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The effect of the number of syllables on handwriting production

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Abstract Four experiments examined whether motor programming in handwriting production can be modulated by the syllable structure of the word to be written. This study manipulated the number of syllables. The items, words and pseudo-words, had 2, 3 or 4 syllables. French adults copied them three times. We measured the latencies between the visual presentation and the first production (L1), the first and second production (L2), and the second and third production (L3). The results show an effect of the number of syllables in L1 for pseudo-words but not for words and on L2 and L3 for all the items (Experiments 1 and 2). Experiment 3 ruled out an interpretation of the latencies for pseudo-words in terms of reading time with a delayed copying task. Experiment 4 replicated the previous results and assessed the effect of varying the temporal interval between the second and third trials. The results of the four experiments confirm the role of the syllable in word writing. The number of syllables of a word modulates the time course of handwriting production.

Keywords Syllable · Latency · Spelling · Handwriting · Words

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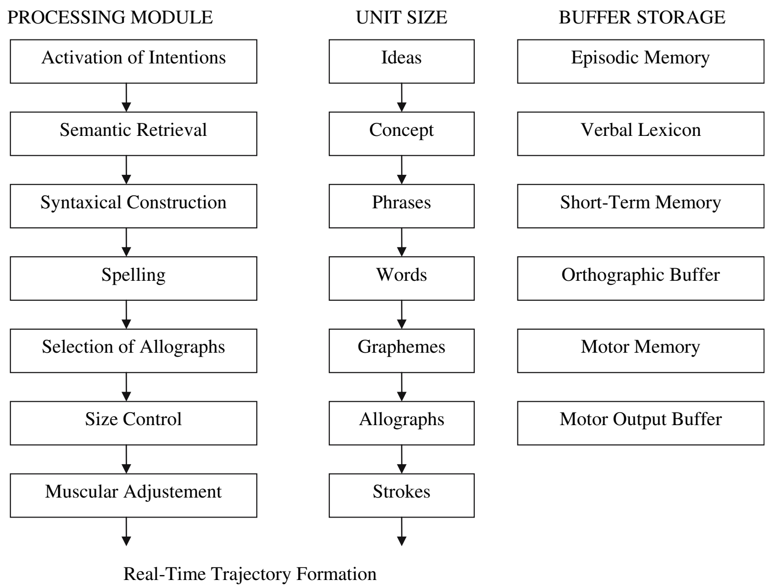

Fig. 1 Van Galen's model of handwriting production

Handwriting production requires a series of processing stages that are organized in a hierarchical manner (Van Galen, 1991) (see Fig. 1). The higher order processing levels are common to the production of other linguistic tasks such as speech (Dell, 1986, 1988; Levelt, 1989, 1992; Levelt, Roelofs, & Meyer, 1999). Handwriting processing differs at the level of spelling recovery, which is then followed by lower order modules like allograph selection, size control and muscular adjustment (Van Galen, 1991). This study concerns the spelling level of handwriting production and attempts to shed some light on the way the letters to be written are chunked into syllables. Research aimed at showing the role of the syllable in handwriting production, but none explored how the system processes the word into its syllable constituents. We used a new paradigm to investigate how the number of syllables within a word modulates the temporal course of handwriting production. The present study also explores how the structure of orthographic representations modulates the encoding and movement programming processes involved in word writing.

In Van Galen's (1991) model of handwriting production, the processing units at the spelling level are words. Their representation only contains information about the identity of the letters and their order (Teulings, Thomassen, & Van Galen, 1983; Van Galen, Smyth, Meulenbroek, & Hylkema, 1989). Their graphemes—i.e., the abstract representation of the letters—constitute the input to the lower levels, known as the "motor modules".

