bigram and Grade, remained significant, while they diminished considerably: $F_2(3, 35) = 4.06$, $p = .014$, $\eta^2 = .26$ for Bigram and $F_2(2, 70) = 4.41$, $p = .016$, $\eta^2 = .11$, for Grade.

Discussion

The main finding of Experiment 1 was that primary school children, including second graders, demonstrate sensitivity to the graphotactic regularities of Spanish orthography. This result, which was obtained with words of low frequency, was clearly replicated in Experiment 2 using pseudo-words. Some small differences appeared between the experiments. In the first case, the effects of bigram disappeared as a significant factor when their relative frequency was introduced in the analysis. In Experiment 2, however, the effect diminished considerably (F_2 values decreased from 35.31 to 4.06), as well as its contribution to the variability among items (from $\eta^2 = .61$ to $\eta^2 = .26$)). It is hard to understand why bigram frequency explained the whole bigram effect in low frequency words (Experiment 1), but gave only a partial account of pseudo-word spelling (Experiment 2). It might be suspected that pseudo-words tend to encourage a simplistic strategy consisting of systematically spelling /b/ using the grapheme b. The procedure used in Experiment 2 was aimed at reducing the effects of this potential artefact. More work is necessary to elucidate this question and the first step will be to set up an experiment in which the same participants spell words presenting a large variety of frequencies mixed with a small proportion of pseudo-words. It might be expected that in this condition both words and pseudo-word will be treated in the same way.

General discussion

The main question of the present study concerned the development of sensitivity to the relative frequency of bigrams in words beginning /b/. The results showed that the use of *v* or *b* strongly depended on the following vowel: *v* was preferred to *b* before *i* and *e* while *b* was preferred to *v* before *u*. The effects of the vowel on the choice of *b* or *v* either disappeared when the relative frequency of bigrams was statistically controlled, as in the case of *v-words*, or fell considerably, as happened with *b-words* and pseudo-words. The bigram frequency factor accurately predicted the choice of *b* or *v*. The present results confirm, in a more transparent system, those obtained in English using a spelling production task by Treiman et al. (Cassar & Treiman, 1997; Hayes et al., 2006; Treiman, 1993; Treiman & Kessler, 2006; Treiman et al., 2002), and in French with wordness tasks, that is, using pseudo-words (Pacton et al., 2001). As mentioned in the introduction, the effects of graphotactic regularities depend on their position in the orthographic items, word or pseudo-words, the beginnings and endings being more salient than the more central parts (Alegría & Mousty, 1996; Pacton et al., 2002; Treiman & Kessler, 2005). This was the reason which led us to begin by examining the possible effects of graphotactic regularities in initial word position. Experiments currently being undertaken by the authors are aimed at comparing initial and non-initial positions.

The present result obtained in a relatively transparent system, as well as those reported by Lehtonen and Bryant (2005) in Finnish, excludes a functional view of spelling inspired by the "orthographic depth hypothesis" (Katz & Frost, 1992, 2001). This theory supposes that in orthographic systems with a relatively high degree of transparency, readers and spellers do not exploit orthographic resources, either lexical or sub-lexical, because phonologically based mechanisms are sufficiently efficient to override the others. The present results, as well as those reported by Lehtonen and Bryant (2005) with Finnish-speaking children, both using spelling instead of reading ability, show that young children do possess knowledge about formal properties of their orthographic system despite its consistency. These authors convincingly argued that formal aspects of orthography are acquired before functional rules.

