LANGUAGE AND COGNITIVE PROCESSES
2006, 21 (5), 531–561

Psychology Press
Taylor & Francis Group

French and Spanish-speaking children use different visual and motor units during spelling acquisition

Sonia Kandel

Laboratoire de Psychologie et NeuroCognition (CNRS), Université Pierre Mendès France, Grenoble, France and Centro de Estudios Lingüísticos y Literarios, El Colegio de México

Sylviane Valdois

Laboratoire de Psychologie et NeuroCognition (CNRS), Université Pierre Mendès France, Grenoble, France

This study used a copying task to examine spelling acquisition in French and Spanish from a perception and action perspective. Experiment 1 compared French and Spanish-speaking monolingual children's performance. Experiment 2 analysed the behaviour of bilingual children when copying words in French and Spanish. Gaze lift analysis showed that in French, first graders tend to use letter and syllable-sized visual units. The analysis of handwriting production indicated that they used syllable-sized units for motor programming. In Spanish, most words were copied without gaze lifts, as whole orthographic units. The children used units larger than the syllable for motor programming. The results suggest that the differences in the orthographic characteristics of French and Spanish lead to differences in the size of the visual and motor units the children use during spelling acquisition.

Correspondence should be addressed to Sonia Kandel, Université Pierre Mendès France, Laboratoire de Psychologie et NeuroCognition (CNRS UMR 5105), B.P. 47, 38040 Grenoble, Cedex 09, France. E-mail: Sonia.Kandel@upmf-grenoble.fr

We are extremely grateful to Juliana Montefiore, Luis Kandel, and Manuel Sánchez del Río; this study would have been impossible without their valuable contribution and enthusiasm. Special thanks to Rebeca Barriga Villanueva from El Colegio de Mexico for her support during the stay of the first author in Mexico. We thank the schools Escuela de Valle, Casa de los Niños, Ambroize Croisat, Lesdiguières, and Lycée Franco-Mexicain. We are also grateful to Carlos J. Alvarez, Elsa Spinelli, Marie-Line Bosse, and Raúl Marcó del Pont. Many thanks to Kathy Rastle, Manuel Carreiras, and another anonymous reviewer who helped us improve the manuscript.

http://www.psypress.com/lcp DOI: 10.1080/01690960500095946

The relationship letters and sounds have in a language determines the way in which children process the words they have to write. We used a copying task to examine this issue from a perception and action perspective. When a child has to copy a word, he/she does a visual analysis of the input letter-string. This information is coded and stored temporarily in the working memory (i.e., the graphemic buffer). This code serves as input to the motor system that will program the movement to write the word. The programming system then generates a motor output that will be used to execute the actual handwriting gesture. Before the child is able to copy the word globally, as a whole spelling unit, he/she segments it into sub-lexical units that vary in size as his/her capacities and lexical knowledge increase with age (Kandel & Valdois, 2006). Therefore, the copying task can provide an insight into the nature of the spelling units mediating perceptual and motor processes. This research examined how the orthographic differences between French and Spanish lead to differences in the visual and motor units the children use during spelling acquisition.

Studies on reading acquisition have shown the importance of phonological knowledge in alphabetic languages. There are studies in German (Ziegler & Jacobs, 1995), English (Berent & Perfetti, 1995), French (Sprenger-Charolles, Siegel, Béchennec, & Serniclaes, 2003), Spanish (Defior, Justicia, & Martos, 1996), Hebrew (Frost, 1995), Italian (Tabossi & Laghi, 1992), Persian (Lukatela & Turvey, 1991), among others. The way in which phonemes are represented by the alphabetical system varies among the languages and may lead to differences in literacy acquisition (Seymour, Aro, & Erskine, 2003). In French and English, for instance, the relationship between graphemes and phonemes can be very complex whereas in German, Italian, or Spanish it is almost unambiguous so that reading and spelling can be reversible operations in most cases (Katz & Frost, 1992). Several studies have shown that children speaking languages with a shallow orthography acquire reading skills earlier than English-speaking children. There are differences with Italian children (Cossu, Shankweiler, Liberman, & Gugliotta, 1995; Cossu, Shankweiler, Liberman, Katz, & Tola, 1988; Lindgren, Derenzi, & Richman, 1985; Thorstad, 1991), Serbo-Croatian children (Ognjenovic, Lukatela, Feldman, & Turvey, 1983), German children (Frith, Wimmer, & Landerl, 1998; Wimmer & Goswami, 1994; Wimmer & Hummer, 1990; Wimmer, Landerl, Linortner, & Hummer, 1991), Turkish children (Oney & Goldman, 1984) and Finnish children (Muller & Brady, 2001). According to the *psycholinguistic grain size theory* (Goswami, Ziegler, Dalton, & Schneider, 2001; Ziegler & Goswami, 2005; Ziegler, Perry, Jacobs, & Braun, 2001), readers of shallow orthographies learn to read earlier because they rely on grapho-phonological correspondences; i.e., small grained units of the size of the phoneme. In deep orthographies like English, readers rely on phonemes but also on bigger units like rimes. Since they have to deal with psycholinguistic units of different linguistic levels, reading skills take longer to acquire.

The present study focuses on the idea that in shallow orthographies *reading units* are indeed small (Goswami, Gombert, & Fraca de Barrera, 1998; Jimenez, Alvarez, Estevez, & Hernandez-Valle, 2000) but *spelling units* should be large. The straightforward relations between letters and sounds in shallow orthographies facilitate phonological recoding and should enable the children to encode more orthographic information in memory (Share, 1995, 1999). More orthographic information results in large and detailed processing units. The spelling units should thus be large and quite specified (Perfetti, 1992). Conversely, in deep orthographies, the child has to deal with a variety of unit sizes when encoding orthographic information. The spelling units should thus be small and less specified during the acquisition period because their elaboration requires the coordination of information from different levels. This hypothesis arose from the fact that in Spanish, children acquiring literacy skills have a higher level of performance in writing than in reading (Manrique, 1993). Moreover, less skilled readers can spell many words that they cannot read and have equivalent spelling abilities as skilled readers (Manrique & Signorini, 1994). These authors affirm that '... in Spanish ... reading ability does not keep pace with spelling.' (Manrique & Signorini, 1994, p. 438). This also happens in Italian, where the children spell most of the words they can read and even some they cannot read (Thorstad, 1991). Children learning deep orthographies like English read more words than they can spell (Shankweiler, 1992; Stuart & Masterson, 1992; Thorstad, 1991). This suggests that in Spanish spelling units should be bigger than reading units. In French reading units should be bigger than spelling units. This investigation aims to examine this prediction in a French–Spanish cross-linguistic study.

French has rather complex grapho-phonological relationships that can be described by a vast set of grapheme to phoneme conversion rules. These rules sometimes concern simple graphemes with one-to-one letter to sound correspondences but can also be very complex, involving groups of letters like *au* (/o/) in *cause* (/kozə/) and *aient* (/ɛ/) in *étaient* (/ɛtɛ/). There are at least 34 complex graphemes, i.e., graphemes of more than one letter (Catach, 1995). Other complex rules are linked to context, like *an* is pronounced /an/ before a vowel like in the word *analyse* (/analizə/) but /ã/ before a consonant like in *antenne* (/ãtɛnə/). With these rules 95% of the French words can be read correctly (Gak, 1976). French is relatively consistent from spelling to phonology, but highly inconsistent from phonology to spelling (Ziegler, Jacobs, & Stone, 1996).

Spanish has a similar syllabic structure to French, but a simpler orthographic set of rules (Seymour et al., 2003). Most Spanish words can be read by applying one-to-one grapho-phonological correspondences. It only has three two-letter graphemes (*rr*, *ch*, *ll*) and few graphemes that depend on context (*c* is pronounced /s/ and *g* is pronounced /x/ before *e* and *i*, also *qu* + *e* or *i* yields /ke/ or /ki/, *gu* + *e* or *i* /ge/ or /gi/, and *gü* + *e* or *i* /gue/ or /gui/ but the latter is rare). It should be pointed out, however, that a Spanish-speaking child must acquire a vast visual lexicon in order to write correctly (Iribarren, Jarema, & Lecours, 2001). There are some phonemes that can be spelt in different ways. For instance, /b/ can be written either B or V, and /s/ can be written S, C or Z in Latin American Spanish. Thus, to learn how to read and write, a French child has to learn a large and very complex set of rules and has to consider context systematically. In contrast, a Spanish-speaking child will have to acquire a more limited number of rules and word context should not be used as often as in French. The idea underlying this research was that these important differences between the two languages will lead to differences in the type of units used during the acquisition of writing skills. The French children should rely on small spelling units because they have to deal with information of different linguistic levels to elaborate orthographic representations. The Spanish-speaking children should be able to rely on large spelling units because phonological recoding is rather simple and automatic in their language, thus facilitating the memorisation of orthographic patterns (Share, 1995, 1999).

To examine this issue, this study used a copying task because it provides information on the spelling units the child uses during visual parsing and the programming of motor outputs. The child produces a gaze lift because he/she needs more information on the spelling of the following letter-string. The information may not be available for several reasons. One possibility is that the child has not seen the word before, so the orthographic information is non-existent in memory. Perhaps, he/she has already seen the word, but the information he/she has is partial or underspecified (Perfetti, 1992). The location of the gaze lift within the word serves as indicator of sub-lexical segmentation (Humblot, Fayol, & Lonchamp, 1994; Kandel & Valdois, 2006; Rieben, Meyer, & Perregaux, 1989; Rieben & Saada-Robert, 1991; Transler, Leybaert, & Gombert, 1999). It thus provides information on the size of visual spelling units. At the motor level, movement duration modulations reveal information on the variables that regulate the child's handwriting gesture (Van Galen, 1991). Handwriting results from a series of processing levels that are organised in a hierarchical structure. The linguistic modules of handwriting – activation of intentions, concepts, syntax, and spelling – are higher in the hierarchy than the more local parameters like letter size, stroke direction, and force. Various processing levels can be active simultaneously. The processing capacities of the motor system are relatively limited, so parallel processing results in duration increases (Van Galen, Meulenbroek, & Hylkema, 1986). The location of duration peaks within the word provides information on the kind of units the motor system recovers to write it. The copying task is therefore a precious tool to investigate how the child segments the letter-string from a visual input, elaborates a graphemic representation of its spelling and uses it to program the handwriting gestures needed to write it down.