Several case studies of patients with acquired dysgraphia suggested, however, that this conception of orthographic representations is too simplistic because words cannot be considered as mere linear sequences of letters. Orthographic representations encode, of course, the identity of the graphemes and their respective positions, but also their consonant/vowel status, an indicator of gemmination and the presence of complex graphemes. They code information about the word's syllable and morphological structure as well (Badecker, Hillis, & Caramazza, 1990; Caramazza, & Miceli, 1990; McCloskey, Badecker, Goodman-Schulman, & Aliminosa, 1994; Miceli, Benvegnu, Capasso, & Caramazza, 1995; Miceli, Capasso, Ivella, & Caramazza, 1997; Tainturier & Caramazza, 1996; Tainturier & Rapp, 2004). Particularly relevant for the purpose of this research is that orthographic representations encode information on the word's syllable boundaries. In other words, the letter strings that compose a word are represented as groups of syllable-like "chunks". Kandel, Alvarez, and Vallée (2006) provided experimental evidence indicating that the syllable boundaries within words regulate the timing of motor programming in the production of French and Spanish words. The present research tries to provide insight into the way syllables regulate the writing process in French. In particular, it focuses on how the number of syllables within a word modulates the time course of handwriting production when writing poly-syllabic words and pseudo-words.

Although many studies focused on the kind of processing units that regulate linguistic tasks, very few were concerned by the nature and format of the units involved in writing. The syllable has been widely described and studied by linguists (Blevins, 1996), who conceived it as a relatively environment-independent phonological unit. Syllable effects have been found in auditory input tasks (Content, Kearns, & Frauenfelder, 2001; Dumay, Frauenfelder, & Content 2002; Kolinsky, Morais, & Cluytens, 1995; Mehler, Dommergues, Frauenfelder, & Ségui, 1981) and visual word recognition (Prinzmetal, 1990; Prinzmetal, Treiman, & Rho, 1986; Rapp, 1992). Research on speech production also insisted on the role of the syllable as a processing unit (Choplin, Schiller, & Levelt, 2004; Lindblom, 1983; MacNeilage, 1998; MacNeilage, & Davis, 2000; Meyer, 1990, 1991; Redford, 1999). Some models 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). Ferrand and colleagues used a masked priming paradigm that demonstrated the role of the syllable during articulatory programming in French and English (Ferrand, Segui, & Grainger, 1996; Ferrand, Segui, & Humphreys, 1997). In French, the articulatory latency was shorter when the prime corresponded to one of the syllables of the target than when the prime presented a different sequence (e.g. BA: *ba.lade* vs *bal.con*). This effect was not reproduced in a lexical decision task, suggesting that it has an impact on articulatory programming only. In Spanish, Carreiras, and Perea (2004) showed the influence of the frequency of the initial syllable on naming latencies of bi-syllabic pseudo-words. In sum, the syllable plays a determinant role in a series of linguistic tasks and in several languages. Hardly any information, however, is available on its role in written production, perhaps because handwriting production itself has been widely neglected in psycholinguistic research (Bonin & Fayol, 2000). This is surprising because handwriting is an essential tool for written communication. Its mastery is determinant in the acquisition, transmission and fixation of information in everyday life (Graham & Harris, 2000). If letter strings are chunked into syllables—i.e., bigger and linguistically oriented—processing units that reduce attentional and memory demands, then the writing system may attend higher level processes as generating content and planning (Graham, Harris, & Fink, 2000).

Two studies aimed at providing empirical evidence that syllable-sized units regulate handwriting production, but they have not been very successful (Bogaerts, Meulenbroek, & Thomassen, 1996; Zesiger, Orliaguet, Boë, & Mounoud, 1994). In Zesiger's delayed copying paradigm, French adults wrote words that began with identical trigrams but differed in the position of the syllable boundary. For example, *pa.role* has a CV initial syllable whereas *par.don* has a CVC initial syllable. The results were non significant in handwriting but a syllable effect appeared in typing. Bogaerts and colleagues used the same experimental principle but the study concerned Dutch adults. They wrote CV and CVC initial syllables like *ga.lant* and *gas.lek* (Bogaerts et al., 1996). The participants had to lift the pen at various positions while writing the target word. The idea was that if the syllable is indeed a unit in handwriting, it would be easier to lift the pen at syllable boundaries (between *a* and *l* in *galant*) than at a within-syllable position (between *a* and *s* in *gaslek*). The results did not yield any syllable effect. However, a post-hoc analysis computed on mean stroke duration and trajectory length suggests that the syllable structure of the word might modulate the time course of handwriting production.