It is worth quoting in the present context the results obtained in Brazilian Portuguese with preschool children who were able to spell words that were dictated but whose spelling productions were not based on phonology or on spellings of the target words (Kessler, Pollo, Treiman, & Cardoso-Martins, 2012; Pollo, Kessler, & Treiman, 2009; Pollo, Treiman, & Kessler, 2008). The results showed that the frequency of the bigrams found in children's spelling corresponded to the frequency of these bigrams in books available to them. This indicates that children as young as four and half years were already sensitive to statistical properties of the orthographic system, and that this occurred before they showed sensitivity to the alphabetic principle. Nonetheless, the adjustment between bigram frequency in pre-schoolers spelling and bigram frequency in their books was a good predictor of their performance in a standardized spelling test two and half years later. Surprisingly, the popular notion that children use the letters of their own names to begin to spell was indeed observed, but this tendency was not correlated with future success in the spelling test. Importantly, sensitivity to statistical properties of the orthographic system seemed to be the real precursor of spelling ability and it was already present before the child began to consider that spelling reflects phonology (see below).

Before discussing the possible mechanisms underlying the acquisition of orthographic knowledge, it might be useful to look at the difference observed between *b* and *v*, which was quantitatively important ($\eta^2 = .44$–.45 Type of word effect by participants and items, respectively, in the global analysis, Experiment 1) and might interfere with the main question. Nonetheless, it reveals some interesting aspects concerning the development of spelling in Spanish-speaking children. Most of the participants used the grapheme *b,* as default spelling despite it being less frequent than *v* (42 % of occurrences in initial word position).[2] This trend might result from several convergent factors. First, *b* comes before *v* in the alphabetic list (2nd and 24th places, respectively, in the Spanish alphabet) and students learn the /b/ → *b* pair before the /b/ → *v*. The letter's names might also have favoured the use of grapheme *b,* whose name is /be/, nearer the phoneme /b/ than the name of the letter *v*, which is named /ube/. Several studies carried out in English have demonstrated that letter names play a not negligible role in word spelling, especially at the beginning of the learning process (Pollo, Treiman, & Kessler, 2008; Treiman, 1994, 2006).

The tendency to use *b* was fairly strong in second grade and fell away with schooling. Second graders used the grapheme *b* 74 % of the time with *b-words* but 72 % with *v-words* (Experiment 1), and 75 % with pseudo-words (Experiment 2). The absence of any difference between *b*- and *v-words* indicates that the conventional spelling of words had a weak impact, if any, on the choice between graphemes *b* and v. Moreover, the use of *b* was similar in pseudo-word spelling (Experiment 2). Two points are to be highlighted. First, the absence of any lexical

[2] If all word positions were considered, b was slightly more frequent than v in the children dictionary (53.5 %). It is difficult however to admit that this small advantage could explain the strong tendency to use b as default spelling.

effect, words and pseudo-words were similarly spelled, and second, the insensitivity to conventional spelling, *b*- and *v-words* were almost identically spelled. This showed that the low frequency words used in Experiment 1 do not belong to the repertoire of orthographic representations of second graders. Hence, the presence of a clear and significant effect of bigram frequency demonstrated that sensitivity to orthographic regularities was already present at this school level.

The tendency to adopt the grapheme *v* increases in pseudo-words (from 25 % in second grade to 46 % in sixth grade) indicating that the use *b* as default spelling faded. Simultaneously, the difference between *b*- and *v-word* increased because participants gradually adopted the conventional spelling. However, this tendency remained relatively modest because the words used in Experiment 1 were of low frequency. In sixth grade for example, children produced 73 % of *b* spellings for *b-words*, correct responses from a conventional point of view, but with *v-words*, *b* spellings still reached 48 %, that is, almost half of the responses were spelling errors according to conventional Spanish orthography. To summarize, this evolution with schooling reveals changes in the underlying spelling mechanisms. The participants were moving from a primitive strategy, the default *b* spelling, towards a more sophisticated strategy including two sources. First, the progressive emergence of the orthographic lexicon: as just mentioned, in sixth grade *b* was more frequently used with *b*- than with *v-words*. Second, and more importantly, the ongoing development of graphotactic knowledge, which was already present in second grade.

