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Syllables as Processing Units in Handwriting Production

Sonia Kandel
Université Pierre Mendès France and El Colegio de México

Carlos J. Álvarez
Universidad de la Laguna and Instituto de Lingüística Andrés Bello

Nathalie Vallée
Université Stendhal/Institut National Polytechnique de Grenoble

This research focused on the syllable as a processing unit in handwriting. Participants wrote, in uppercase letters, words that had been visually presented. The interletter intervals provide information on the timing of motor production. In Experiment 1, French participants wrote words that shared the initial letters but had different syllable boundaries. In Experiment 2, French- and Spanish-speaking participants wrote cognates and pseudowords with a letter sequence that was always intrasyllabic in French and intersyllabic in Spanish. In Experiment 3, French–Spanish bilinguals wrote the cognates and pseudowords with the same type of sequences. In the 3 experiments, the critical interletter intervals were longer between syllables than within syllables, indicating that word syllable structure constrains motor production both in French and Spanish.

Keywords: syllables, processing units, French, Spanish, handwriting

Handwriting is a linguistic motor task involving different processing stages. From the intention of writing to the actual movement execution, there are different processing levels, such as semantic activation, syntax construction, spelling recovery, allograph selection, size control, and muscular adjustment (Van Galen, 1991). These different stages are organized in a hierarchical manner, as most models of speech production assume (Dell, 1986, 1988; Levelt, 1989, 1992; Levelt, Roelofs, & Meyer, 1999). However, whereas experimental investigation of speech production has developed considerably in recent years, written production has not received comparable systematic attention (Bonin & Fayol, 2000). This study focuses on the spelling level of handwriting production in French and Spanish and attempts to shed some light on the kind of units that are activated at this level. We examined whether handwriting production merely involves the activation of letter strings, as researchers have postulated until recently (Caramazza, Miceli, Villa, & Romani, 1987; Teulings, Thomassen, & Van Galen, 1983; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989; Wing & Baddeley, 1980), or involves some other, higher order linguistic unit (Caramazza & Miceli, 1990; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994).

Research has shown that the temporal and spatial features of handwriting gestures can be influenced by higher order information processes, such as the linguistic characteristics of the target. A study by Zesiger, Mounoud, and Hauert (1993) reported results suggesting, for example, that lexical status and trigram frequency may affect handwriting performance in French. Identical trigrams embedded in words yielded shorter durations and trajectory lengths than when embedded in pseudowords. Furthermore, these two measures were more important for low-frequency trigrams than for high-frequency trigrams embedded in pseudowords. Also, Orliaguet and Boë (1993) showed that the morphological structure of words modulated the kinematics of handwriting production. For instance, the French word *vers* has two meanings but is always pronounced [vɛR]. When it is monomorphemic, it means *toward*. When it is plurimorphemic, by application of the pluralization rule *s* (*ver* + *s*; the pronunciation is vɛR in singular and plural), it means *worms*. The authors showed that latency and movement time increased when the participants had to write *vers* in a plurimorphemic context because they had to apply the pluralization rule to solve spelling uncertainty.

These duration modulations observed in handwriting production can be explained in the context of Van Galen's (1991) mixed linear and parallel model of handwriting production. Handwriting is the result of several processing levels organized in a hierarchical architecture so that the output of one level constitutes the input of the next lower one. The model involves several processing levels: intentions, semantic, syntactic, spelling, selection of allographs, size control, and muscular adjustment. Each level or module uses

Sonia Kandel, Laboratoire de Psychologie et NeuroCognition, Centre National de la Recherche Scientifique (CNRS) UMR 5105, Université Pierre Mendès France, Grenoble, France, and Centro de Estudios Lingüísticos y Literarios, El Colegio de México, Distrito Federal, México; Carlos J. Álvarez, Departamento de Psicología Cognitiva, Universidad de la Laguna, Tenerife, Spain, and Instituto de Lingüística Andrés Bello, Tenerife, Spain; Nathalie Vallée, Institut de la Communication Parlée, CNRS UMR 5009, Université Stendhal/Institut National Polytechnique de Grenoble, Grenoble, France.

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Correspondence concerning this article should be addressed to Sonia Kandel, Laboratoire de Psychologie et NeuroCognition, CNRS UMR 5105, Université Pierre Mendès France, BP 47-38040 Grenoble, Cedex 9, France. E-mail: sonia.kandel@upmf-grenoble.fr

different processing units and buffers. The first three modules are analogous to Levelt's (1989) speech production model. At the spelling level, the processing units are words and concern the orthographic buffer. At the selection of allographs module, the processing units are graphemes, and the buffer storage concerns motor memory. At the size control level, the processing units are allographs and concern the motor output buffer. All processing levels can be active simultaneously, but the higher order modules are supposed to be further ahead during the execution of a movement than the lower ones. The role of the buffers is to guarantee the continuity of performance. They store temporarily the output of one level before it is used as input for the following level. The parallel character of the model allows for higher order modules to anticipate and process information related to forthcoming parts of the word while writing a current sequence. When various modules are active simultaneously and because processing capacities are limited, movement duration increases. Thus, in this theoretical framework, the linguistic characteristics of words, such as the lexical status, trigram frequency, and morphological structure, are considered as supplementary cognitive loads that slow down movement execution. In the present experiments, we examined whether another linguistic characteristic of words, namely their syllabic structure, can play a major role in the production of handwriting movements. We conducted the experiments in French and Spanish because these are languages with quite clear syllable boundaries. Indeed, syllable breaks are predictable both in French (Noske, 1982) and in Spanish (Harris, 1983).

The role of the syllable as a processing unit has been supported by research on speech production (Lindblom, 1983; MacNeilage, 1998; MacNeilage & Davis, 2000; Redford, 1999). Current models in that domain include syllables in the word-form lexicon (Dell, 1986, 1988) or, in later levels, as articulatory motor units (Levelt, 1989, 1992; Levelt et al., 1999; Levelt & Wheeldon, 1994). Sternberg, Monsell, Knoll, and Wright (1978) found that the latency between the presentation of the word or the image and the beginning of its pronunciation only varied as a function of the number of syllables. They suggested that the differences are due not to articulatory demands but to the recovery from the buffer. This double mechanism, which recovers the word as a whole and then analyzes it into syllabic constituents, could explain the systematic relation between the latency and the number of syllables. Levelt and Wheeldon (1994) also found syllabic effects on word production tasks. In particular, they found a facilitative effect of the frequency of the second syllable that was independent of word frequency. They proposed that speakers routinely access a mental syllabary containing articulatory–phonetic syllable programs. However, when controlling the initial sound, other studies have failed to replicate this syllabic effect (Hendricks & McQueen, 1996). Nevertheless, several studies in Spanish have also found that syllabic structures are used in the phonological encoding of production (Costa & Sebastian-Gallés, 1998; Santiago, MacKay, & Palma, 2002; Santiago, MacKay, Palma, & Rho, 2000). Also in Spanish, Carreiras and Perea (2004) found facilitative effects of the frequency of the first syllable in three naming experiments (see also Perea & Carreiras, 1998). This set of results supports the proposal of a mental syllabary but does not exclude the possibility that this hypothesis is only relevant for some languages, namely the syllabic ones, such as French and Spanish.

In French, the role of the syllable has also been confirmed in word, pseudoword, and picture-naming tasks (Ferrand, Grainger, & Seguí, 1994; Ferrand, Seguí, & Grainger, 1996). With a masked priming task, Ferrand and colleagues showed that participants produced the consonant–vowel (CV) word *ba.lade* (henceforth, a dot marks a syllable boundary; the stimuli did not contain the dots) faster when it was preceded by the syllabic prime *ba%%%%* than by when it was preceded by *bal%%%*. Conversely, they found the opposite pattern for consonant–vowel–consonant (CVC) words such as *bal.con*. According to Ferrand et al. (1996), the syllable should be involved at the phonological output level. However, Brand, Rey, and Peereman (2003) failed to replicate this outcome in the same language.