A third study, conducted by Kandel et al. (2006), finally provided evidence of syllable effects in handwriting. Their methodology was inspired on the two studies mentioned in the previous paragraph. The participants wrote words in upper-case letters and had to lift the pen between each letter. They measured the duration of the inter-letter intervals. In the first experiment, French adults wrote words sharing the initial letters but with different syllable boundaries. The first part of the experiment used words with CV and CVC initial syllables, but the results were not statistically significant in the by-item analysis. In contrast, the second part of the experiment used syllables starting by a consonant cluster, like CCV and CCVC (e.g. *tra.ceur* and *trac.tus*). The syllable effect was significant this time. The inter-letter intervals were longer at the between-syllable positions (between *a* and *c* in *traceur*) than at the within-syllable positions (between *a* and *c* in *tractus*). The latencies did not yield any significant effects.

The duration modulations observed in the studies mentioned above can be explained within the theoretical framework proposed by Van Galen's (1991) model of handwriting production (Fig. 1). Handwriting is conceived as the result of several processing stages, in which the output of one level is the input of the next lower one. There are seven processing levels: Intentions, semantic, syntactic, spelling, allograph selection, size control and muscular adjustment. Each level or module uses 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. In this model, all the modules may be active in parallel but the higher-order levels are supposed to be further ahead during the execution of a movement than the lower ones. The role of the buffers is to ensure the continuity of performance. They store temporarily the output of one module before it is used as input for the following one. 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. Movement duration is longer at syllable boundaries than within syllables because the system prepares the production of the following syllable in parallel to the production of the current motor sequence.

Cross-linguistic experiments confirmed the syllable effect in French and extended it to Spanish (Kandel et al., 2006). French and Spanish-speaking adults wrote cognates. Cognates are words that share the same root in both languages and are orthographically identical (e.g. *magnolia*) or similar (e.g. *incendie – incendio*). They also wrote pseudo-words that were derived from the words. All the items had an embedded *gn* letter sequence. This reason for choosing this kind of sequence is that it is intra-syllabic in one language and inter-syllabic in the other: *ma.gnolia* in French and *mag.nolia* in Spanish. The results showed that the inter-letter intervals were longer between syllables than within syllables, suggesting that word syllable structure constrains motor production, both in French and Spanish. Another experiment with French-Spanish bilinguals confirmed this idea. The same participant produced longer *gn* inter-letter intervals at syllable boundaries—i.e., in Spanish—than within syllables (i.e. in French). This indicates that motor programming depends on the syllabification of each language. Finally, it should be mentioned that the latency analysis only revealed lexicality effects: Words yielded shorter latencies than pseudo-words. This means that the activation of orthographic representations facilitates the preparation of the writing process.

In sum, these experimental studies reveal that the orthographic representations of the words processed at the spelling level of handwriting production are not simple linear sequences of letters but also contain information on the way the letters are chunked into syllables. All of these studies aimed at showing the role of the syllable in handwriting production, but little is known on the way the writing systems works. The aim of the present study was to provide an insight into this issue. We explored the influence of orthographic representation activation by testing lexicality and word frequency effects, which are classical effects in the psycholinguistic literature. The second question was more practical and investigated how the writing system deals with words that have more than two syllables.

This research used a new paradigm. The participants copy words or pseudo-words that appear on a computer screen. They write each item three times on a digitizer tablet. The item disappears from the screen when the pen tip touches the digitizer. The participant can only see his/her current production. We measured the latencies between the visual presentation of the item and the beginning of first handwritten production (L1), the temporal interval between the end of the first production and the beginning of the second one (L2) and the temporal interval between the end of the second production and the beginning of the third one (L3). The idea is that the three latencies do not involve the same processes. A part of L1 concerns visual encoding and another is devoted to spelling activation and movement programming. At L1 we expect to observe, as in Kandel et al. (2006), lexical and word frequency effects. L2 and L3 only involve spelling and movement preparation processes, because the visual analysis of the word has already been done. If handwriting is indeed regulated by syllable structure, L2 and L3 should be affected by the item's number of syllables, for both words and pseudo-words. In Experiment 1 the participants copied two- and four-syllable words and pseudo-words. In Experiment 2 we reduced the number of syllables difference by presenting two and three-syllable words of low and high frequency. In Experiments 3 and 4, there was a delay between the presentation of the item and the beginning of the writing movement. The participants had to start writing after hearing an auditory signal. The idea was to dissociate the visual coding of the letter sequence from the processes involved in the preparation of the written production. In Experiment 3 the duration of the delay was constant whereas in Experiment 4 it was variable, so we could evaluate the differential impact of the delay on the writing latencies.