As regards the possible mechanisms involved in acquisition of these two sources of orthographic knowledge, a first candidate was the "self-teaching hypothesis" proposed by Share (1995, 1999, 2004) and its ancestor, the stage-like version by Frith (1985). The basic claim of these authors is that orthographic representations of words are gradually stored in memory through the repeated identification of words using phonological decoding mechanisms (using the alphabetic procedure in Frith's formulation). The key words of these models are phonological decoding and repetition. As was reported in the Introduction, the major prediction of this theory has been successfully tested in English as well as in some more transparent orthographic system. Several studies have established significant correlations between phonological decoding and self-teaching related abilities (for example, Caravolas, Hulme, & Snowling, 2001; Cunningham, 2006; but see Nation et al., 2007, for some restrictions to a strict application of this notion). In a similar vein, a recent study comparing the development of orthographic representations of words in French and Spanish, the former more opaque than the latter, have shown that the word frequency effect appeared earlier in Spanish than in French (Carrillo et al., 2013; see also Caravolas, 2004). The authors speculate that orthographic representations, which underlie word frequency effects, develop more rapidly in Spanish because written words in this language are easier to decode than French words. Spanish learners begin to identify words on their own earlier than French learners. This difference might be easily interpreted in the frame of the "self-teaching hypothesis". The question now is whether the "self-teaching hypothesis" might adequately account for the graphotactic sensitivity phenomenon observed in the present study.

While the "self-teaching hypothesis" provides a general description for the acquisition of orthographic representations of specific words, it is unclear how it deals with the acquisition of formal sub-lexical knowledge, as observed in the present study. The principal problem with the "self-teaching hypothesis" concerns the ambiguity of the notion of orthographic knowledge. It might mean either specific knowledge about written words and/or statistical knowledge about the orthographic system. A Spanish-speaking speller might correctly spell words like *buey* (beef) and *verde* (green) using the graphemes *b* and *v* respectively, because these words belong to his orthographic lexicon or because, according to his statistical knowledge of Spanish orthography, *bu* is more probable than *vu* and *ve* is more probable than *be*. It is important to disentangle these two aspects of "orthographic knowledge", and a careful examination of the factors involved in the development of each is indispensable. It is interesting that phonological decoding, the basic mechanism underlying storing specific word representations, was not involved in the acquisition of statistical orthographic knowledge in Brazilian-Portuguese children (Kessler et al., 2012; Pollo et al., 2009).

All of the data reported here concerning sensitivity to orthographic regularities are more easily handled in the theoretical context of implicit learning whereby whole words have no special status (Brown & Loosemore, 1994; Pacton et al., 2001; Pacton, Fayol, & Perruchet, 2005; Pacton & Perruchet, 2006). It is, indeed, conceivable that the "self-teaching hypothesis" is nothing but a special case of implicit learning. Unfortunately, studies considering a possible dissociation of these two mechanisms are lacking.

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Appendix 1

See Table 2.

Table 2 List of words and frequencies of their corresponding lemmas (number of tokens per million) in Martínez and García (2004) (M&G) and LEXESP dictionaries

V-words	Tokens per million		B-words	Tokens per million	
	M & G	LEXESP		M & G	LEXESP
Vainas (pods)	3.85	3.55	Baches (potholes)	3.08	2.49
Varicela (chicken pox)	2.31	0.00	Bancal (plot of land)	0.77	1.24
Vasallo (vassal)	3.46	2.66	Baranda (railing)	1.92	3.91
Vadean (they ford a river)	1.54	0.89	Batía (he/she beats)	11.54	19.18
Vagaron (they wandered)	3.46	11.72	Balancea (he/she rocks)	21.15	7.28
Verdugo (executioner)	3.08	8.88	Berzas (cabbages)	1.92	0.89
Vejiga (bladder)	10.77	3.55	Betún (polish)	1.54	2.13
Venado (deer)	3.46	3.20	Becerro (calf)	12.69	1.60
Veneran (they venerate)	5.77	9.77	Beneficia (he/she benefits)	4.62	50.98
Verifica (he/she verifies)	1.92	12.61	Berrea (bellowing)	11.54	1.95