Kandel and Valdois (2006) used a copying task to study the acquisition of writing skills in French. The children copied bi-syllabic words and pseudo-words of varying length. First and second graders lifted their gaze very often, decomposing most of the items into their syllable components. Third, fourth, and fifth graders copied most items as whole orthographic units, without producing any gaze lifts. The analysis of movement duration revealed that all the children programmed their movements syllable-by-syllable, regardless of lexical status and item length. Therefore, for first and second graders, the syllable serves as a common spelling unit that allows them to coordinate visual inputs and motor outputs. The articulation of inputs and outputs through a common unit is of particular importance for the acquisition of writing skills because there is a linguistically oriented coherence between perceptual parsing and motor programming. This facilitates the recovery of orthographic information from the buffer at the spelling level of handwriting production. Then, the syllable is 'unwrapped' into its letter constituents at the lower levels of the writing process.

We examined whether the orthographic differences of French and Spanish lead to differences in the size of the visual and motor units first and second graders use. We expected the French children to rely on letter and syllable-sized units. In Spanish, the children should rely on syllable and whole word visual and motor units. A syllable effect may appear because in Spanish children the frequency of the initial syllable plays a major role in activating lexical candidates during visual word recognition (Jimenez, Guzman, & Artiles, 1997; Jimenez & Rodrigo, 1994). Experiment 1 compared French and Spanish-speaking monolingual first and second graders' copying behaviour. In Experiment 2, bilingual French–Spanish children copied the words in both languages. The French–Spanish differences in orthographic shallowness should lead to differences in the size of the spelling units, both at the visual and motor levels.

EXPERIMENT 1

Method

Participants. A total of 75 right-handed children participated in this experiment. Among the French monolinguals, there were 23 first graders (mean age 6;8 ranging from 6;0 to 7;1, $\sigma = 4$ months) and 18 second graders (mean age 7;8 ranging from 7;0 to 8;3, $\sigma = 5$ months). They were all pupils of two schools of the Grenoble urban area and were tested in March. We made sure that their mother tongue was French. The teachers reported the reading method was mixed. Among the Spanish-speaking monolinguals, there were 16 first graders (mean age 6;8 ranging from 6;1 to 7;2, $\sigma = 5$ months) and 18 second graders (mean age 7;9 ; ranging from 7;1 to 8;7, $\sigma =$ 7 months). These children attended two schools in the State of Mexico and were tested at the end of January and the beginning of February. Their mother tongue was Spanish. The teachers reported the reading method was based on grapho-phonological correspondences. In the French, as well as in the Mexican schools, reading and writing explicit instruction started in first grade. None of the participants were repeating or skipping a grade and they were attending their grade at the regular age. They all had normal or corrected-to-normal vision and reported no hearing impairments, learning disability, brain, or behavioural problems. School attendance was regular.

Material. As in Frith et al.'s (1998) study, the children copied French–Spanish orthographic cognates in order to have an equivalent material in both languages. Cognates are words that share common orthographic roots and have the same meaning in both languages (Appendix 1). They were 4–10 letters long and had 2–4 syllables. The French and Spanish words had the same number of letters and only differed in one letter in most cases (e.g., *incendi***e**-incendi**o** or *import***ar**-*import***er**). To control for lexical frequency we used the LEXIQUE data base for French words (New, Pallier, Ferrand, & Matos, 2001) and a data base for Spanish words (Alameda & Cuetos, 1995). Lexical frequency was variable, ranging from very frequent words like *entr***e**-*entr***e** (frequency values yield 1026.48 pm in French and 1685 pm in Spanish) to rather unfamiliar words as *insect***e**-*insect***o** (frequency values yield 6.03 pm in French and 8 pm in Spanish). All the words have similar frequencies in both languages (Appendix 1) with a mean frequency of 65.27 pm in French and 91.37 pm in Spanish ($t(24) = -.31$, $p = .75$). None of the words had any diacritics or accents, since they have different values in French and Spanish and could lead to eventual biases. The matched words in French and Spanish included the same sequence of two letters that corresponded to a complex grapheme in French (a phoneme which is represented by two letters). For example, in the word ***on**de* (/õdə/which means *wave*) the *on* in French represents the phoneme /õ/. This implies that *o* and *n* cannot be dissociated if the word is to be written correctly. The French target complex grapheme was, of course, not complex in Spanish, where *o* = /o/ and *n* = /n/, and can be written correctly if dissociated. The target graphemes were either vowel-consonant (VC, e.g., ***on**de-**on**da* /õdə/-/onda/), vowel-vowel (VV, e.g., ***au**se-c**au**sa* /kozə/-/kawsa/) or consonant-consonant (CC, e.g., ***gn**e-si**gn**o* /siŋə/-/signo/). Note that in the latter category of words (four words in total) the syllable structure is different in both languages: in French, the *g* and *n* belong to the same syllable (e.g., *si/gne*) whereas in Spanish, they are separated (e.g., *sig/no*). The target grapheme was embedded in the first syllable, except for the four CC words. To avoid biases due to the high degree of inconsistency of French orthography, the 24 words were consistent and regular, either feedforward or feedback (Ziegler et al., 1996): *on* in *onde* is unambiguously /õ/; *en* in *entre* and *entrer* is unambiguously /ã/; *in* in *insecte*, *insulte*, *interne* etc. is unambiguously /ɛ̃/; *im* in *importer* and *imprimer* is always /ɛ̃/ because it is followed by a *p*; *au* in *cause*, *pause*, etc. is unambiguously /o/, because the /o/ sound in French initial syllables is the closed /o/, which is noted *au* (e.g., *pose* is pronounced /pɔs/ with an open ɔ and means *to pose* and not *pause*); *gn* is always noted /ŋ/ and cannot have a different spelling. In addition, in the copying task, the child could see the correct spelling of the word as long as he/she desired. Also, the target grapheme was always embedded in the first syllable so the child had the correct spelling available since the beginning of the task.

Procedure. Each word was presented in front of the child, on the centre of the screen of a laptop written in lower case Times New Roman font size 18. An auditory signal and a fixation point (200 ms duration) preceded word presentation. The participants' task was to copy the item on a digitiser (Wacom Intuos 1218, sampling frequency 200 Hz, accuracy 0.02 mm). The digitiser was connected to a computer (Sony Vaio PCG-FX203K) that monitored the motor gesture the child executed. The children were instructed to copy the items as they did in class, i.e., in cursive handwriting. They had to write with a special pen (Intuos Inking Pen) on a lined paper that was stuck to the digitiser; this paper is like the one they usually use to write on when they are in school (the vertical limit is 0.8 cm and the horizontal limit is 17 cm). The children became familiar with the material by writing their name. Two practice items (*maison-casa* which mean *house* and *chat-gato* which mean *cat*) preceded the experiment. No time limit or speed constraints were imposed. The following word was presented once the child accomplished the previous one. Each time the child lifted his/her gaze, the experimenter pressed the space bar of the laptop's keyboard. A special computer program notes the position within the word at which the experimenter presses the space bar.

The 24 words were divided in two sets of 12 items to avoid exceeding the children's attention capacities. The items were randomised across participants and the order of each set was counter-balanced. Between each set the children could rest for a while if they desired. Before starting a second set, the children read a paragraph of a text extracted from St. Exupéry's *The little prince* (Appendix 2). The text in French was, of course, the original 1946 text and the text in Spanish was a professional translation (both texts have 104 words). We measured reading time and number of errors. If the child made an error but corrected him/herself, it was not counted as an error. With this reading task we estimated the reading level of each child in an equivalent manner in both languages. The idea was to examine whether reading performance is correlated with the visual parsing observed in the copying task. In general, good readers are good spellers because they have stable and detailed orthographic representations (Sprenger-Charolles et al., 2003). The experiment lasted between 20 to 30 minutes and the children were tested individually in a quiet room inside the school.

Data analysis. A gaze lift (GL) was counted as such when the child lifted the gaze to extract further information while producing a letter or immediately after producing it. Note that in this task a GL did not require a head movement. If the participant lifted his/her gaze during the production of the *o* of *onde*, for instance, we counted a gaze lift on the *o*. If the child did a gaze lift between the *o* and the *n* (before starting the production of the *n*), we also counted the GL for the *o*. We adopted this procedure because if the child lifts his/her gaze while writing the *o*, he/she knows that an *o* has to be written (i.e., it is already programmed), so the GL is done to extract information on the identity of the following letters. GLs at the last letter were extremely rare. We did not count them as GLs because they were always produced for verification and not for information extraction. With this information on GLs, we calculated the 'gaze lift coefficient'. It corresponded to the number of times the child lifted his/her gaze with respect to the total possible gaze lifts if he/she copied the item with a letter-by-letter analysis. For example, the French word *ignorer*, has 7 letters, thus 6 possible GL if it is copied letter-by-letter. If the child did 2 GL, then the GL coefficient is (2/6)*100, i.e., 33.3. In this manner, the gaze lifts for all the words in the experiment can be compared irrespective of their length (a GL in a four letter word does not have the same value as in an eight letter word). If the visual units used during the copying task by French and Spanish-speaking children have the same size, no significant differences in GL coefficient should be observed. If shallowness has an effect on the size of the spelling units the children use, then GL coefficients should differ.