In addition to the syllabic effects found in speech production, a considerable amount of empirical evidence supports the notion of syllables as relevant functional units in French and Spanish, both in speech perception (Mehler, Dommergues, Frauenfelder, & Segui, 1981; Sebastián-Gallés, Dupoux, Seguí, & Mehler, 1992) and in word reading (Álvarez, Carreiras, & De Vega, 2000; Álvarez, Carreiras, & Perea, 2004; Álvarez, Carreiras, & Taft, 2001; Carreiras, Alvarez, & de Vega, 1993; Carreiras & Perea, 2002, 2004; Perea & Carreiras, 1998). Recent studies have found that the role of syllables in reading has a phonological origin, suggesting some kind of phonological activation in the processing of written words (Álvarez et al., 2004). In fact, in the written picture naming of isolated words, researchers have also obtained some evidence suggesting that the build-up of orthographic activation from pictures is phonologically constrained (Bonin, Chalard, Méot, & Fayol, 2002; Bonin & Fayol, 2000; Bonin, Fayol, & Gombert, 1998; Bonin, Peereman, & Fayol, 2001).

Previous studies on adult handwriting have attempted to provide empirical evidence that the syllable—at a phonological or orthographic level of processing—could be a relevant processing unit during the production of writing movements, but they have not been very successful (Bogaerts, Meulenbroek, & Thomassen, 1996; Zesiger, Orliaguet, Boë, & Mounoud, 1994). In the study by Zesiger et al. (1994), participants had to write and type French words that began with identical trigrams that differed in syllable structure—for example, the words *pa.role* (CV initial syllable) and *par.don* (CVC initial syllable). Results computed on several spatial and temporal measures showed no effect of syllable structure in handwriting. In contrast, in typing, interkeypress intervals located at the syllable boundary (e.g., the interval between *a* and *r* in *pa.role*) were longer than the intervals located within the first syllable (e.g., in *par.don*). Bogaerts et al. (1996) compared the handwriting production of Dutch words with CV and CVC initial syllables, such as *ga.lant* and *gas.lek*. The participants had to lift the pen at various positions while writing the word. The idea was that if the syllable was a unit in handwriting, it would be easier to lift the pen at syllable boundaries (between *a* and *l* in *ga.lant*) than at a within-syllable position (between *a* and *s* in *gaslek*). The results showed no effect of syllable position. Post hoc analysis indicated, however, that the syllable could be used as a unit during handwriting: Mean stroke duration and trajectory length of the first letter of CVC words were longer than for CV words. In addition, these two measures were always higher at the first letter of the second syllable (e.g., at letter *l* in *ga.lant* and letter *l* in *gas.lek*). The authors concluded that this analysis provided some support for the notion of the syllable as a processing unit in handwriting but was not enough to validate it. Although these two studies could not provide clear evidence of the importance of the syllable in the production of handwriting movements, we think this is an issue that deserves more exploration. Syllables could be used to chunk grapheme units into larger processing units in a coherent—that is, linguistically oriented—way. Three different lines of research suggest that this could be the case.

First, a developmental study analyzing children's handwriting production supports this notion (Kandel & Valdois, in press). French first to fifth graders copied words and pseudowords. The analysis of movement time revealed systematic syllabic effects at all school levels and regardless of lexical status and item length. The distribution of movement duration throughout the items suggests that the children prepared the gesture to produce the first syllable before movement initiation (or perhaps letter by letter during the production of the first syllable, for the younger children). As in Bogaerts et al.'s (1996) study, there was a significant and systematic duration increase at the first letter of the second syllable. Then duration decreased progressively toward the end of the item. This pattern of data indicates that the motor system prepares the gesture to write the second syllable while producing its first letter. Syllables therefore appear to modulate the motor stages of processing during the acquisition of writing skills.

The second line of research concerns neuropsychological data obtained with brain-impaired patients who had damage to a level of processing where graphemic representations are computed. Caramazza and Miceli (1990) presented an Italian case study (Patient L.B.) revealing that graphemic information is not merely coded as letter strings with information on letter identity and order (Caramazza et al., 1987; Wing & Baddeley, 1980). They observed that L.B.'s spelling errors were constrained by the rules that determine the combination of vowel and consonant graphemes into graphosyllables (i.e., orthographic syllables). This led them to hypothesize that orthographic representations are multidimensional (see also McCloskey et al., 1994): One level concerns the identity of the graphemes that constitute the spelling of the word, a second one stores information on the CV status of graphemes, and a third one contains information about the graphosyllabic structure of the word. This multidimensional structure of graphemic representations arises from the fact that L.B. almost always substituted consonants for consonants and vowels for vowels and respected the syllable structure of the word. An additional level distinguishes geminate from nongeminate consonant clusters (Tainturier & Caramazza, 1996). If orthographic representations are multidimensional and contain information on letter identity and status as well as syllable structure (Jónsdóttir, Shallice, & Wise, 1996; Shallice, Rumiati, & Zadini, 2000), handwriting production cannot be limited to the retrieval of grapheme strings (Van Galen, 1991) but should also be mediated by the syllable components of words, as Bogaerts et al.'s (1996) study suggested.

The third source of evidence comes from very recent experiments carried out in Spanish with nonimpaired adult participants via a methodology very similar to the one used in the present article. Álvarez and Cottrell (2005) presented both auditory words and pictures. The participants had to write the word in uppercase letters and lift the pen between each letter. The reason for this instruction was to obtain clear data on the beginning and end of each letter. In addition, individuals lift the pen more often when writing in uppercase letters than when writing in script lowercase letters or in cursive handwriting, so this task could seem more natural. The authors measured the duration of the interletter intervals (the interval between lifting the pen to finish one letter and starting to write the next one). They found that the interletter intervals were longer when they corresponded to a syllable boundary (the interval between *a* and *r* in the Spanish word *ba.res*) than when the two letters belonged to the same syllable (*a* and *r* in *bar.ba*).

In sum, a large amount of research supports the idea that the syllable constitutes a processing unit in word production (and recognition), at least in languages with clear syllable boundaries, such as French and Spanish. Thus, the goal of the present study was to examine whether the syllable constitutes a processing unit in the handwriting production of French and Spanish nonimpaired adult writers. We hypothesized that the word's syllable structure plays a major role in chunking information on the letter string and thus mediates the production of the movement needed to write. In other words, although the letter—or, in fact, its abstract representation, the grapheme—constitutes a processing unit in handwriting production (Teulings et al., 1983; Van Galen et al., 1989), larger units, such as the syllable, could also be involved at higher levels in the hierarchy of representations (Caramazza & Miceli, 1990; Tainturier & Rapp, 2000), at least in syllable-timed languages. To that end, we used a new methodology, inspired by Zesiger et al. (1994), Bogaerts et al. (1996), and Álvarez and Cottrell (2005). Participants had to write words in uppercase letters and lift the pen between each letter. We measured the duration of the interval between the letters. If the syllable is a processing unit in handwriting production, the interletter intervals between syllables will be consistently longer than within syllables. If words are written syllable by syllable, the motor system should anticipate the movements to write the subsequent syllable at interletter intervals located at syllable boundaries. This constitutes a supplementary processing load with respect to interletter intervals located at within-syllable positions. Between-syllables intervals should thus be longer than within-syllable intervals, because in the former, the movement has to be prepared, whereas in the latter, the gesture has already been processed. With this methodology, we conducted three experiments to assess whether syllable structure constrains motor production in handwriting. In the first experiment, participants wrote words with CV and CVC initial syllables as well as words with more complex initial syllables, such as consonant–consonant–vowel (CCV) and consonant–consonant–vowel–consonant (CCVC). The second experiment was a cross-linguistic French–Spanish study in which we compared the production of orthographic cognates that differ in the position of the syllable boundary (e.g., *ma.gnolia* in French and *mag.nolia* in Spanish). In the last experiment, French–Spanish bilinguals wrote cognates differing in syllable boundary location in French and Spanish.