Experiment 1

This experiment investigated whether the number of syllables in a word modulates the way in which we organize our writing movements. The participants had to copy words and pseudo-words. All the items had the same number of letters but differed in the number of syllables. For instance, the word *concours (contest)* has two syllables (*con.cours*) whereas *original* (original) has four (*o.ri.gi.nal*). The participants had to write the items three times. The goal was to measure the latencies before starting to write (L1), and after having written the items once (L2) and twice (L3). The former latency concerns visual and spelling processes. L2 and L3 only involve the spelling and movement preparation processes, since the visual encoding is accomplished during the first latency. We expected a lexical effect on the latency preceding the first production (L1): word writing should require less preparation time than pseudo-words. More relevant for the purpose of this study is the hypothesis according to which L1, L2 and L3 should be affected by the items' number of syllables. If writing movements are indeed modulated by the items' syllable structure the latencies should be longer when having to prepare the movements to write four syllable items than two syllable items.

Method

Participants

Twenty-one volunteer undergraduates (6 men and 15 women), students of the University of Poitiers participated in the experiment. They were all right-handed, native French speakers with normal or corrected-to-normal vision. Their mean age was 23;9.

Material

The corpus consisted of a total of 32 two- and four-syllable items of eight letters: 16 words and 16 pseudo-words[1] (Appendix A). The pseudo-words were constituted from the syllables of the words. There were 8 two-syllable words (e.g., *fonction*, function), 8 four-syllable words (e.g., *activité*, activity), 8 two-syllable pseudo-words (e.g., *coutrait*), and 8 four-syllable pseudo-words (e.g., *covinima*). All the words were mono-morphological nouns. The mean frequencies were 51 occurrences per million for the two-syllable words and 53 occurrences per million for the four-syllable words (from the BRULEX© lexical database; Content, Mousty, & Radeau, 1990). The words and pseudo-words were also matched on syllable frequency (calculated regardless of the position in the word: occurrences per million[2]: 4,818 for two-syllable words; 5,152 for four-syllable words; 4,780 for two-syllable pseudo-words; 4,746 for four-syllable pseudo-words). An analysis of variance showed that the item sets did not differ significantly in syllable frequency, $F\text{s} < 1$.

Procedure

The experiment was run on a PC computer with a Wacom© type UD1212 digitizer tablet. Data was collected by a real-time analysis program called G-Studio©, a custom-designed software package developed by our laboratory (Chesnet, Guillabert, & Espéret, 1994). The participant was seated facing the screen at a distance of 80 cm. He/she was instructed to copy the items on a special sheet that was stuck to the digitizer (see Fig. 2). The participants copy items that are presented visually in a computer screen. We privileged copying instead of dictation to make sure that the participants' productions refer to the same letter sequences, both in words and pseudo-words. Since pseudo-words, by definition, do not have a standard spelling they can be written in many ways. For example, the pseudo-word *hutofari* could be written *hutaufari*, *hutophari* and even *hutaupharie*. This would imply changes in the number of letters in the sequences and would therefore limit our control of the number of letters to be written. At the onset, there was a fixation point displayed at the centre of the screen. The participant then had to put the pen on the start box. After a 500-ms beep (800 Hz), the target item appeared in the centre of the screen in 3.5 cm lowercase black letters on a gray background. The participant had to copy the item three times in a row in the boxes presented on the sheet. The boxes were laid out in such a way that the distance between each pen move was the same for all three copies. As soon as the pen touched the sheet for the first time, the item disappeared from the screen. To prevent the participant from looking back at previous copies, they were hidden as soon as they were completed. The items were

[1] The term "pseudo-word" will be used here to refer to a meaningless string of letters with a legal phonological structure in French

[2] For each syllable, we calculated its positional frequency. That is, the sum of the word frequencies in which the syllable appears in a specific position. For example, the word PROCHAIN, has PRO as initial syllable. We calculated the sum of all the words containing PRO as initial syllable (PROBABILITE, PROBABLE, PROBLEME…).