To provide an insight on the visual spelling units used during the copying task, we noted the position of the first gaze lift within the word. The first GL corresponds to the first GL produced after the initial glance. It refers to the GL once the child has already started copying the word and needs more visual information to continue copying it. We determined five different 'unit' sizes, according to the position at which the children produced the first GL. We defined the 'letter' unit as the situation in which the child produced the first GL during or immediately after the first letter. In general, when the child produces a GL at the first letter, he/she does letter-by-letter copying, at least throughout the first syllable. The 'syllable' unit concerned the situation in which the child did the first GL during or immediately after the item's syllable boundary. The 'non-syllable' unit was noted when the child did the first GL during or immediately after the item's second or third letter which does not correspond to the syllable boundary. The 'other' unit was noted when the child did the first GL at any other position not mentioned above. When the child copied the word without any gaze lift we noted a 'whole word unit'.

As in Kandel and Valdois (2006) we measured movement duration to investigate whether the orthographic structure of each language could influence the motor aspects of the handwriting gesture. We followed the standard procedure of movement analysis. First, the data were smoothed with a Finite Impulse Response filter (Rabiner & Gold, 1975) with a 12 Hz cut-off frequency. The trajectory and tangential velocity were then used to segment each word into its letter constituents, by using geometric (cuspids and curvature maxima) and kinematic (velocity minima) criteria. With this segmentation procedure we obtained the duration of each letter in the words. The duration measure concerned actual movement execution. The time the child took to produce a gaze lift or any other kind of pause were not considered in this measure. The duration of each letter was divided by the number of strokes it contained according to a standard segmentation procedure (Meulenbroek & Van Galen, 1990). An *l*, for instance, has two strokes: an up-stroke and a down-stroke. If the duration of the *l* was 180 ms, then the mean stroke duration was $180/2 = 90$ ms. This normalisation procedure allowed for comparisons among all letters, irrespective of the number of the strokes they contained. Then, for each letter, we calculated the ratio of the mean stroke duration to the sum of all the mean stroke durations of the word, and then converted it to percentages. Letter duration percentages reveal information on the global organisation of the handwriting gesture because they provide information on the distribution of the duration throughout the entire word. Duration increases at specific locations within the word arise from additional processing loads due to programming of following sequences (Van Galen, 1991; Van Galen et al., 1986). In addition, duration percentages allow comparisons among all participants, from very slow to very fast ones. For instance, the mean stroke duration of a given letter can be 100 ms for one child and 200 ms for another, but if the duration percentages for this letter for both children are around 17%, then both children organise their handwriting gesture in the same manner. This is very important in this study because the children's age varied from 6 to 8. Many authors have shown that absolute movement duration decreases as the child grows up (Meulenbroek & Van Galen, 1986, 1988, 1989; Mojet, 1991; Zesiger, Mounoud, & Hauert, 1993). Finally, copying errors were so rare that they could not be analysed.

Results

This section presents the results calculated from gaze lifts, movement duration and reading performance. Analyses of variance (ANOVA) were conducted using both participants (F_1) and items (F_2) as random factors. The other factors concern language (French, Spanish) and school level (first, second grade).

Gaze lift analysis

Gaze lift coefficient. Figure 1 presents first and second graders' mean gaze lift coefficients as a function of their mother tongue. The analysis revealed that the French children lifted their gaze more often than the Spanish-speaking children, $F_1(1, 71) = 26.88$, $p < .001$; $F_2(1, 23) = 310.81$, $p < .001$, suggesting that the former used smaller units than the latter. The effect of school level was also significant, $F_1(1, 71) = 35.98$, $p < .001$; $F_2(1, 23) = 697.56$, $p < .001$, indicating that first graders lifted their gaze more often than second graders.

The interaction between the two factors was significant, $F_1(1, 71) = 17.11$, $p < .001$; $F_2(1, 23) = 321.97$, $p < .001$). School level was only determinant for the French-speaking children, $F_1(1, 71) = 56.28$, $p < .001$; $F_2(1, 23) = 775.88$, $p < .001$): GL coefficients decreased from 61.37 in first grade to 18.17 in second grade. The difference between French and Spanish-speaking children was only significant in first grade, $F_1(1, 71) = 44.48$, $p < .001$; $F_2(1, 23) = 549.13$, $p < .001$). We conducted a post-hoc analysis comparing the 10 French first graders with the lowest reading times (mean = 207.1 s) with the 10 Spanish-speaking first graders with the highest reading times (mean = 403.9 s). The analysis still revealed that the French children lifted their gaze more often (GL coefficient = .61) than the Spanish-speaking children, GL coefficient = .26, $F_1(1, 18) = 12.14$, $p < .01$; $F_2(1, 23) = 10.42$, $p < .01$.

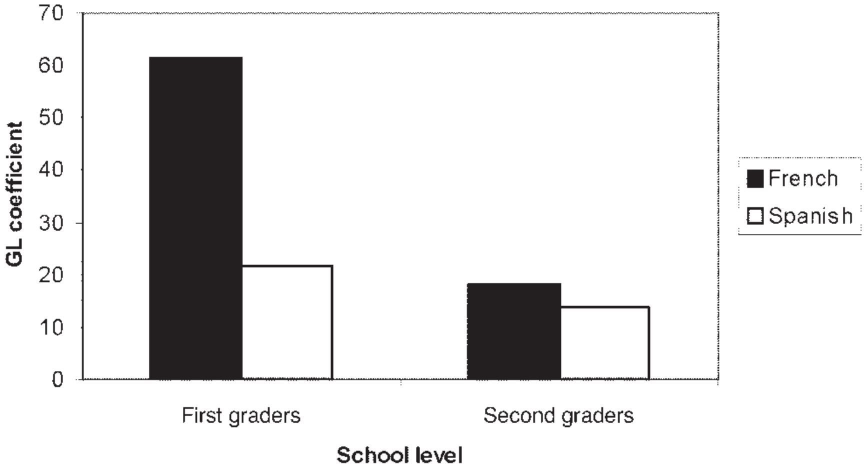

Figure 1. Mean gaze lift coefficient as a function of school level (first, second grade) and mother tongue (French, Spanish).

We analysed gaze lifts at the target grapheme position to determine whether the children separated the two letters by a gaze lift. If the grapheme was split by a GL, we noted a 1, otherwise we noted a 0. In French, first graders (.79) split the complex grapheme more often than second graders (.31); in Spanish, results yielded .32 for first graders and .28 for second graders. The ANOVA revealed that the target grapheme was split more often in French than in Spanish, $F_1(1, 71) = 23.67$, $p < .001$; $F_2(1, 23) = 374.13$, $p < .001$. The effect of school level was also significant, $F_1(1, 71) = 48.78$, $p < .001$; $F_2(1, 23) = 243.80$, $p < .001$, as was the interaction between the two factors, $F_1(1, 71) = 5.32$, $p < .001$; $F_2(1, 23) = 128.64$, $p < .001$. The French children split the target grapheme more often than the Spanish-speaking children only in first grade, $F_1(1, 71) = 36.16$, $p < .001$; $F_2(1, 23) = 297.42$, $p < .001$.

Unit analysis. In this section, the first gaze lift determined the size of the 'units' the children used to copy the words. There were five different units according to the position in the item at which the children produced the first gaze lift: letter, syllable, non-syllable, other, and whole word. The ANOVA included unit type (letter, syllable, non-syllable, other, whole word) as random factor. The analysis showed significant effects of language, $F_1(1, 71) = 8.22$, $p < .01$ (non significant in the by items analysis) and unit, $F_1(4, 284) = 31.59$, $p < .001$; $F_2(4, 92) = 42.35$, $p < .001$. The interactions between language and unit, $F_1(4, 284) = 22.39$, $p < .001$; $F_2(4, 92) = 62.20$, $p < .001$ and between school level and unit, $F_1(4, 284) = 13.72$, $p < .001$; $F_2(4, 92) = 51.62$, $p < .001$ were significant. The

TABLE 1
Unit type used by French and Spanish-speaking first and second grade monolinguals

		Letter	*Syllable*	*Non-syllable*	*Other*	*Whole word*
First grade	French	0.39	0.32	0.19	0.07	0.04
	Spanish	0.11	0.17	0.12	0.07	0.51
Second grade	French	0.11	0.21	0.11	0.18	0.40
	Spanish	0.10	0.14	0.05	0.07	0.61

interaction between the three factors was significant as well, $F_1(4, 284) = 5.68$, $p < .001$; $F_2(4, 92) = 22.49$, $p < .001$.

As Table 1 shows, French-speaking first graders used many more letter units when copying words than Spanish-speaking first graders, $F_1(1, 71) = 28.26$, $p < .001$; $F_2(1, 23) = 68.87$, $p < .001$. The same pattern was observed for syllable, $F_1(1, 71) = 11.19$, $p < .001$; $F_2(1, 23) = 9.92$, $p < .01$ and non-syllable units, $F_1(1, 71) = 5.94$, $p < .001$; $F_2(1, 23) = 5.08$, $p < .05$. The French speaking children used far fewer whole word units than the Spanish-speaking children, $F_1(1, 71) = 31.56$, $p < .001$; $F_2(1, 23) = 288.14$, $p < .001$. The French first graders mostly used letter and syllable units (the higher proportion of letter units than syllable units was only significant by items: $F_2(1, 23) = 4.28$, $p < .05$). The scores for these units were significantly higher than the scores for the other kinds of units: letter > non-syllable, $F_1(1, 71) = 31.04$, $p < .001$; $F_2(1, 23) = 13.24$, $p < .001$, letter > other, $F_1(1, 71) = 48.52$, $p < .001$; $F_2(1, 23) = 88.0$, $p < .001$ and letter > whole word units, $F_1(1, 71) = 20.71$, $p < .001$; $F_2(1, 23) = 88.31$, $p < .001$; syllable > non-syllable, $F_1(1, 71) = 23.31$, $p < .001$; $F_2(1, 23) = 4.42$, $p < .05$, syllable > other, F_1 $(1, 71) = 44.03$, $p < .001$; $F_2(1, 23) = 57.84$, $p < .001$ and syllable > whole word units, $F_1(1, 71) = 13.66$, $p < .001$; $F_2(1, 23) = 77.34$, $p < .001$. The Spanish-speaking children mostly used whole word units: differences were significant with letter, $F_1(1, 71) = 17.62$, $p < .001$; $F_2(1, 23) = 112.01$, $p < .001$, syllable, $F_1(1, 71) = 12.81$, $p < .001$; $F_2(1, 23) = 33.18$, $p < .001$), non-syllable, $F_1(1, 71) = 23.14$, $p < .001$; $F_2(1, 23) = 107.50$, $p < .001$ and other units, $F_1(1, 71) = 39.70$, $p < .001$; $F_2(1, 23) = 123.18$, $p < .001$. They otherwise used letter, syllable, non-syllable, and other units in an equivalent proportion. The post-hoc analysis comparing the ten French first graders with the lowest reading times with the ten Spanish-speaking first graders with the highest reading times revealed that the French children (.36) used more letter units than the Spanish-speaking children, .12, $F_1(1, 18) = 11.75$, $p < .01$; $F_2(1, 23) = 9.38$, $p < .01$; the difference was not statistically significant for the syllable unit (.33 vs. .22, respectively); the French children hardly copied the word as a whole (.06) whereas the Spanish-speaking children did it more often, .41,