Experiment 1

This first experiment was a French replica of Zesiger et al.'s (1994) and Bogaerts et al.'s (1996) studies, but with our new methodology. In Experiment 1A, the participants wrote words that shared the same initial trigram but had different syllable boundary positions. The words had CV and CVC initial syllables. For instance, in the word *pa.rent* the interval between *a* and *r* is at the syllable boundary, whereas in *par.don* it is inside the CVC syllable. In Experiment 1B, the words had a more complex initial syllable, namely CCV and CCVC, as in *tra.ceur* and *trac.tus*. If handwriting production is influenced by word syllable structure, the interletter interval in between-syllables positions should be longer than in within-syllable positions. In other words, assuming that the syllable is a processing unit in handwriting, we expected longer intervals during pen lifts in between-syllables situations than in within-syllable situations. We hypothesized that in the between-syllables condition, participants would prepare the movement to execute the following syllable during the interval, whereas in the within-syllable condition, participants would process the last letter of the initial syllable either before movement initiation or online, during the production of first syllable.

Method

Participants

Fifty-four right-handed students (mean age = 23 years old, *SD* = 2.4; 20 men and 34 women) from the Université Pierre Mendès France, Grenoble, France, participated in Experiments 1A and 1B. They were all native French speakers and unaware of the purpose of the experiment. They all had normal or corrected-to-normal vision and no motor or hearing disorders.

Materials

Experiment 1A. The corpus consisted of a total of 36 French words: Eighteen words had a CV structure in the first syllable, and the other 18 had a CVC structure in the first syllable (see Appendix A). Both types of words were selected in pairs sharing the first trigram (*pa.rent–par.don*). In both types of words there was a critical interletter interval, which was the same in both cases and in the same serial position within a word (the interval between *a* and *r* marks the boundary between syllables in CV words but is intrasyllabic in CVC words). The words were matched, as much as possible, for number of letters (they were six to eight letters long), word frequency, bigram frequency, orthographic uniqueness point, and orthographic neighborhood. According to the Lexique French Data Base (New, Pallier, Ferrand, & Matos, 2001), the mean word frequency was 6.85 per million (range = 0.32–22.03, *SD* = 5.99) for CV words and 11.02 per million (range = 0.39–29.71, *SD* = 11.11) for CVC words, $t(18) = -1.60$, $p = .12$. The mean bigram frequency was 6,367 (range = 1,910–10,022; *SD* = 2,447) for CV words and 6,027 (range = 2,036–9,182; *SD* = 2,449) for CVC words, $t(18) = 0.94$, $p = .35$. The mean orthographic uniqueness point was 5.66 (range = 5.00–8.00, *SD* = 0.90) for CV words and 5.66 (range = 5.00–7.00, *SD* = 0.80) for CVC words. The mean number of orthographic neighbors was 3.55 for CV words (range = 1.00–8.00, *SD* = 2.63) and 3.33 for CVC words (range = 0.00–8.00, *SD* = 2.52).

Experiment 1B. The stimuli consisted of 12 words with a CCV syllable in the initial position and 12 words with a CCVC syllable also in the initial position (see Appendix B). Both types of words shared the first four letters (*tra.ceur–trac.tus*). The critical interletter interval was the same in both cases (the interval between *a* and *c*: intrasyllabic in CCV words and intersyllabic in CCVC words). Both conditions were matched for number of letters; the words were six to eight letters long. We tried to match them for word frequency, bigram frequency, orthographic uniqueness point, and orthographic neighborhood as much as possible. Indeed, CCV and CCVC syllable initial words are much more limited in number than words with CV or CVC syllables in initial position (New et al., 2001). Thus, the control of the different factors was restricted by the possible items to select. The mean word frequency (New et al., 2001) was 9.79 per million (range = 0.16–38.74, *SD* = 15.01) for CCV words and 25.72 per million (range = 0.32–256.16, *SD* = 72.86) for CCVC words, $t(12) = -0.84$, $p = .41$. The mean bigram frequency was 3,755 (range = 1,446–7,206; *SD* = 1,697) for CCV words and 3,497 (range = 1,422–6,047; *SD* = 1,201) for CCVC words, $t(12) = 0.80$, $p = .43$. The mean orthographic uniqueness point was 5.58 for CCV words (range = 0.00–8.00, *SD* = 2.77) and 6.91 for CCVC words (range = 5.00–8.00, *SD* = 1.08). The mean number of orthographic neighbors was 1.50 for CCV words (range = 0.00–4.00, *SD* = 1.56) and 1.33 for CCVC words (range = 0.00–3.00, *SD* = 0.98).

Procedure

Each word was presented in front of the participant, on the center of the screen of a laptop (Sony Vaio PCG-FX203K) written in uppercase Times New Roman size 18. Word presentation was preceded by an auditory signal and a fixation point for 200 ms. The participants' task was to copy the item on the digitizer (Wacom Intuos 1218; sampling frequency = 200 Hz, accuracy = 0.02 mm), which was connected to a computer that monitored the movement the participant executed. The participants were instructed to copy the words in uppercase letters and lift the pen naturally between each letter (there were no particular instructions regarding the pen lifts). The height of the pen lift just consisted of a small upward–downward wrist movement of a few millimeters. Participants practiced lifting the pen between letters by writing their name several times, until they thought they could do it almost spontaneously for the purposes of the experiment. In addition, they had to start counting aloud as soon as they saw the word on the screen. They started at 1 and continued counting until they finished the production of the word. Van Orden, Pennington, and Stone (1990) showed that phonological recoding plays an important role in word identification. This double task was to prevent phonological recoding of words during word identification. We tried to avoid phonological recoding of the visual stimulus because the syllable has an important phonological component (cf. Álvarez et al., 2004) and the aim of this study was to examine the role of that unit in handwriting. In other words, we did not want phonological recoding to induce the participants to produce handwriting movements influenced by or based on that information. The participants had to start writing as soon as possible but to write the words at their natural writing speed. There were no time limits or speed constraints. They had to write (with an Intuos Inking Pen) on a lined paper that was stuck to the digitizer (the vertical limit was 8 mm, and the horizontal limit was 17 cm). The next item was presented once the participant accomplished the previous one. Two practice items preceded the experiment so that the participant became familiar with the digitizer and the pen. The 60 items were randomized and presented in four blocks of 15 stimuli. The experiment was conducted individually in a quiet room and lasted approximately 50 min.

Data Processing and Analysis

The data were smoothed with a Finite Impulse Response filter (Rabiner & Gold, 1975) with a 12-Hz cutoff frequency. We measured the duration of the intervals between the critical letters for each item. The interval was defined as the period in which two letters were separated by a pen lift. The letter end corresponded to pressure = 0, and the onset of the following letter corresponded to pressure > 0. Latency concerned the time period from the stimulus presentation on the screen to movement initiation (pressure > 0). Although the main measure was the interletter interval duration, we also measured latency because it provides information on the time needed for the visual analysis of the word as well as the time required for preparing the handwriting movement.

Results and Discussion

We submitted critical interletter intervals and latencies for the CV and CVC syllable initial words (Experiment 1A) and for the CCV and CCVC syllable initial words (Experiment 1B) to separate analyses of variance (ANOVAs), performed both by participants (F_1) and by items (F_2). We excluded from the analysis latencies more than 2.00 standard deviations above or below the mean for each participant and each condition (2% in Experiment 1A and 5% in Experiment 1B). The mean interletter interval durations and latencies for Experiments 1A and 1B are shown in Tables 1 and 2, respectively.

Experiment 1A

The analysis revealed that there were no significant differences between within-syllable intervals (the interval between *a* and *r* in

Table 1
Mean Latencies (in ms) and Mean Critical Interletter Intervals (in ms) for Words in Experiment 1A

Latency and interval	Type of word (structure of the first syllable): CV (*pa.rent*) (intersyllable interval)	CVC (*par.don*) (within-syllable interval)
Latency		
M	1,310	1,370
SD	232	242
Interletter interval		
M	90	84
SD	26	27

Note. The critical interletter interval is marked by boldface. Dots mark the syllable boundary of the stimuli. CV = consonant–vowel; CVC = consonant–vowel–consonant.

par.don) and between-syllables intervals (*a* and *r* in *pa.rent*). The interletter interval durations were slightly longer between syllables than within syllables, but the difference was only significant in the analysis by participants, $F_1(1, 53) = 4.82$, $MSE = 6.64$, $p = .03$; $F_2(1, 34) = 1.27$, $MSE = 249.48$. Also, the ANOVA on latencies showed no significant differences. The CVC initial syllable words took longer than the CV initial syllable words, but the difference was also significant only in the analysis by participants, $F_1(1, 52) = 5.31$, $MSE = 18{,}107.41$, $p = .02$; $F_2(1, 33) = 1.61$, $MSE = 17{,}348.22$.