Table 2 continued

V-words	Tokens per million		B-words	Tokens per million	
	M & G	LEXESP		M & G	LEXESP
Vigor (vigour)	11.54	7.82	Biela (connecting rod)	1.92	0.89
Viruela (smallpox)	1.15	4.09	Birrete (biretta)	0.38	0.18
Viruta (wood chip)	5.38	0.53	Bisagra (hinge)	1.92	1.78
Vibran (they vibrate)	0.00	8.70	Birlo (he/she pinches/robs)	1.15	1.60
Vierte (he/she pours)	6.54	12.97	Bizquea (he/she squints)	1.54	1.24
Voraces (voracious)	2.69	3.55	Borrasca (storm)	1.92	2.31
Voltaje (voltage)	1.92	1.24	Bólidos (sports cars)	3.46	1.07
Volutas (scrolls)	0.77	1.60	Boceto (sketch)	0.38	2.13
Volcaba (it turned over)	6.92	19.01	Bogando (prowing)	1.15	0.36
Vomito (vomit)	13.08	11.90	Bostezan (they yawn)	16.92	3.91
Vulgares (vulgar)	10.77	23.98	Butifarra (Catalan sausage)	0.77	2.31
Vudú (Voodoo)	0.38	0.89	Buche (craw)	2.69	2.31
Vuelcan (they capsize)	7.69	19.01	Buñuelo (fritter)	6.92	1.78
Vulnera (he/she violates)	0.77	4.80	Burlo (I tease)	0.00	17.76
			Bufaba (he/she puffed)	6.92	1.42

Appendix 2

See Table 3.

Table 3 Number of occurrences (token frequency) of words containing the target bigram in initial and all positions, and relative frequency per bigram (Vx/[Vx + Bx]) in Martínez & García (M & G) and LEXESP dictionaries

Bigrams	Initial position				All positions			
	Absolute frequency		Relative frequency		Absolute frequency		Relative frequency	
	M & G	LEXESP	M & G	LEXESP	M & G	LEXESP	M & G	LEXESP
VU	1,772	3,181	.194	.255	2,147	4,144	.127	.201
VA	10,176	15,353	.489	.430	24,476	46,461	.307	.342
VO	8,608	9,092	.546	.538	18,714	32,384	.553	.605
VE	23,797	33,805	.909	.858	39,577	69,385	.674	.699
VI	16,429	29,836	.745	.780	35,984	64,942	.507	.504
BU	7,364	9,302	.806	.745	14,752	16,520	.873	.799
BA	10,627	20,390	.511	.570	55,324	89,574	.693	.658
BO	7,154	7,806	.454	.462	15,138	21,157	.447	.395
BE	2,376	5,589	.091	.142	19,126	29,832	.326	.301
BI	5,635	8,432	.255	.220	34,989	63,914	.493	.496
V_Tot	60,782	91,267	.577	.572	120,898	217,316	.465	.496
B_Tot	33,156	51,519	.423	.428	139,329	220,997	.535	.504

The corpus consists of 2.6 million words in M & G and 5.6 million in LEXESP dictionaries

Appendix 3

See Table 4.

Table 4 Number of different words (type frequency) containing the target bigram in initial and in all positions, in Martínez & García (M & G) and LEXESP dictionaries

Bigrams	Initial position		All position	
	M & G	LEXESP	M & G	LEXESP
VU	51	80	171	195
VA	460	639	2,411	3,497
VO	328	370	1,451	2,258
VE	795	997	2,702	3,347
VI	753	1,051	2,921	3,573
BU	368	462	1,081	1,363
BA	1,020	1,493	7,104	7,689
BO	531	737	1,611	2,142
BE	383	605	1,364	1,890
BI	251	490	1,706	2,634
V_Tot	2,387	3,137	9,656	12,870
B_Tot	2,553	3,787	12,866	15,718

The corpus consists of 2.6 million words in M & G and 5.6 million in LEXESP dictionaries

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