$F_1(1, 18) = 11.15, p < .01$; $F_2(1, 23) = 10.59, p < .01$. Their behaviour is therefore similar to the whole first grade population.

In second grade, all the children mostly used whole word units, but words were more frequently copied as a whole in Spanish than in French, $F_1(1, 71) = 6.26, p < .01$; $F_2(1, 23) = 31.49, p < .001$. Syllable units were still used in second grade for both language groups in an equivalent proportion.

Movement time analysis

Movement duration examined whether the orthographic differences between the two languages produced differences in the units the children use to organise their handwriting gestures. Kandel and Valdois (2006) observed that in French there was a systematic duration increase at the first letter of the second syllable, regardless of word length and school level. The same pattern of results should thus be observed in this experiment for the French children. Therefore, movement duration percentages were analysed at the syllable boundary (which corresponded to the position of the target grapheme): *n* corresponded to the first letter of the second syllable; *n–1* corresponded to the last letter of the first syllable; *n+1* corresponded to the second letter of the second syllable. For example, the word *entrer*/*entrar* is separated *en*/*trer*/*en*/*trar* in both languages, therefore *n* = t, *n–1* = n and *n+1* = r. The four CC words have different syllable boundaries in French and Spanish, so they were processed in a separate analysis. In French, the *gn* constitutes a grapheme and cannot be split (for example, *digne* is separated *di*/*gne*), so *n* = g, *n–1* = i and *n+1* = n. In Spanish, the *g* and the *n* are always situated on either side of the syllable boundary (for example, *digno* is separated *dig*/*no*), so *n* = n, *n–1* = g and *n+1* = o. The ANOVA included letter position within the word's syllable boundary (*n–1*, *n* and *n+1*) as random factor.

The analysis for the VV and VC words revealed a significant effect of mother tongue, $F_1(1, 71) = 19.78, p < .001$; $F_2(1, 18) = 8.74, p < .01$ and letter position, $F_1(2, 142) = 123.46, p < .001$; $F_2(2, 36) = 15.39, p < .001$. Grade level did not yield significant effects. The interaction between language and letter position was significant, $F_1(2, 142) = 35.23, p < .001$; $F_2(2, 36) = 10.10, p < .001$. There was a syllable boundary effect for French-speaking children but not for the Spanish-speaking children (Figure 2).

For the French children, duration percentages for the $n-1$ position were significantly lower than at the *n* position, $F_1(1, 71) = 120.06, p < .001$; $F_2(1, 18) = 35.11, p < .001$, and duration percentages at the *n* position were higher than at the *n+1* position, $F_1(1, 71) = 252.53, p < .001$; $F_2(1, 18) = 20.96, p < .001$. A different organisation appeared for the Spanish-

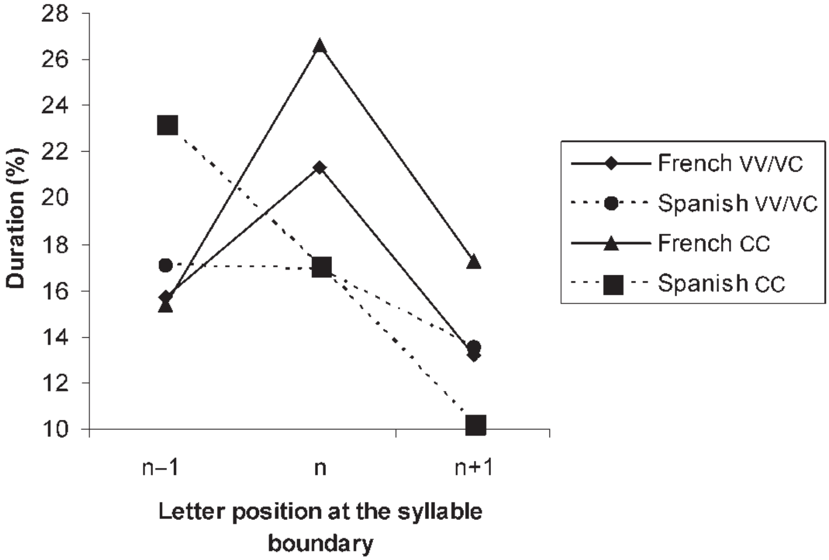

Figure 2. Mean duration percentages in VC/VV and CC words for French and Spanish-speaking monolinguals as function of letter position within the syllable boundary.

speaking children: duration percentages for the *n–1* position were equivalent to the ones observed at the *n* position, and duration percentages at the *n* position were higher than at the *n+1* position, $F_1(1, 71) = 36.62$, $p < .001$; $F_2(1, 18) = 11.91$, $p < .01$. The differences between the French and Spanish-speaking children's productions were significant at positions *n–1*: $F_1(1, 71) = 9.11$, $p < .01$; $F_2(1, 18) = 14.11$, $p < .001$ and *n*: $F_1(1, 71) = 80.81$, $p < .001$; $F_2(1, 18) = 15.59$, $p < .001$.

For the CC words, the ANOVA revealed significant effects of language, $F_1(1, 71) = 77.51$, $p < .001$; $F_2(1, 3) = 12.67$, $p < .05$ and letter position, $F_1(2, 142) = 67.23$, $p < .001$; $F_2(2, 6) = 22.68$, $p < .001$. The interaction between language and letter position was again significant, $F_1(2, 142) = 87.50$, $p < .001$; $F_2(2, 6) = 44.55$, $p < .001$, showing a syllable boundary effect for the French children but not for the Spanish-speaking children. As Figure 2 shows, duration percentages for the French children at the *n–1* position were significantly lower than at the *n* position, $F_1(1, 71) = 131.07$, $p < .001$; $F_2(1, 3) = 37.37$, $p < .01$, and higher at the *n* position than at the *n+1* position, $F_1(1, 71) = 109.95$, $p < .001$; $F_2(1, 3) = 45.95$, $p < .01$. Again, a different pattern was observed for the Spanish-speaking children: durations at the *n–1* position were higher than the ones observed at the *n* position, $F_1(1, 71) = 32.57$, $p < .001$; $F_2(1, 3) = 35.23$, $p < .01$, in turn at the *n* position they were higher than at the *n+1* position, $F_1(1, 71) = 48.65$, $p < .001$; $F_2(1, 3) = 38.33$, $p < .01$. Furthermore, it is noteworthy that duration percentages for the *g* were significantly higher for the French children (*n* position) than for the Spanish-speaking children (*n–1* position), $F_1(1, 71) = 10.38$, $p < .001$; $F_2(1, 3) = 64.15$, $p < .01$; no significant differences were observed for the *i*, *n*, and *e*/*o*.

The post-hoc analysis comparing the ten French first graders with the lowest reading times with the ten Spanish-speaking first graders with the highest reading times showed the same pattern of results. The French children exhibited a duration peak at the first letter of the second syllable, $n < n{-}1$: $F_1(1, 18) = 81.07$, $p < .001$; $F_2(1, 18) = 27.16$, $p < .001$ for VV and VC words and $F_1(1, 18) = 11.75$, $p < .001$; $F_2(1, 3) = 10.98$, $p < .05$ for CC words; $n > n+1$: $F_1(1, 18) = 186.32$, $p < .001$; $F_2(1, 18) = 39.40$, $p < .001$ for VV and VC words and $F_1(1, 18) = 12.96$, $p < .01$; $F_2(1, 3) = 10.85$, $p < .05$ for CC words. The Spanish-speaking children seem to organise their gesture according to units bigger than the syllable, $n > n{-}1$: non significant for VV and VC words and $F_1(1, 18) = 9.62$, $p < .01$; $F_2(1, 3) = 11.76$, $p < .05$ for CC words; $n > n+1$: $F_1(1, 18) = 13.16$, $p < .001$; $F_2(1, 18) = 63.71$, $p < .001$ for VV and VC words and $F_1(1, 18) = 10.74$, $p < .01$; $F_2(1, 3) = 13.24$, $p < .05$ for CC words.

Reading performance

Reading performance concerned the time needed to read the *Little Prince* paragraph and the number of errors. The results are presented in Table 2.