The results revealed that interletter durations at between-syllables intervals were equivalent to durations at within-letter intervals. The results for latencies were not conclusive either. However, in the by-participants analysis, between-syllables intervals were longer than within-syllable intervals. So, as in Zesiger et al. (1994) and Bogaerts et al. (1996), this experiment suggests that the syllable could play a role in handwriting production, but the results are not robust and should be taken with caution. The reason for the absence of clear results could be that CV and CVC syllabic structures are very simple and most frequent in French. Calculations conducted on the BDLex-v2.1.2 French lexicon (Pérennou & De Calmès, 2002) revealed that they represent 54.2% and 18%, respectively, of the observed syllables (Rousset, 2004). The production of these syllables may thus be automatic or require fewer processing demands than the more complex and less frequent ones. Syllable frequency is directly related to its complexity. The more complex syllables are the least frequent ones (Blevins, 1995; Rousset & Vallée, 2002). In French, no more than 10% of all syllables have a CCV structure, 2.87% are CVCC, and less than 1% are CCCV, CCVCC, or CCCVC (Rousset, 2004). In fact, some recent results in the literature have suggested that very simple, frequent syllables, such as CV syllables, can be processed by default in languages in which these structures are the canonical ones (Álvarez et al., 2004; Marín & Carreiras, 2002, in visual word recognition; Costa & Sebastian-Gallés, 1998, in speech production). It is therefore not surprising that we did not find syllabic effects with CV and CVC initial syllables in French. For this reason, in Experiment 1B, the participants wrote words with less frequent and less canonical syllable structures. The idea was that the production of this kind of word is less automatic and requires more processing demands than production of the words used in Experiment 1A.

Experiment 1B

The ANOVA showed that within-syllable intervals (the interval between *a* and *c* in *trac.tus*) were shorter than the same intervals in the between-syllables condition (*a* and *c* in *tra.ceur*), $F_1(1, 53) = 16.35$, $MSE = 83.30$, $p < .001$; $F_2\ (1, 22) = 5.61$, $MSE = 56.55$, $p = .02$. Post hoc analysis conducted on the durations of between-syllables interletter intervals of all the words revealed that the size of the following syllable (two, three, or four letters) had an effect on the interval duration. When CCV words were followed by a two-letter syllable the mean interletter interval duration was 124 ms ($SD = 12$), when they were followed by a three-letter syllable the mean interval duration was 150 ms ($SD = 11$), and when they were followed by a four-letter syllable the mean interval duration was 188 ms ($SD = 35$). When CCVC words were followed by a two-letter syllable the mean interletter interval duration was 91 ms ($SD = 5$), when they were followed by a three-letter syllable the mean interval duration was 111 ms ($SD = 10$), and when they were followed by a four-letter syllable the mean interval duration was 123 ms ($SD = 17$). Finally, the difference between both kinds of words was not significant in the analysis on latencies, $F_1(1, 52) = 2.70$, $MSE = 26.71$ ($F_2 < 1$).

As expected, the results revealed that when the initial syllables of words were more complex, the syllabic effect became clearer: The between-syllables intervals were significantly longer than the within-syllable intervals. Furthermore, the size of the following syllable had an effect on the interval duration, supporting the idea that the movements to produce the following syllable are prepared during the intersyllabic interval. The latencies for both types of words did not differ significantly. If the syllabic effect obtained in the critical interletter intervals was due to some influence of the characteristics of the words (e.g., word frequency) or was a result of the task input (i.e., the visual stimulus presented to be copied), we would have observed the effect (more clearly and, perhaps, in addition) in the latencies. The fact that the syllabic effect appeared only in the interletter intervals indicates that the effect took place in the process of handwriting. Also, latencies can be influenced by several factors related to the processing of the visual input. For this reason, we think that we cannot draw any strong conclusion from this measure.

Taken together, these results support the idea that the syllable constrains motor production in adult handwriting, at least in

Table 2
Mean Latencies (in ms) and Mean Critical Interletter Intervals (in ms) for Words in Experiment 1B

Latency and interval	Type of word (structure of the first syllable): CCV (*tra.ceur*) (intersyllable interval)	CCVC (*trac.tus*) (within-syllable interval)
Latency		
M	1,555	1,503
SD	342	310
Interletter interval		
M	155	119
SD	78	43

Note. The critical interletter interval is marked by boldface in the stimuli. Dots mark the syllable boundary of the stimuli. CCV = consonant–consonant–vowel; CCVC = consonant–consonant–vowel–consonant.

French, a language with clear syllable boundaries. Zesiger et al.'s (1994) French study showed a syllable effect in typing but not in handwriting. They argued that they failed to show the effect in handwriting because these movements are too slow with respect to the ones used to produce speech and typing. According to the authors, other processes, such as the processes located below the grapheme level, could interfere in handwriting and mask the effect of graphosyllabic structure. In our experiment, the double task slowed down handwriting even more but maybe avoided the interference of other processes that could neutralize the syllable effect, such as some phonological recoding influence of the visual input. Furthermore, Zesiger et al. used global measures (trigram total movement time, trajectory length, and average velocity), and our study reveals that the effect is more local, restricted to the temporal interval between letters. Bogaerts et al. (1996) used more local measures, and, although they were not successful in providing evidence of a syllable effect, post hoc analysis on mean stroke duration and trajectory length indicated that syllable structure may constrain handwriting production. We point out that in Dutch, ambisyllabicity is quite frequent and could have influenced the strength of the syllable effect. In fact, there is a considerable amount of evidence that suggests that syllabic effects in word recognition and production could be restricted to syllable-timed languages (Álvarez et al., 2001; Álvarez, Taft, & Carreiras, 1998; Carreiras & Perea, 2004). To examine this cross-linguistic issue, we designed Experiment 2 to test whether the syllabic effects observed in French can be obtained in another syllabic language, such as Spanish. We used identical interletter transitions that differ in their syllabic status according to the language in which they appear.

Experiment 2

In this experiment, we investigate whether the syllable effect observed in Experiment 1 can be generalized to other languages, namely Spanish. This language has a transparent orthography with a very close grapheme-to-phoneme correspondence. It has a very regular syllabic structure with clearly defined syllable boundaries that are resistant to stress, and there is almost no ambisyllabicity (Álvarez et al., 2001). In addition, the syllabic method is one of the most frequently used methods for teaching children to read Spanish (Carreiras et al., 1993). In fact, there is an important amount of empirical evidence supporting the psychological function of syllables in visual word recognition (see Álvarez et al., 2001, 2004, for reviews) and in speech production (Carreiras & Perea, 2004). In this experiment, groups of French- and Spanish-speaking participants wrote orthographic cognates with an embedded *gn* sequence, which is always intrasyllabic in French and intersyllabic in Spanish (*ma.gnolia* and *mag.nolia*, respectively). Moreover, *gn* in French represents a phoneme, so *g* and *n* cannot be separated. In Spanish, *g* represents /g/ and *n* represents /n/, and they are always situated at either side of the syllable boundary. If motor production in handwriting is constrained by syllable structure, the interletter interval between *g* and *n* should thus be shorter in French than in Spanish, both in words and in pseudowords. In addition, we used another embedded sequence that is very similar (*gm*) as a comparison condition, as this sequence is always intersyllabic in both languages.

Method

Participants

One hundred eight students participated in the experiment: 54 French-speaking students (mean age = 23 years old, SD = 2.4; 20 men and 34 women) from the Université Pierre Mendès France (the same participants as in Experiments 1A and 1B), and another 54 Spanish-speaking students (mean age = 21 years old, SD = 3.8; 29 men and 25 women) from the Universidad Nacional Autonóma de Mexico, Mexico City, Mexico. They were all native French or Spanish speakers. They were all right handed and had normal or corrected-to-normal vision and no motor or hearing disorders. They were all naive regarding the purpose of the experiment.

Materials

For each language (French and Spanish), we selected eight words with an embedded *gn* sequence and another eight words with an embedded *gm* sequence (see Appendix C). The words were all French–Spanish orthographic cognates—that is, words that share a common orthographic root and have the same meaning in both languages (e.g., *pigment–pigmento*). The *gn* and *gm* sequences could appear at any position within the word, but they occurred at the same position in French and Spanish. In the French words, the *gn* interletter interval was always intrasyllabic (e.g., *consi.**gn**er*). We made sure that the French participants considered the *gn* sequence as intrasyllabic by asking them to syllabify the words after the experiment. In Spanish, the *gn* sequence was always intersyllabic (e.g., *consi**g.n**ar*). The *gm* interletter interval was always intersyllabic in both languages (e.g., *asti**g.m**ate* in French and *asti**g.m**ático* in Spanish). The *gn* and *gm* words in each language were matched for number of letters: The French items were 5 to 10 letters long, and the Spanish items were 5 to 11 letters long (e.g., *consi**gn**er* and *asti**gm**ate* both have 9 letters). We derived 16 pseudowords from the words essentially by changing one or two vowels (e.g., we derived the pseudoword *mo**gn**ot* from *ma**gn**at*).

In French (New et al., 2001), the mean word frequency was 19.29 per million (range = 0.68–102.61, SD = 34.81) for *gn* words and 2.72 per million (range = 0.06–8.06, SD = 2.59) for *gm* words, $t(8) = 1.35$, p = .21. For the Spanish words (Alameda & Cuetos, 1995), the mean word frequency was 13.8 per million (range = 0.0–50.0, SD = 19.1) for *gn* words and 6.8 per million (range = 0.0–18.5, SD = 7.4) for *gm* words, $t(8) = 0.87$, $p = .41$. The difference in word frequency of French and Spanish words was not statistically significant for *gn* words, $t(8) = 0.59$, $p = .57$, or for *gm* words, $t(8) = -1.82$, $p = .11$. In French, the mean orthographic uniqueness point was 6.00 for *gn* words (range = 0.00–10.00, SD = 3.02) and 7.62 for *gm* words (range = 5.00–10.00, SD = 1.68). In Spanish (LEXESP; Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000), it was 6.60 (range = 5.00–8.00, SD = 1.30) for *gn* words and 7.34 for *gm* words (range = 5.00–9.00, SD = 1.50). In French, the mean number of orthographic neighbors was 1.50 (range = 0.00–9.00, SD = 3.11) for *gn* words and 0.75 (range = 0.00–23.00, SD = 0.70) for *gm* words. In Spanish, it was 1.00 (range = 0.00–2.00, SD = 0.90) for *gn* words and 0.12 (range = 0.00–1.00, SD = 0.35) for *gm* words. In French (Content & Radeau, 1988), the positional mean bigram frequency was 989 (range = 729–2,923; SD = 384) for *gn* words and 943 (range = 665–1,331; SD = 257) for *gm* words, $t(8) = 0.30$, $p = .77$. In Spanish, it was 844 (range = 402–1,416; SD = 323) for *gn* words and 759 (range = 459–1,274; SD = 289) for *gm* words, $t(8) = 0.55$, $p = .59$. Also, the difference in bigram frequency of French and Spanish words was not statistically significant for *gn* words, $t(8) = 1.21$, $p = .26$, or for *gm* words, $t(8) = 1.19$, $p = .27$.

Procedure and Data Analysis

The procedure and data analysis were identical to those of Experiment 1. Both French- and Spanish-speaking participants wrote 16 words and 14 filler words (not containing *gn* or *gm* sequences) taken from other experiments. They also wrote 16 pseudowords and 14 filler pseudowords (not containing *gn* or *gm* sequences) taken from the other experiments. The items were randomized and presented in four blocks of 15 stimuli (words and pseudowords were presented in different blocks). Word and pseudoword block presentation was alternated and counterbalanced among participants. Before each pseudoword block, the experimenter told the participant that he or she would have to write "invented words." The experiment lasted approximately 50 min.

Results and Discussion

This section presents the results calculated from interval durations and latencies for *gn* and *gm* words and pseudowords written by both the French- and the Spanish-speaking participants. We conducted separate ANOVAs for both measures, with language (French vs. Spanish speakers), lexicality, and embedded sequence (*gn*–*gm*) as factors. We excluded from the analysis latencies more than 2.00 standard deviations above or below the mean for each participant and each condition (2% of the data).

Interletter Interval Duration

Mean interletter interval durations (in milliseconds) are shown in Table 3. Analysis revealed that interletter intervals were significantly longer between *g* and *m* (between-syllables interval for both languages) than between *g* and *n* (between-syllables interval in Spanish but within-syllable interval in French) both for words and for pseudowords, $F_1(1, 106) = 8.52$, $MSE = 42.47$, $p = .004$; $F_2(1, 28) = 11.57$, $MSE = 29.74$, $p = .002$. Language was not significant, $F_1(1, 106) = 2.32$, $MSE = 157.34$ ($F_2 < 1$), and lexicality did not reach significance either ($F_1 < 1$, $MSE = 32.86$; $F_2 < 1$). Most interesting was the significant interaction between the embedded sequence and language, $F_1(1, 106) = 18.69$, $MSE = 42.47$, $p < .001$; $F_2(1, 28) = 6.17$, $MSE = 14.61$, $p = .01$. For French speakers, the *gn* interletter intervals (within syllable) were shorter than the *gm* ones (between syllables), $F_1(1, 106) = 26.23$, $MSE = 42.47$, $p < .001$; $F_2(1, 28) = 32.17$, $MSE = 12.23$, $p < .001$. In contrast, Spanish speakers did not exhibit significant duration differences between *gn* and *gm* sequences (both are between syllables; $F_1 < 1$), $F_2(1, 28) = 1.27$, $MSE = 32.13$. Furthermore, the interval between *g* and *n* was significantly longer in Spanish than in French, $F_1(1, 106) = 17.81$, $MSE = 62.77$, $p < .001$; $F_2(1, 28) = 5.16$, $MSE = 14.61$, $p = .03$, whereas the interval between *g* and *m* was equivalent in both languages ($F_1 < 1$), $F_2(1, 28) = 1.54$, $MSE = 14.61$. No interaction including lexicality was significant.

Table 3
*Mean Critical Interletter Intervals (in ms) in Experiment 2 as a Function of the Participant's Language (French vs. Spanish), Lexicality (Word vs. Pseudoword), and Sequence (*gn *vs.* gm*)*

	French		Spanish	
Sequence	Word	Pseudoword	Word	Pseudoword
gn				
M	97	110	131	121
SD	27	28	32	34
gm				
M	127	126	121	123
SD	57	47	43	42

Latency

Table 4 presents the mean latencies (in milliseconds) for the *gn* and *gm* words and pseudowords written by French- and Spanish-speaking participants. The results only revealed a lexicality effect: Latencies for pseudowords were higher than for words, $F_1(1, 106) = 225.33$, $MSE = 65{,}632.50$, $p < .001$; $F_2(1, 28) = 42.75$, $MSE = 78{,}069.00$, $p < .001$. Language did not yield significant effects ($F_1 < 1$), $F_2(1, 28) = 4.14$, $MSE = 60{,}874.91$, $p = .05$. Also, the type of sequence (*gn* or *gm*) was nonsignificant, $F_1(1, 106) = 4.65$, $MSE = 122{,}701.30$, $p = .03$; $F_2(1, 28) = 2.98$, $MSE = 78{,}069.00$. The interaction was not significant ($F_1 < 1$), $F_2(1, 28) = 2.91$, $MSE = 60{,}874.91$.