Reading time analysis revealed a significant school-level effect, $F(1, 71) = 21.71$, $p < .001$. The effect of language did not reach significance, $F(1, 71) = 3.51$, $p = .06$. The interaction between language and school level was significant, $F(1, 71) = 5.38$, $p < .05$, revealing that the differences between the French and Spanish-speaking children were only significant in first grade, $F(1, 71) = 26.71$, $p < .001$. For reading errors, there were significant effects of language, $F(1, 71) = 6.27$, $p < .01$ and school level, $F(1, 71) =$

TABLE 2
Mean reading time (s) and number of errors for French- and Spanish-speaking children

	Reading time (s)		*Reading errors*	
	French	*Spanish*	*French*	*Spanish*
First grade	545.91 ($\sigma = 400.02$)	306.18 ($\sigma = 158.51$)	31.52 ($\sigma = 24.10$)	12.18 ($\sigma = 7.73$)
Second grade	147.00 ($\sigma = 120.18$)	172.55 ($\sigma = 86.89$)	7.3 ($\sigma = 7.21$)	9.55 ($\sigma = 6.43$)

15.41, $p < .001$. The interaction between the two factors was significant, $F(1, 71) = 9.95$, $p < .05$, showing differences between the children in first grade, $F(1, 71) = 24.47$, $p < .001$ but not in second grade. Finally, reading time and number of errors were positively correlated, $r(75) = .71$, $p < .05$, indicating that the children who took longer to read the text also made more errors while reading it.

The gaze lift coefficient was positively correlated with text reading time, $r(75) = .57$, $p < .05$, and the number of errors, $r(75) = .52$, $p < .05$, indicating that the children who lifted their gaze often were the ones who had the lowest reading performance. Moreover, reading performance was significantly correlated with unit use. Letter unit scores were positively correlated with text reading time, $r(75) = .58$, $p < .05$ and number of errors, $r(75) = .49$, $p < .05$, indicating that the children who took longer to read and who made more errors were more keen to use letter units when copying. The same pattern holds for correlations with syllable units, $r(75) = .24$, $p < .05$ for reading time and $r(75) = .29$, $p < .05$ for errors, and non-syllable units, $r(75) = .38$, $p < .05$ for reading time and $r(75) = .41$, $p < .05$ for errors. There were negative correlations between whole word units and reading time, $r(75) = -.45$, $p < .05$ and errors, $r(75) = -.47$, $p < .05$, showing that the children who used word units read faster and made less errors.

Discussion

The results for the gaze lift coefficient revealed that French first graders lifted their gaze much more often than the Spanish-speaking children. French first graders used letter and syllable sized units quite frequently and whole word units very rarely. The Spanish-speaking first graders mostly used whole word units and no major differences were observed with second graders. Thus, the shallowness of a language seems to determine the size of the visual spelling units the children used, but only during the first school year. These results on the visual aspects of the spelling process support the idea that the Spanish-speaking children use larger spelling units than French-speaking children to parse the input letter-string. Correlation analysis also suggests that the unit used in the copying task was highly related to reading performance, since the children who used letter and syllable spelling units were the ones who took longer to read the text and made more errors while reading it than the children who used whole word units. These correlations suggest a strong link between reading and copying performance.

The movement time analysis revealed that the French children organised their handwriting gesture according to the word's syllable structure, as showed by Kandel and Valdois (2006). The motor system programs the gesture to produce the first syllable before starting to write. The gesture to write the second syllable is programmed online, during the production of its first letter. This confirms that the syllable plays a major role in handwriting production in French children. The Spanish-speaking children organise their motor gesture in a different manner. There was no duration peak at the syllable boundary suggesting that the gesture to produce the second syllable could be programmed either before starting to write the word or online, throughout the production of the previous syllable. It is difficult to determine which kind of processing unit the Spanish-speaking children used, but it is clear that it was bigger than the syllable, more in an adult-like fashion (Zesiger, Orliaguet, Boë, & Mounoud, 1994). These results indicate that also at the motor level, the French-speaking children used smaller spelling units than the Spanish-speaking children.

Taken together, these results support the idea that when first graders have to learn how to spell in an orthographically complex language such as French, the visual and motor spelling units they use are smaller than the ones used by children who speak a more shallow language like Spanish. This idea is supported by the fact that the post-hoc tests comparing the French first graders with the best reading levels to the Spanish-speaking first graders with the lowest reading levels exhibit an equivalent pattern of results as the ones calculated on the whole population, both on the visual and motor domains. It is noteworthy that the pattern of results was equivalent for both language groups even when the reading time for the French children was half the time of that for the Spanish-speaking children. It should also be noted that the Spanish-speaking children were tested approximately one month before the French children, which reinforces our results. The French children had to coordinate letter and syllable-sized visual units with syllable-sized motor units. The Spanish-speaking children used word-like visual and motor units. In other words, the French children had to articulate units of different sizes whereas the Spanish-speaking children had a common unit during visual parsing and motor programming.

To show that the differences were exclusively due to the orthographic structure of the languages, despite the timing difference and to control for personal (e.g., age, short-term memory abilities, IQ) and environmental factors (reading method, teacher effect, etc.), in Experiment 2 the same child did the copying and reading tasks in both languages. Experiment 2 repeats Experiment 1 with first and second graders who are learning how to read and write in French and Spanish simultaneously.

EXPERIMENT 2

Method

Participants. Twenty-two right-handed children participated in this experiment. There were 8 first graders (mean age 6;7 ranging from 6;2 to 6;11, $\sigma = 3$ months) and 14 second graders (mean age 7;8 ranging from 7;1 to 8;2, $\sigma = 5$ months). They were all pupils at the Lycée Franco-Mexicain of Coyoacan, Mexico City. All the children came from families in which at least one of the parents has French as mother tongue and the other parent Spanish. They were tested in February. Most of the teaching in this school is done in French, except for one morning per week, in which reading and writing in Spanish is taught by a native Spanish-speaker. The French teachers reported that the reading method was mixed. In Spanish the teaching method was essentially based on grapho-phonological conversions rules. We will call this population the 'bilingual' children because they learn how to read and write in both languages. None of the participants were repeating or skipping a grade and they were attending their grade at the regular age. They all had normal or corrected-to-normal vision and reported no hearing impairments, learning disability, brain or behavioural problems. School attendance was regular.

Material, procedure and data analysis. The material, procedure and data analysis were exactly the same as in Experiment 1. All the children did the experiment in both languages but in different sessions separated of at least 3 days. A session was done either in French or Spanish. The order was counterbalanced.

Results

This section presents the results for the bilingual children when performing the copying and reading tasks in French and Spanish. These results required the use of non-parametric tests, because the number of children, especially in first grade, was not enough to perform ANOVAs. The within-participants effects were tested with the Wilcoxon signed ranks test (Z) and the between-participants effects with the Mann–Whitney test (z). The analyses were done by participants (Z_1 and z_1) and items (Z_2).

Gaze lift analysis

Gaze lift coefficient. Figure 3 presents first and second graders' mean gaze lift coefficients as a function of the language in which they performed the copying task. For first graders, the analysis revealed that the children's GL coefficients were higher when copying words in French than in

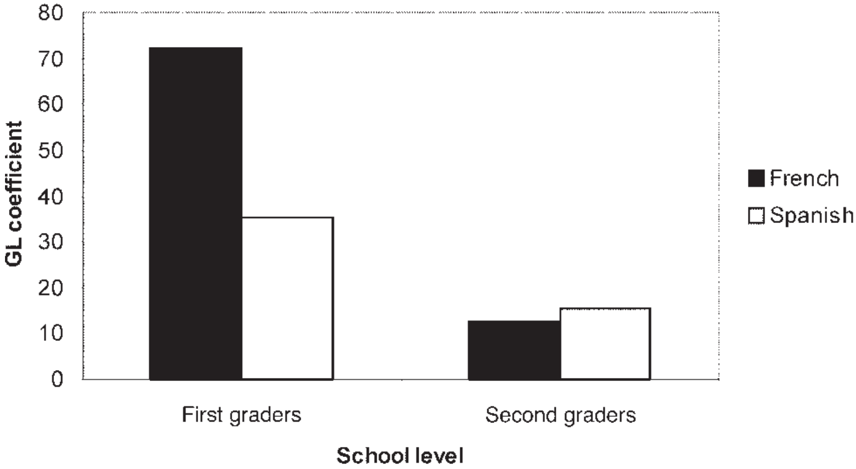

Figure 3. Mean gaze lift coefficient as a function of school level (first, second grade) and language in which the copying task was performed (French, Spanish).

Spanish, $Z_1(8) = 2.10$, $p < .05$; $Z_2(24) = 4.28$, $p < .001$. The differences were not significant for second graders.

The comparison of first and second graders' performance revealed a significant GL coefficient decrease both when the copying task was done in French, $z_1(22) = 2.76$, $p < .01$; $Z_2(24) = 4.28$, $p < .001$ and Spanish, $z_1(22) = 2.25$, $p < .05$; $Z_2(24) = 4.28$, $p < .001$.

Unit analysis. Table 3 shows that first-grade bilinguals used more letter units when copying in French than Spanish, $Z_1(8) = 2.52$, $p < .01$; $Z_2(24) = 3.82$, $p < .001$, and more whole word units when copying Spanish than French words, $Z_1(8) = 2.36$, $p < .01$; $Z_2(24) = 4.11$, $p < .001$. The differences did not reach significance for the syllable, non-syllable, and other units.