We can summarize the main result of this experiment as follows: The temporal interletter intervals were influenced by the syllabic status of the sequence in two languages with clear syllable boundaries, French and Spanish. Even when we used few stimuli because of availability, the results showed clearly that intersyllable intervals were longer than intrasyllable intervals. In addition, we found that the same sequence produced significant differences when it constituted a syllabic boundary in a language versus when it was intrasyllabic. For instance, between-syllables intervals (*gm* in French) were significantly longer than within-syllable intervals (*gn* in French). However, both *gn* and *gm* sequences are between-syllables intervals in Spanish and therefore yielded equivalent interval durations. Additionally, latencies for pseudowords were longer than for words, and no other effect was significant on latencies. These results are in line with Zesiger et al.'s (1993) study. They found an effect of lexical status on movement duration and trajectory length. It is important to mention that this pattern of data suggests that the effects found in the interletter intervals, especially those showing a syllabic effect, do not seem to occur at early levels of motor production or in the recognition process of the visual input. Instead, they suggest that the syllable is acting at a later level of processing. Finally, we point out that the results cannot be explained by differences in teaching method. Reading and writing instruction in France is generally done with a mixed method. The children learn to apply graphophonological conversion rules and simultaneously use global procedures. In Mexico, reading and writing instruction essentially concerns the application of letter-to-sound conversion rules.

Experiment 3

The previous experiment showed that word syllable structure constrains motor production in handwriting, at least in languages with clear syllable boundaries, such as French and Spanish. One may argue, however, that the effects observed in Experiment 2 are not conclusive because the number of stimuli was limited. Despite this limitation—there are few *gm* words in French and Spanish—we decided that the *gm* control condition was relevant, so at least one of the intervals was the same in both languages. As the results revealed no significant interval duration differences between French and Spanish for *gm* words, in Experiment 3 we only used *gn* words and therefore had a bigger set of stimuli. However, if we only used *gn* words and asked French and Spanish speakers to write them, we could explain the differences by eventual individual or environmental differences. To rule out this possibility, we decided to study French–Spanish bilinguals. In this case, the same individual wrote in both languages, so the explanation could

Table 4
*Mean Latency in Experiment 2 as a Function of the Participant's Language (French vs. Spanish), Lexicality (Word vs. Pseudoword), and Sequence (*gn *vs.* gm*)*

	French		Spanish	
Sequence	Word	Pseudoword	Word	Pseudoword
gn				
M	1,479	1,865	1,502	1,865
SD	278	435	284	415
gm				
M	1,575	1,960	1,561	1,906
SD	332	487	323	486

only be due to the processing constraints of each language. If syllable structure constrains handwriting production and the syllable structure of the cognate in both languages is different, the participant should produce different interval duration patterns according to the location of the syllable boundary. Thus, in Experiment 3, French–Spanish bilinguals wrote cognate words and pseudowords containing *gn* sequences in both languages. We included pseudowords to increase the number of stimuli. If the motor system prepares subsequent syllable units at syllable boundaries, then *gn* interletter intervals should be shorter when the participant writes in French (within-syllable interval) than when he or she writes in Spanish (between-syllables interval). In addition, if we obtained different effects in both languages but produced by the same writers, this would be a stronger support for the hypothesis that interletter intervals are affected by the syllabic status of each language.

Method

Participants

Twenty 12th-grade French–Spanish bilingual students (mean age = 17.4 years, *SD* = 6 months; 8 men and 12 women) from the Lycée Franco-Mexicain, Mexico City, Mexico, participated in the experiment. They all spoke, read, and wrote French and Spanish fluently and without any difficulty. They had all attended the Lycée Franco-Mexicain since kindergarten. Therefore, they all learned how to read and write in both languages at the same time—that is, around 6 years old, during the 1st grade. Most of the teaching in this school is done in French, except for 1 morning per week, in which reading and writing in Spanish are 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 graphophonological conversions rules. For 17 students, one of the parents was a native French speaker and the other parent was a native Spanish speaker. For another 2 students, both parents were native Spanish speakers, and for the other 1, both parents were native French speakers. They were all right-handed and had normal or corrected-to-normal vision and no motor or hearing disorders. All the students were attending 12th grade at the regular age. They were all naive regarding the purpose of the experiment.

Materials

We selected French–Spanish orthographic cognates with an embedded *gn* sequence (see Appendix D). The *gn* sequence could appear at any position within the word but occurred at the same position in French and Spanish. As in the previous experiment, in the French words the *gn* interletter interval was intrasyllabic, whereas in Spanish it was intersyllabic. We also derived pseudowords from the words by changing one or two vowels. French and Spanish items were 5 to 10 letters long. Each participant thus wrote a total of 120 items. The French filler words were the stimuli from Experiment 1. The Spanish filler words were those used in Experiment 2. The fillers for the pseudoword lists were the same pseudowords that did not contain *gn* sequences used in Experiment 2.

The mean word frequency was 12.10 per million (range = 0.68–102.61, *SD* = 23.60; New et al., 2001) for the French words and 9.20 (range = 0.00–50.00, *SD* = 13.70; Alameda & Cuetos, 1995) for the Spanish words, $t(18) = 0.85$, $p = .40$. The mean orthographic uniqueness point was 5.88 for the French words (range = 0.00–10.00, *SD* = 3.02) and 6.50 for the Spanish words (range = 5.00–9.00, *SD* = 0.90). The mean number of orthographic neighbors was 1.38 for the French words (range = 0.00–9.00, *SD* = 2.14) and 0.67 for the Spanish words (range = 0.00–2.00, *SD* = 0.80). The mean positional bigram frequency was 1,123 for the French words (range = 547–1,891; *SD* = 350; Content & Radeau, 1988) and 853 for the Spanish words (range = 398–1,416; *SD* = 329; Sebastián-Gallés et al., 2000).

Procedure and Data Analysis

The procedure and data analysis were identical to those of Experiments 1 and 2. All the students did the experiment in both languages but in different sessions separated by at least 1 week. A session was carried out either in French or in Spanish. The order was counterbalanced. Two practice items preceded the experiment so that the participant became familiar with the digitizer and the pen. In French, each participant wrote 18 experimental words and 12 filler words taken from the stimuli for Experiments 1 and 2. They also wrote 18 experimental pseudowords and 12 fillers not containing *gn* or *gm* sequences that we chose at random from lists of previous experiments. In Spanish, the procedure was exactly the same. For each session, the items were randomized and presented in four blocks of 15 stimuli (words and pseudowords were presented in different blocks). Word and pseudoword presentation was alternated and counterbalanced among participants. Before each pseudoword block, the experimenter told the participant that he or she would have to write "invented words." Each session lasted approximately 50 min.

Results and Discussion

As for Experiments 1 and 2, this section presents the results calculated from the interletter interval durations and latencies for *gn* words and pseudowords written by French–Spanish bilinguals. We conducted ANOVAs both by participants and by items, with language and lexicality as factors. We excluded from the analysis latencies more than 2.00 standard deviations above or below the mean for each participant and each condition (3% of the data).

Interletter Interval Duration

Table 5 presents the mean interletter intervals (milliseconds) for *gn* sequences embedded in words and pseudowords written by French–Spanish bilinguals. Analysis revealed that the interletter intervals between *g* and *n* were significantly longer in Spanish than in French, $F_1(1, 19) = 26.34$, $MSE = 42.72$, $p < .001$; $F_2(1, 34) = 14.18$, $MSE = 147.32$, $p < .001$. Lexicality was not significant ($F_1 < 1$; $F_2 < 1$), and the interaction between the two factors did not reach significance either, $F_1(1, 19) = 1.30$, $MSE = 52.52$; $F_2\ (1, 34) = 1.03$, $MSE = 77.19$.

Latency

Table 5 presents the mean latencies (milliseconds) for the *gn* words and pseudowords written by French–Spanish bilinguals. The results only revealed a lexicality effect: Latencies for

Table 5
Mean Critical Interletter Intervals (in ms) and Mean Latencies in Experiment 3 as a Function of Language (French vs. Spanish) and Lexicality (Word vs. Pseudoword)

Interval and latency	French		Spanish	
	Word	Pseudoword	Word	Pseudoword
Interval				
M	93	88	121	135
SD	28	17	34	59
Latency				
M	1,439	1,901	1,435	1,920
SD	209	371	201	483

pseudowords were longer than for words, $F_1(1, 19) = 38.60$, $MSE = 116{,}243.80$, $p < .001$; $F_2(1, 34) = 25.91$, $MSE = 138{,}796.80$, $p < .001$.

The results confirm the outcomes observed in Experiment 2. When the bilingual participants wrote in French, the interletter intervals between *g* and *n* (within-syllable interval) were shorter than when participants wrote the same letters in the Spanish cognate, where the interletter interval between *g* and *n* was a between-syllables interval. Thus, the interletter intervals depended on their syllabic status in each language. When bilinguals wrote the same letters in two languages, the interletter interval was always shorter in the intrasyllabic condition than when the interval constituted a syllabic boundary. Furthermore, latencies were higher for pseudowords than for words. As in Experiment 2, the fact that no other difference yielded significance on latencies suggests that the syllabic effects obtained in the interletter intervals did not take place in early levels of handwriting production or in the recognition process of the visual input, although latency data should be taken with caution, as we have previously commented.

General Discussion

The goal of this study is to provide empirical evidence that the syllabic structure of a word constrains the organization of motor production in adult handwriting. We used a new methodology that allowed us to register the process of handwriting online (measuring interletter interval durations and latencies with a good temporal resolution), following the logic of Zesiger et al. (1994), Bogaerts et al. (1996), and Álvarez and Cottrell (2005). In the first experiment, the selected words shared the same initial letters but differed in the location of the syllable boundary. In Experiment 1A, syllable initials were either CV or CVC, which are the most simple and frequent syllables in French (Rousset, 2004). The results were not conclusive because between-syllables interletter intervals were significantly longer than within-syllable ones only in the by-participants analysis. Zesiger et al. (1994) and Bogaerts et al. (1996) also failed to provide clear results with this kind of material. It is likely that very simple, frequent syllables—such as the canonical CV in French and Spanish—are processed by default, masking any syllabic processing, as has been suggested recently (Álvarez et al., 2004; Marín & Carreiras, 2002; in visual word recognition; Costa & Sebastian-Gallés, 1998; in speech production). In Experiment 1B we thus used more complex and less frequent syllables, namely words with CCV and CCVC initial syllables (Rousset, 2004; Rousset & Vallée, 2002). With this material, the syllable effect appeared clearly: Between-syllables interletter intervals were indeed longer than within-syllable ones. We designed Experiments 2 and 3 to confirm the syllable effect in French and generalize it to another language with clear syllable boundaries, such as Spanish. The stimuli consisted of words and pseudowords with an embedded *gn* sequence. In French, the interval between *g* and *n* is always intrasyllabic, whereas in Spanish it is always intersyllabic. Experiment 2 showed that *gn* interletter intervals were shorter when written by the French participants than when written by the Spanish-speaking participants. Experiment 3 reinforced these results because it showed that when French–Spanish bilinguals wrote in French, the *gn* interletter interval was systematically shorter than when they wrote in Spanish. In the last two experiments, the only interesting result in the case of latencies was that they were longer for pseudowords than for words, but because latencies could be affected by factors coming both from the visual word processing and from motor preparation, we do not think that any definite conclusion can be achieved from this kind of measure.

Taken together, these results support the idea that syllable structure constrains motor production in adult handwriting. The three experiments reported in this study reveal that interletter intervals were longer at the syllable boundary than when the same interletter interval occurred within a syllable, both in French and in Spanish. A very recent study by Álvarez and Cottrell (2005) found a similar pattern of results in Spanish, using the same manipulation and methodology but presenting auditory words and pictures as inputs instead of a visual word to copy. This delay at the syllable boundary suggests that the motor system prepares the movement to write the following syllable during the interval between the letters, irrespective of the input modality. There is abundant empirical evidence about the role of the syllable as a processing unit, at least in languages with clear syllable boundaries. Syllabic effects have been obtained in visual word recognition in Spanish (Álvarez et al., 2000, 2001, 2004; Carreiras & Perea, 2002; Perea & Carreiras, 1998) and French (Mathey & Zagar, 2002). Some other studies have suggested that the syllable is also a functional unit in speech production (Ferrand et al., 1994, 1996, in French; Carreiras & Perea, 2004, in Spanish; and Levelt & Wheeldon, 1994, in Dutch). In addition and more important, some studies showed that syllable-sized units mediate the production of written words. This evidence has come from experimental studies (Bogaerts et al., 1996), neuropsychological data (Caramazza & Miceli, 1990; Caramazza et al., 1987; Jónsdóttir et al., 1996; Shallice et al., 2000), and developmental research (Kandel & Valdois, in press).

The results of the present study are in agreement with the anticipatory conception of handwriting production proposed by Van Galen (1991). In addition, our data agree with the idea that supplementary processing loads due to processing of linguistic variables produce duration increases. However, the model does not incorporate syllables as processing units in handwriting. The results of the present study reveal that the processing of the following syllable slowed down the movement within a letter string. It increased the interletter intervals situated at the syllable boundary. Therefore, syllables and not only letters (Teulings et al., 1983; Van Galen et al., 1989) may be used as units during motor production in handwriting. The syllable could be an intermediate-grained unit between words (at the spelling module) and graphemes (at the allograph module). In other words, handwriting production could also involve the activation of a syllabic module containing a sort of mental syllabary (Levelt & Wheeldon, 1994) that stores syllables as processing units. An activated word at the spelling module would constitute the input to the syllabic module. At this level, the letter string would be decomposed into its syllable constituents, and each syllable would serve as input to the allograph module, which would, in turn, decompose the syllables into graphemes for allograph selection. This kind of processing would be particularly important in writing polysyllabic words, at least in syllable-timed languages. The syllable would allow the decomposition of the word into a coherent and linguistically oriented structure that would facilitate motor processing. For instance, to write the word *présager*, it is easier to process and recover from the buffer the syllable *pré*, then *sa*, and finally *ger*, than *prés* and then *ager*, because the latter decomposition does not produce a linguistically coherent structure. This decomposition, even if it involves two units instead of three, would be more timing consuming because it is more difficult to keep in memory. More research is, of course, needed to assess this issue. Finally, we point out that this syllabic conception of handwriting production is in line with the hypothesis that graphosyllables are processed and stored in orthographic representations (Caramazza & Miceli, 1990) because the interletter interval duration is determined by (a) the position of the syllable boundary (Experiment 1) and (b) the orthographic syllabification of each language (Experiments 2 and 3). Note that in French, phonological and orthographic syllables are sometimes different. For example, the word *signe* is monosyllabic in speech but bisyllabic orthographically (*si.gne*). The results of our study indicate that when the participants wrote in French, they organized their handwriting movements according to the graphosyllabic structure of the word, that is, the orthographic syllabification. They wrote *si* and then *gne*, in two distinct graphosyllables, as postulated by Caramazza and Miceli's (1990) notion of orthographic representations.

Another issue that deserves attention is that one could argue that some of the observed syllabic effects were due to or influenced by the task input, which was linguistic material, in particular visually presented words. In other words, there could have been contamination resulting from the recognition process. However, there are three reasons why this is not likely to be the case. First, the syllabic effects appeared online, in the process of handwriting (the interletter intervals), and not in the latencies. The effects on latencies only concerned lexicality. Second, we observed the delay at syllabic boundaries systematically, irrespective of the serial position of the critical interletter interval (between the first and the second syllable in Experiment 1 and also in subsequent positions in Experiments 2 and 3). Finally, another argument that rules out this possibility is that syllabic effects at interletter intervals have been obtained with different inputs: auditory-presented words; nonlinguistic stimuli, such as pictures (Álvarez & Cottrell, 2005); and visually presented words (this study).

In the last two experiments, latencies were longer for pseudowords than for words. We thus observed the lexical effect before movement initiation, whereas the syllable effect appeared during movement execution. In spite of the problems with latency data already mentioned, this suggests that lexical search in the spelling module is carried out before movement initiation. Then, once the orthographic representation is activated, its graphosyllabic components constitute the inputs to the more peripheral modules of the motor production system. These results are in line with Zesiger et al. (1993), who found an effect of lexical status on movement duration and trajectory length.