TABLE 3
Unit type used by bilingual first and second graders when performing the copying task in French and Spanish

		Letter	*Syllable*	*Non-syllable*	*Other*	*Whole word*
First grade	French	0.48	0.24	0.14	0.05	0.13
	Spanish	0.21	0.22	0.12	0.08	0.4
Second grade	French	0.07	0.12	0.13	0.20	0.51
	Spanish	0.10	0.20	0.10	0.07	0.60

When copying words in French, first graders used more letter than syllable units, $Z_1(8) = 2.02$, $p < .05$; $Z_2(24) = 2.82$, $p < .01$, also letter > non-syllable, $Z_1(8) = 2.24$, $p < .05$; $Z_2(24) = 2.44$, $p < .05$, letter > other, $Z_1(8) = 2.10$, $p < .05$; $Z_2(24) = 3.90$, $p < .001$ and letter > whole word units, $Z_1(8) = 2.87$, $p < .05$; $Z_2(24) = 2.52$, $p < .001$. In addition, when copying in French syllable > non-syllable, $Z_1(8) = 2.24$, $p < .05$; $Z_2(24) = 2.69$, $p < .01$, syllable > other, $Z_1(8) = 2.12$, $p < .05$; $Z_2(24) = 3.35$, $p < .01$ and syllable > whole word units, $Z_1(8) = 2.02$, $p < .05$; $Z_2(24) = 2.84$, $p < .01$. In Spanish first graders mostly used whole word units: differences were significant with letter, $Z_1(8) = 2.52$, $p < .05$; $Z_2(24) = 10.85$, $p < .001$, syllable, $Z_1(8) = 2.11$, $p < .05$; $Z_2(24) = 4.94$, $p < .01$, non-syllable, $Z_1(8) = 2.13$, $p < .05$; $Z_2(24) = 3.10$, $p < .01$ and other units, $Z_1(8) = 2.12$, $p < .05$; $Z_2(24) = -3.98$, $p < .01$. No significant differences were observed between the sub-lexical units.

The copying units used in second grade were similar for both languages. They were mostly whole word units. The only significant difference concerned the other units: more other units were done in French (.20) than in Spanish (.07), $Z_1(14) = 2.83$, $p < .01$; $Z_2(24) = 3.66$, $p < .001$. The type of unit used while copying varied with school level. In French, second graders did fewer letter and syllable units than first graders, $z_1(22) = 3.43$, $p < .001$; $Z_2(24) = 3.60$, $p < .001$ and $z_1(22) = 2.35$, $p < .01$; $Z_2(24) = 2.33$, $p < .01$, respectively, and more word units, $z_1(22) = -2.79$, $p < .01$; $Z_2(24) = 4.25$, $p < .001$. In Spanish, second graders did more whole word units than first graders, $z_1(22) = 2.01$, $p < .05$; $Z_2(24) = 4.28$, $p < .001$.

Movement time analysis

As in Experiment 1, we calculated mean stroke duration percentages on the n, $n{-}1$, and $n+1$ letters of the syllable boundary. Again, one analysis concerned the VC and VV words and the other one the CC words. The analysis for the words containing the VC and VV graphemes (Figure 4), revealed a movement duration increase at the syllable boundary in both languages. For the French words, duration percentages yielded $n{-}1 < n$, $Z_1(8) = 2.38$, $p < .01$; $Z_2(20) = 3.21$, $p < .001$ for first graders and $Z_1(14) = 3.29$, $p < .001$; $Z_2(20) = 2.23$, $p < .05$ for second graders and $n > n+1$, $Z_1(8) = 2.52$, $p < .01$; $Z_2(20) = 3.47$, $p < .001$ for first graders and $Z_1(14) = 3.29$, $p < .001$; $Z_2(20) = 3.35$, $p < .001$ for second graders. When the children copied the Spanish words, durations for first and second graders yielded $n{-}1 < n$, $Z_1(8) = 2.38$, $p < .01$; $Z_2(20) = 2.42$, $p < .01$ and $Z_1(14) = 3.29$, $p < .001$; $Z_2(20) = 2.98$, $p < .01$, respectively, and $n > n+1$ (but the difference was only significant for second graders: $Z_1(14) = 3.29$, $p < .001$; $Z_2(20) = 2.46$, $p < .01$. There were no significant differences between the two school levels, neither in French nor in Spanish.

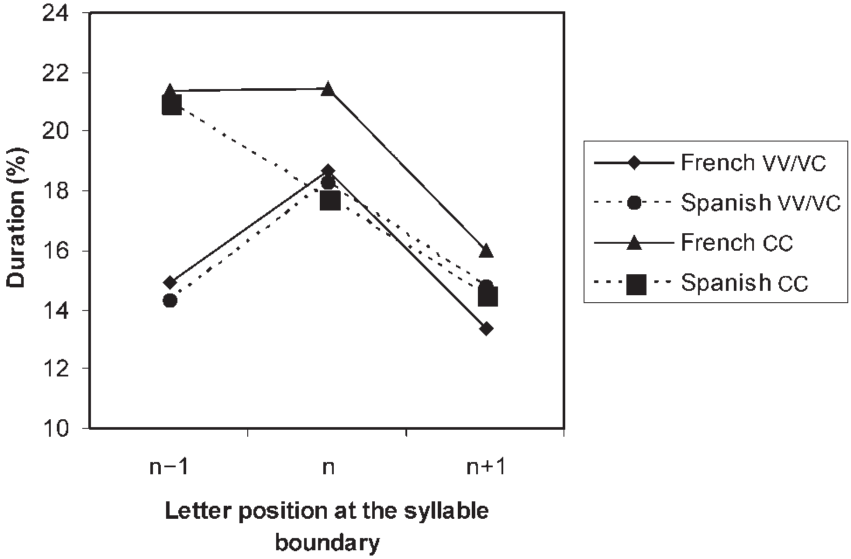

Figure 4. Mean duration percentages in VC/VV and CC words for bilinguals copying in French and Spanish as a function of letter position within the syllable boundary.

For the CC words, the results were less clear. When the children copied the French words, durations for first and second graders yielded $n{-}1 \approx n$ and $n > n{+}1$; the latter was only significant for second graders and by participants: $z_1(14) = 3.29$, $p < .001$. The differences between the two school levels did not reach significance, except at the $n{+}1$ position, $z_1(22) = 2.32$, $p < .05$; not significant in the by-items analysis. For the Spanish words, durations for first graders also yielded $n{-}1 \approx n$ but $n{-}1 > n$ for second graders, $Z_1(14) = 2.79$, $p < .01$; non significant by items. Furthermore, duration percentages yielded $n \approx n{+}1$ for first graders and $n > n{+}1$ for second graders, $Z_1(14) = 2.91$, $p < .01$; non significant by items. No significant differences were observed between the two school levels.

Reading performance

In Experiment 2, each participant had a score for reading time and number of errors in French and Spanish (Table 4).

In first grade, bilinguals took longer to read the text in French than in Spanish, $Z(8) = 1.89$, $p < .05$. No significant differences were observed for second graders. There was a strong school level effect: reading time decreased from first to second grade in French, $z(22) = 3.5$, $p < .001$ and Spanish, $z(22) = 3.82$, $p < .001$. The children made more errors when

TABLE 4
Mean reading time (s) and number of errors for bilinguals when reading the text in French and Spanish

	Reading time (s)		*Reading errors*	
	French	*Spanish*	*French*	*Spanish*
First grade	452.5 ($\sigma = 156.42$)	396.87 ($\sigma = 130.85$)	29.87 ($\sigma = 14.22$)	17.37 ($\sigma = 8.56$)
Second grade	99.35 ($\sigma = 21.87$)	99.50 ($\sigma = 23.31$)	9.28 ($\sigma = 4.51$)	6.42 ($\sigma = 2.06$)

reading the text in French than in Spanish, $Z(8) = 1.90$, $p < .05$ for first graders and $Z(14) = 2.19$, $p < .02$ for second graders. Reading errors also decreased with school level, $z(22) = 3.02$, $p < .01$ when reading the text in French and $z(22) = 3.37$, $p < .001$ in Spanish. Again, reading time and number of errors were positively correlated, $r(22) = .86$, $p < .05$: the children who took longer to read the text also made more errors when reading it.

Furthermore, there was a significant correlation between GL coefficient and reading time, $r(22) = .51$, $p < .05$, suggesting that the children who lifted their gaze often took longer to read the text. Reading time and errors were positively correlated to letter units, $r(22) = .63$, $p < .05$ and $r(22) = .43$, $p < .05$, respectively and reading time was negatively correlated to whole word units, $r(22) = -.45$, $p < .05$. These results suggest that the children who used small units when copying had a lower reading performance than the children who used whole word units.

Discussion

In this experiment, the same child had to copy and read in French and Spanish. The results for the gaze lift coefficient revealed that first graders lifted their gaze more often when copying French than Spanish words. When observing the position of the first gaze lift during the copying task, analysis revealed that the size of the spelling units the children used to copy words also differed in French and Spanish. First graders mostly used letter and syllable-sized spelling units when copying French words but they preferred whole word units when copying Spanish words. Thus, visual spelling units were smaller in French than in Spanish. In second grade, the children mostly used whole word units, irrespective of the language. Correlations showed that the children who took longer and made more errors when reading the text were the ones who privileged letter units. In contrast, the children with the best reading performance tended to use more whole word units when copying. This is particularly relevant when thinking that with one morning per week of Spanish lessons and a grapho-phonological reading/writing method, the children are already capable of using larger units than in French.

Movement time analysis revealed that the children programmed their handwriting movements according to the syllable structure of the word, in both languages. This means that in French, the children articulated letter and syllable-sized visual units with syllable-sized motor units, exhibiting the same behaviour as monolinguals. In Spanish, the children coordinated whole word visual units with syllable-sized motor units. This could be due to the difficulty of having to learn both languages at the same time. It may be easier for the children to adopt the same motor programming strategy, irrespective of the language.

GENERAL DISCUSSION

The aim of this study was to demonstrate that deep and shallow orthographies lead to different unit sizes during the acquisition of writing skills. The study focused on the size of visual and motor units first and second graders used in a word copying task. Experiment 1 compared French and Spanish-speaking monolingual children's performance whereas Experiment 2 analysed the behaviour of bilingual children when copying words in French and Spanish.