Kandel and Valdois (in press) showed that children from 6 to 10 years old organized their handwriting movements according to the syllable structure of words and pseudowords. Their results revealed that the child prepared the movement to write the first syllable before its initiation. The child then processed the second syllable while producing its first letter. There was a systematic and significant duration increase at the first letter of the second syllable, irrespective of syllable and word length. On this basis, the present results therefore indicate that although handwriting becomes more and more automatic with development, the syllable still remains as a processing unit in adulthood. As Kandel and Valdois suggested, the syllable could be used as a unit for chunking information in the letter string. For instance, the syllable *tri* in the word *tri.cher* is likely to be familiar because it also belongs to words we already know, such as *tri.coter*. The syllable *tri* will therefore facilitate the representation of the input even if we are capable of encoding more letters: *Tri* is easier to keep in the buffer than *tric* because it can be matched to a *tri* already present in memory. Because the motor system relies on orthographic representations that are stored as chains of graphosyllables (Caramazza & Miceli, 1990), it is also likely that *tri* rather than *tric* is used to recall the spelling of the letter string and constitute the input for the lower modules of motor production.

Finally, as previously mentioned, this study is in line with research on speech production and perception as well as written language production and perception: Syllable structure constrains language processing, at least in languages with clear syllable boundaries. The evidence obtained on reading in French and Spanish suggests that the skills and processes developed in the course of learning to read can be applied to writing. This issue requires further research. In addition, our new methodology seems to be an efficient tool to investigate very local effects in handwriting production and offers the possibility of identifying with more precision the locus of the syllabic effect in written word production, which is clearly a matter for further research.

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Appendix A

CV and CVC Syllable Initial Words Used in Experiment IA and Their Corresponding Word Frequency (per Million)

CV words	Word frequency	CVC words	Word frequency
TARIF	6.61	TARTE	5.48
PURIN	1.48	PURGE	1.26
BARON	13.13	BARBE	29.71
MARIN	22.03	MARGE	17.26
CARAT	0.87	CARGO	4.58
FORAIN	1.81	FORMAT	5.97
GARAGE	12.29	GARNIR	1.74
BALADE	3.71	BALCON	17.29
CARAFE	2.35	CARTON	20.65
MARAIS	9.65	MARBRE	27.10
PARENT	6.74	PARDON	27.61
PALACE	4.74	PALPER	2.52
PARURE	2.52	PARVIS	3.58
PARADE	7.77	PARDON	27.61
POLAIRE	5.19	POLTRON	0.39
CAPUCHE	0.32	CAPSULE	1.87
CARESSE	17.32	CARBURE	1.32
PAROISSE	4.90	PARTERRE	2.55
M	6.85		11.02
SD	5.99		11.11

Note. CV = consonant–vowel; CVC = consonant–vowel–consonant.

Appendix B

CCV and CCVC Syllable Initial Words Used in Experiment IB and Their Corresponding Word Frequency (per Million)

CCV words	Word frequency	CCVC words	Word frequency
PRISON	38.74	PRISME	2.26
CRAMER	1.10	CRAMPE	1.55
TRACEUR	0.16	TRACTUS	0.42
FROMAGE	12.52	FRONTON	3.60
PRENANT	37.52	PRENDRE	256.16
TREMOLO	0.45	TREMPER	2.97
SPECIALE	23.71	SPECTRAL	2.03
FRICOTER	0.19	FRICTION	1.42
FRISELIS	0.71	FRISQUET	0.32
PRESAGER	1.35	PRESTIGE	20.35
PROSODIE	0.58	PROSCRIT	1.26
FRACASSE	0.52	FRACTION	16.35
M	9.79		25.72
SD	15.01		72.86

Note. CCV = consonant–consonant–vowel; CCVC = consonant–consonant–vowel–consonant.

Appendix C

French and Spanish Cognate Words (and Their Corresponding Word Frequency per Million) and Pseudowords Containing *gn* and *gm* Sequences Used in Experiment 2

gn			*gm*		
French words	Word frequency	French pseudowords	French words	Word frequency	French pseudowords
SIGNE	102.61	FIGNE	DOGME	3.06	DUGME
MAGNAT	0.68	MOGNOT	ENIGME	3.71	UNEGME
DIGNITE	24.61	DEGNOTE	PIGMENT	0.32	PUGMANT
BENIGNE	2.65	BOLIGNE	SEGMENT	8.06	SUGMANT
MAGNOLIA	0.81	MOGNALEA	SYNTAGME	0.06	SONTIGME
MAGNITUDE	4.65	MUGNETUDE	PARADIGME	3.77	PORUDEGME
CONSIGNER	1.16	CANSAGNIR	ASTIGMATE	1.65	OSTEGMITE
MAGNIFIQUE	17.19	MIGNEFOQUE	DIAPHRAGME	1.16	DEOPHRAGME
M	19.29			2.72	
SD	34.81			2.59	

gn			*gm*		
Spanish words	Word frequency	Spanish pseudowords	Spanish words	Word frequency	Spanish pseudowords
SIGNO	50.00	FIGNO	DOGMA	6.50	DUGMA
BENIGNO	4.50	BOLIGNAR	ENIGMA	18.50	UNEGMA
DESIGNAR	9.50	DESOGNAR	PIGMENTO	1.00	PUGMANTE
MAGNOLIA	0.00	MOGNALEA	SEGMENTO	7.50	SUGMANTE
DIGNIDAD	38.00	DEGNOTIR	SINTAGMA	0.50	SONTIGMO
CONSIGNAR	1.50	CANSEGNIR	PARADIGMA	17.50	PORUDEGMO
MAGNETISMO	4.50	MOGNITESMIR	ASTIGMATICO	0.00	OSTEGMITICO
MAGNIFICO	2.50	MIGNAFICO	DIAFRAGMA	3.50	DEOPRAGMO
M	13.80			6.80	
SD	19.10			7.40	

Appendix D

French and Spanish Cognate Words (and Their Corresponding Word Frequency per Million) and Pseudowords Used in Experiment 3

French			Spanish		
Words	Word frequency	Pseudowords	Words	Word frequency	Pseudowords
SIGNE	102.61	FIGNE	SIGNO	50.00	FIGNO
REPUGNE	2.84	RIPOGNE	REPUGNA	0.50	RIPOGNE
MALIGNE	2.74	MABIGNE	MALIGNO	9.50	MABIGNO
BENIGNE	2.65	BOLIGNE	BENIGNO	4.50	BOLIGNE
IGNORER	14.48	AGNARER	IGNORAR	6.00	AGNARAR
INDIGNE	6.84	ENDEGNE	INDIGNO	3.50	ENDAGNE
DESIGNER	16.48	DESOGNER	DESIGNAR	9.50	DESOGNAR
ASSIGNER	3.10	OSSEGNER	ASIGNAR	1.50	OSEGNAR
MAGNIFIQUE	17.19	MIGNEFOQUE	MAGNIFICO	2.50	MIGNAFICO
DIGNEMENT	2.58	DEGNIMENT	DIGNAMENTE	3.50	DEGNIMENTE
CONSIGNER	1.16	CANSAGNIR	CONSIGNAR	1.50	CANSEGNIR
IGNORANT	8.00	IGNARONT	IGNORANTE	5.50	IGNARONTA
MAGNESIUM	2.71	MEGNOSIUM	MAGNESIO	3.00	MEGNOSIA
MAGNOLIA	0.81	MOGNALEA	MAGNOLIA	0.00	MOGNALEA
MAGNETISME	3.74	MOGNITESME	MAGNETISMO	4.50	MOGNITESME
MAGNAT	0.68	MOGNOT	MAGNATE	1.00	MOGNOTE
MAGNITUDE	4.65	MUGNETUDE	MAGNITUD	21.50	MUGNETUD
DIGNITE	24.61	DEGNOTE	DIGNIDAD	38.00	DEGNOTIR
M	12.10			9.20	
SD	23.60			13.70	

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