In both experiments first grade GL coefficients were higher in French than in Spanish. This means that gaze lifts occurred much more often in French than in Spanish. The visual units used for copying French words were much smaller than in Spanish. In French, the children used letter and syllable-sized units quite often and whole word units very rarely. It should be noted that Kandel and Valdois (2006) have shown that French children essentially use syllable-sized units. In Experiments 1 and 2, the children also used letter units when copying French words. This difference could be due to the fact that Kandel and Valdois (2006) used high frequency words whereas in this study most of the items were low frequency words. Spanish-speaking monolinguals copied most words as a whole unit, without producing any gaze lifts. Bilinguals behaved in a similar manner, although they used more letter than syllable-sized units in French and fewer whole word units in Spanish. These slight differences could be due to the fact that bilinguals were tested in February and French monolinguals in March and, of course, to the difficulty of having to deal with two languages simultaneously at a very critical period of the acquisition process. The fact that the bilingual first graders behaved differently in French and Spanish supports the idea that the shallowness of the language determines the size of the visual units the children use. Visual units in French are letters or syllables. In Spanish the child encodes the whole word and uses it as input to the motor system.

Although the Spanish-speaking children use small-grained units during reading processes (Goswami et al., 1998), our results support the idea that during spelling processes they privilege big units. The straightforward relationships between phonemes and graphemes allow the children to encode the spelling of the whole word. This information is kept in the graphemic buffer and then serves as input for programming the handwriting movements. This explains why in Spanish the children can spell better than they can read (Manrique & Signorini, 1994). French reading requires processing groups of several letters and the application of many contextual rules, i.e., large reading units. Our results revealed that during spelling this orthographic complexity leads the French children to privilege relatively small units and of different sizes (letters and syllables). They were unable to encode the spelling of the whole word, so they had to segment it into various sub-lexical units. Therefore, in Spanish the children can encode more spelling information than in French and they do not have to deal with units of different levels (cf. Ziegler & Goswami, 2005).

Movement time analysis revealed that the production of French words was globally organised according to their syllable structure. As in Kandel and Valdois (2006), there was a systematic duration increase at the first letter of the second syllable, for monolinguals as well as for bilinguals and regardless of school level. This duration distribution suggests that the first syllable was either programmed before starting to write or letter-by-letter, as observed in some cases, especially in first grade (Zesiger, 1995). The motor system programmed the movement to produce the second syllable while producing its first letter (Van Galen, 1991; Van Galen et al., 1986). These results are in agreement with the idea that the orthographic representations used as inputs in handwriting production contain information on the syllabic structure of the word (Caramazza & Miceli, 1990). In Spanish, first and second grade monolinguals exhibited a progressive duration decrease from the beginning of the word towards the end. According to Van Galen's (1991) model, this could be explained by the fact that the spelling module was active before starting to write and maybe while producing the first letters of the word. The progressive decrease towards the end of the word translates a diminishing processing load in motor programming. This means that the motor system only processed the more local parameters on-line. This pattern of results suggests that the motor unit in Spanish is bigger than the syllable and could be the whole word. However, there was a syllable boundary effect for bilinguals when they copied VV and VC Spanish words. Further research needs to be done to establish the size of the motor units in Spanish.

In summary, both experiments revealed that bilinguals roughly used the same kind of visual units as monolinguals. They behaved like French monolinguals in French and like the Spanish-speaking monolinguals in Spanish. At the motor level, the French monolinguals and the bilingual children performing in French used syllable-sized units. In Spanish, monolinguals used units bigger than the syllable whereas bilinguals mostly used syllable-sized units. Therefore, the orthographic complexity of French leads to smaller spelling units than in Spanish, at the visual level and very likely at the motor level too. It is noteworthy that in French, first graders coordinated letter and syllable-sized visual units with syllable-sized motor units. In second grade, visual whole word units were coordinated with syllable sized motor units. In Spanish, first and second graders used visual and motor units that were bigger than the syllable. Thus, in Spanish the children use the same size of spelling units for visual parsing and motor programming. So, in Spanish the size of visual and motor units is similar in most cases whereas in French, the child has to coordinate different visual and motor units relatively often. This could delay spelling acquisition and explain the differences we observed in first grade (Ziegler & Goswami, 2005).

Why do the children privilege big spelling units in Spanish if they can write correctly by applying grapho-phonological conversion rules? Because to write correctly, they must acquire an important visual lexicon (Iribarren et al., 2001). The strictly phonological transcription strategy does not guarantee correct spelling in every case, and irregularities show up frequently in ordinary language. In other words, although grapho-phonological rules are easier to acquire in Spanish than in French, the Spanish-speaking children cannot limit themselves to phonological transcription. They have to privilege global instead of analytic processing because they need a wide graphic lexicon to spell many words correctly. This idea is supported by a study where children of different ages wrote words and non-words to dictation (Valle Arroyo, 1989). Error analysis revealed that the children used analytical but also lexical strategies when writing. Other results with adults also suggest that writing in Spanish relies on global orthographic information (Cuetos, 1993). Moreover, research done by Sebastian-Galles indicates that in Spanish both adults and children do not systematically make use of straightforward grapheme-phoneme correspondences while reading (Sebastian-Gallés, 1991; Sebastian-Gallés & Parreno Vacchiano, 1995).

Finally, it should be pointed out that these differences between French and Spanish-speaking children were only observed during the first grade and disappeared during the second, indicating that the consequences of the differences between French and Spanish orthographies are not as important as was shown for English and German (Frith et al., 1998) or

English and Italian (Thorstad, 1991). Moreover, the results for the bilingual children strongly suggest that the differences in unit size were due to orthographic complexity and cannot be explained by the children's cognitive capacities or environmental factors. Apparently, French spelling, and probably other languages with deep orthographies, take longer to assimilate because they require the elaboration of several intermediate spelling units (Laberge & Samuels, 1974).

Manuscript received October 2004
Revised manuscript received February 2005
First published online March 2006

REFERENCES

Alameda, J. R., & Cuetos, F. (1995). *Diccionario de frecuencias de las unidades lingüísticas del castellano*. Oviedo: Servicio de Publicaciones de la Universidad de Oviedo.

Berent, I., & Perfetti, C. A. (1995). A rose is a reez: The two-cycles model of phonology assembly in reading English. *Psychological Review*, *102*, 146–184.

Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. *Cognition*, *37*, 243–297.

Catach, N. (1995). *L'orthographe française*. Paris: Nathan.

Cossu, G., Shankweiler, D., Liberman, I. Y., & Gugliotta, M. (1995). Visual and phonological determinants of misreadings in a transparent orthography. *Reading and Writing: An Interdisciplinary Journal*, *7*, 1–20.

Cossu, G., Shankweiler, D., Liberman, I. Y., Katz, L., & Tola, G. (1988). Awareness of phonological segments and reading ability in Italian children. *Applied Psycholinguistics*, *9*, 1–16.

Cuetos, F. (1993). Writing processes in a shallow orthography. *Reading and Wrting: An Interdisciplinary Journal*, *5*, 17–28.

Defior, S., Justicia, F., & Martos, F. J. (1996). The influence of lexical and sublexical variables in normal and poor Spanish readers. *Reading and Writing: An Interdisciplinary Journal*, *8*, 487–497.

Frith, U., Wimmer, H., & Landerl, K. (1998). Differences in phonological recoding in German- and English-speaking children. *Scientific Studies of Reading*, *2*(1), 31–54.

Frost, R. (1995). Phonological computation and mising vowels: Mapping lexical involvement in reading. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *21*, 398–408.

Gak, V. G. (1976). *L'orthographe du français: essai de description théorique et pratique*. Paris: Selaf.

Goswami, U., Gombert, J.-E., & Fraca de Barrera, L. (1998). Children's orthographic representations and linguistic transparency: Nonsense word reading in English, French, and Spanish. *Applied Psycholinguistics*, *19*, 19–52.

Goswami, U., Ziegler, J. C., Dalton, L., & Schneider, W. (2001). Pseudohomophone effects and phonological recoding procedures in reading development in English and German. *Journal of Memory and Language*, *45*, 648–664.

Humblot, L., Fayol, M., & Lonchamp, K. (1994). La copie de mots en CP et CE1. *Repères*, *9*, 47–60.

Iribarren, I. C., Jarema, G., & Lecours, A. R. (2001). Two different dysgraphic syndromes in a regular orthography, Spanish. *Brain and Language*, *77*, 166–175.

Jimenez, J. E., Alvarez, C. J., Estevez, A., & Hernandez-Valle, I. (2000). Onset-rime units in visual word recognition in Spanish normal readers and children with reading disabilities. *Learning Dissabilities Research & Practice*, *15*(3), 135–141.

Jimenez, J. E., Guzman, R., & Artiles, C. (1997). Effects of positional syllable frequency in visual word recognition and learning to read. *Cognitiva*, *1*, 3–27.

Jimenez, J. E., & Rodrigo, M. (1994). Is it true that the differences in reading performance between students with and without LD cannot be explained by IQ? *Journal of Learning Disabilities*, *27*, 155–163.

Kandel, S., & Valdois, S. (2006). Syllables as functional units in a copying task: A visuo-orthographic and graphomotor approach. *Language and Cognitive Processes*, *21*, 432–452.

Katz, L., & Frost, R. (1992). The reading process is different for different orthographies: The orthographic hypothesis. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology and meaning* (pp. 67–84). Amsterdam: Elsevier Science Publishers.

Laberge, K. S., & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology*, *6*, 293–323.

Lindgren, S. D., Derenzi, E., & Richman, L. C. (1985). Cross-national comparisons of developmental dyslexia in Italy and the United States. *Child Development*, *65*, 1404–1417.

Lukatela, G., & Turvey, M. T. (1991). Phonological acces of the lexicon: Evidence from associative priming with pseudohomophones. *Journal of Experimental Psychology: Human Perception and Performance*, *17*(4), 951–966.

Manrique, A. M. B. (1993). *Alfabetizacion emergente: diferencias socioculturales.* University of Buenos Aires, Buenos Aires.

Manrique, A. M. B., & Signorini, A. (1994). Phonological awareness, spelling and reading abilities in Spanish-speaking children. *British Journal of Educational Psychology*, *64*, 429–439.

Meulenbroek, R. G. J., & Van Galen, G. P. (1986). Movement analysis of repetitive behavior of first, second and third grade primary school children. In H. S. R. Kao & G. P. V. Galen & R. Hoosein (Eds.), *Graphonomics: Contemporary research in handwriting* (pp. 71–92). Amsterdam: North Holland.

Meulenbroek, R. G. J., & Van Galen, G. P. (1988). The acquisition of skilled handwriting: Discontinuous trends in kinematic variables. In A. M. Cooley & J. R. Beech (Eds.), *Cognition and action in skilled behavior* (pp. 273–281). Amsterdam: North Holland.

Meulenbroek, R. G. J., & Van Galen, G. P. (1989). The production of connecting strokes in cursive writing: Developing co-articulation in 8 to 12 year-old children. In R. Plamondon, C. Y. Suen, & M. L. Simner (Eds.), *Computer recognition and human production of handwriting*. Singapore: World Scientific.

Meulenbroek, R. G. J., & Van Galen, G. P. (1990). Perceptual-motor complexity of printed and cursive letters. *Journal of Experimental Education*, *58*, 95–110.

Mojet, W. (1991). Characteristics of developing handwriting skills in elementary education. In W. J. Wann, W. A. M. Wing, & N. Søvik (Eds.), *Development of graphic skills* (pp. 53–75). London: Academic Press.

Muller, K., & Brady, S. (2001). Correlates of early reading performance in a transparent orthography. *Reading and Writing: An Interdisciplinary Journal*, *14*, 757–799.

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). Une base de données lexicales du français contemporain sur internet: Lexique. *L'Année Psychologique*, *101*, 447–462.

Ognjenovic, V., Lukatela, G., Feldman, L., & Turvey, M. T. (1983). Misreading by beginning readers of Serbo-Croatian. *Quarterly Journal of Experimental Psychology*, *35*, 97–109.

Oney, B., & Goldman, S. R. (1984). Decoding and comprehension skills in Turkish and English: Effects of the regularity of grapheme-phoneme correspondences. *Journal of Educational Psychology*, *76*, 557–568.

Perfetti, C. A. (1992). The representation problem in reading acquisition. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 145–174). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rabiner, L. R., & Gold, B. (1975). *Theory and application of digital signal processing*. Englewood Cliffs, NJ: Prentice-Hall.

Rieben, L., Meyer, A., & Perregaux, C. (1989). Différences individuelles et représentations lexicales : comment cinq enfants de 6 ans recherchent et copient des mots. In L. Rieben & C. A. Perfetti (Eds.), *L'apprenti lecteur* (pp. 145–169). Neuchâtel: Delachaux & Niestlé.

Rieben, L., & Saada-Robert, M. (1991). Developmental patterns and individual differences in the word-search strategies of beginning readers. *Learning and Instruction*, *1*, 67–87.

Sebastian-Gallés, N. (1991). Reading by analogy in a shallow orthography. *Journal of Experimental Psychology: Human Perception and Performance*, *17*(2), 471–477.

Sebastian-Gallés, N., & Parreno Vacchiano, V. (1995). The development of analogical reading in Spanish. *Reading and Writing*, *7*, 23–38.

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation of literacy acquisition in European orthographies. *British Journal of Psychology*, *94*(2), 143–174.

Shankweiler, D. (1992). *Surmounting the consonant cluster in beginning reading and writing. Symposium of phonological awareness.* Paper presented at the AERA Annual Meeting, San Francisco.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, *55*, 151–218.

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, *72*, 95–129.

Sprenger-Charolles, L., Siegel, L., Béchennec, D., & Serniclaes, W. (2003). Development of phonological and orthographic processing in reading aloud, in silent reading, and in spelling: A four-year longitudinal study. *Journal of Experimental Child Psychology*, *84*, 194–217.

Stuart, M., & Masterson, J. (1992). Patterns of reading and spelling in 10-year-old children related to prereading phonological abilities. *Journal of Experimental Child Psychology*, *54*, 168–187.

Tabossi, P., & Laghi, L. (1992). Semantic priming in the pronunciation of words in two systems: Italian and English. *Memory and Cognition*, *20*, 303–313.

Thorstad, G. (1991). The effect of orthography on the acquisition of literacy skills. *British Journal of Psychology*, *82*, 527–537.

Transler, C., Leybaert, J., & Gombert, J.-E. (1999). Do deaf children use phonological syllables as reading units? *Journal of Deaf Studies and Deaf Education*, *4*(2), 124–143.

Valle Arroyo, F. (1989). Errores en lectura y escritura: Un modelo dual. *Cognitiva*, *2*, 35–63.

Van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science*, *10*, 165–191.

Van Galen, G. P., Meulenbroek, R. G., & Hylkema, H. (1986). On the simultaneous processing of words, letters and strokes in handwriting: Evidence for a mixed linear and parallel model. In H. S. R. Kao, G. P. V. Galen & R. Hoosain (Eds.), *Graphonomics: contemporary research in handwriting* (pp. 5–20). Amsterdam: North Holland.

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading development: Word recognition in English and German children. *Cognition*, *51*, 91–103.

Wimmer, H., & Hummer, P. (1990). How German-speaking first graders read and spell: Doubts on the importance of the logographic stage. *Applied Psycholinguistics*, *11*, 349–368.

Wimmer, H., Landerl, K., Linortner, R., & Hummer, P. (1991). The relationship of phonemic awareness to reading acquisition: More consequence than precondition, but still important. *Cognition*, *40*, 219–249.

Zesiger, P. (1995). *Ecrire. Approches cognitive, neuropsychologique et développementale*. Paris: PUF.

Zesiger, P., Mounoud, P., & Hauert, C. A. (1993). Effects of lexicality and trigram frequency on handwriting production in children and adults. *Acta Psychologica*, *82*, 353–365.

Zesiger, P., Orliaguet, J. P., Boë, L. J., & Mounoud, P. (1994). The influence of syllabic structure in handwriting and typing production. In C. Faure, G. Lorette & A. Vinter (Eds.), *Advances in handwriting and drawing: a multidisciplinary approach* (pp. 389–401). Paris: Europia.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*, 3–29.

Ziegler, J. C., & Jacobs, A. M. (1995). Phonological information provides early sources of constraint in the processing of letter strings. *Journal of Memory and Language*, *34*, 567–593.

Ziegler, J. C., Jacobs, A. M., & Stone, G. O. (1996). Statistical analysis of the bidirectional inconsistency of spelling and sound in French. *28, 4*, 504–515.

Ziegler, J. C., Perry, C., Jacobs, A. M., & Braun, M. (2001). The DRC model of visual word recognition and reading aloud: An extension to German. *European Journal of Cognitive Psychology*, *12*, 413–430.

APPENDIX 1

Corpus and lexical frequency (per million). The blank space indicates the syllable boundary. In bold the target complex grapheme in French

	French words	*Freq.*	*Spanish Words*	*Freq.*	*Translation*
	On de	34.61	On da	19	wave
	En tre	1026.48	En tre	1685	between
	En trer	78.29	En trar	125	to enter
	In sec te	6.03	In sec to	8	insect
	In sul te	5.97	In sul to	5.5	insult
VC gr	**In** ter ne	25.74	In ter no	17	internal
	Im por ter	1.87	Im por tar	2	to import
	Im pri mer	4.45	Im pri mir	5	to print
	In cen die	15.90	In cen dio	16.5	fire
	In cli ner	3.97	In cli nar	2.5	to bend
	In for mer	7.32	In for mar	5.5	to inform
	In dus triel	22.03	In dus trial	39.5	industrial
	C**au** se	166.23	Cau sa	130.5	cause
	F**au** ne	8.48	Fau na	7	fauna
	P**au** se	6.58	Pau sa	25.5	pause
VV gr	Fr**au** de	4.42	Frau de	3.5	fraude
	Tr**au** ma	0.26	Trau ma	4.5	trauma
	Au to ri ser	3.48	Au to ri zar	1.5	authorize
	I n**au** gu rer	1.19	I nau gu rar	3	inaugurate
	N**au** fra ger	0.03	Nau fra gar	1.5	to shipwreck
	Di **gn**e	20.94	Dig no	23	worthy
CC gr	Si **gn**e	102.61	Sig no	50	sign
	I **gn**o rer	14.48	Ig no rar	6	to ignore
	Con si **gn**e	5.23	Con sig na	6.5	instruction

APPENDIX 2

The little prince text for evaluating reading performance in French and Spanish. The French text was extracted from the 1997 edition published by Gallimard (Paris). The Spanish text was translated by Martha Valdés, in 1976, for Editorial Epoca (Mexico).

Text in French
J'appris bien vite à mieux connaître cette fleur. Il y avait toujours eu, sur la planète du petit prince, des fleurs très simples, ornées d'un seul rang de pétales, et qui ne tenaient point de place, et qui ne dérangeaient personne. Elles apparaissaient un matin dans l'herbe, et puis elles s'éteignaient le soir. Mais celle-là avait germé un jour, d'une graine apportée d'on ne sait où, et le petit prince avait surveillé de très près cette brindille qui ne ressemblait pas aux autres brindilles. Ça pouvait être un nouveau genre de baobab. Mais l'arbuste cessa vite de croître, et commença de préparer une fleur.

Text in Spanish
Pronto aprendí a conocer mejor esa flor. En el planeta del principito siempre había habido flores muy sencillas, adornadas con una sola hilera de pétalos, que casi no ocupaban espacio y que a nadie molestaban ni llamaban la atención. Aparecían una mañana entre la hierba y morían por la tarde. Pero aquélla había germinado un día de una semilla venida de algún lugar desconocido y el principito había cuidado muy de cerca a esa brizna y no tenía ninguna semejanza a las otras briznas. Esta podía ser un nuevo género de baobab. Pero el arbusto, de pronto, dejó de crecer y brotó una flor.