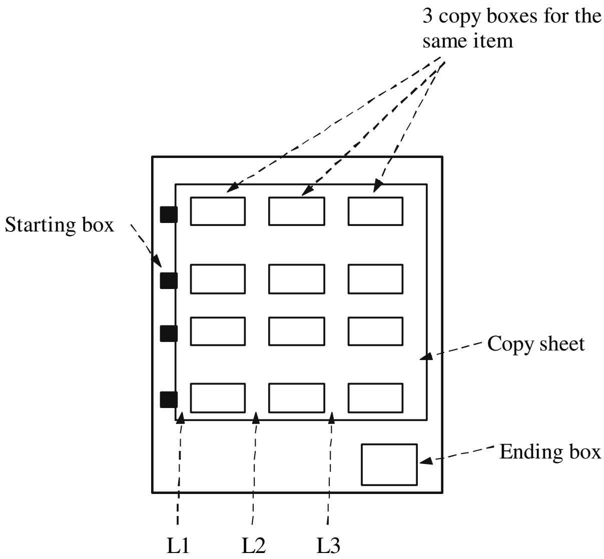

Fig. 2 Experimental device

presented in random order. The only constraint was that no two consecutive items had any syllables in common. The participants did six practice items before starting the experiment.

Data analysis

The data concerned the latencies on each of the three productions. The latency before the first copy (L1) refers to the temporal interval between the visual presentation of the item on the screen and the moment at which the pen touched the copy sheet for the first time (pressure > 0). The other two latencies were measured between the end of a copy and the onset of the next one. L2 refers to the temporal interval between the end of the first production (measured by a pen lift after the production of the last letter, i.e., pressure = 0) and the beginning of the second production (pressure > 0). L3 refers to the temporal interval between the end of the second production (measured by a pen lift after the production of the last letter, i.e., pressure = 0) and the beginning of the third production (pressure > 0).

Results and discussion

An analysis of variance (ANOVA) was conducted with latency number (L1, L2, L3), lexicality (word, pseudo-word) and number of syllables (two, four syllables) as repeated factors. The reported F-values concern analysis by participants (F_1) and items (F_2). The productions with errors -none for words, 5 out of 336 (1.5%) for pseudo-words—were discarded.

Table 1 presents the mean latencies for productions 1, 2, and 3, for words and pseudo-words as a function of the number of syllables. The analysis revealed that the first latency (L1) was longer than the second (L2), $F_1(1, 20) = 185.42, p < .001$; F_2 $(1, 28) = 1{,}608.1, p < .001$, and third (L3), $F_1(1, 20) = 161.68, p < .001$; F_2 $(1, 28) = 1{,}432.5$, $p < .001$. The difference between L2 and L3 was not significant, $F_1 < 1$; $F_2 < 1$. This suggests that movement preparation before the first production does indeed involve more processing than the following two.

The expected interaction between latency number and lexicality was significant, $F_1(2, 40) = 61.70, p < .001$; $F_2(2, 56) = 132.42, p < .001$. The interaction between latency number and number of syllables was also significant, $F_1(2, 40) = 29.58$, $p < .001$; $F_2(2, 56) = 4.44, p < .02$).

Furthermore, L1 was longer for pseudo-words than for words, $F_1(1, 20) = 59.64$, $p < .001$; $F_2(1, 28) = 133.49$, $p < .001$, both for two-syllable items, $F_1(1, 20) = 36.05$, $p < .001$; $F_2(1, 14) = 38.29$, $p < .001$ and four-syllable items, $F_1(1, 20) = 76.31$, $p < .001$; $F_2(1, 14) = 105.35$, $p < .001$. This result confirmed our hypothesis regarding the lexicality effect in L1. The activation of the orthographic information for words seems to reduce the processing demands for movement preparation as compared to the processing demands for pseudo-words. The number of syllables affected significantly pseudo-word copying, $F_1(1, 20) = 78.05$, $p < .001$; $F_2(1, 14) = 7.80$, $p < .05$, but not word copying, $F_1 < 1$; $F_2 < 1$. The presence of a number of syllables effect on pseudo-word copying suggests that when the letter sequence does not correspond to an orthographic representation, its processing requires parsing and then matching of phonological and graphemic units. These units would be chunked into syllable-like letter groups. Therefore, the operation is longer when the items have more syllables.

There were no significant differences between words and pseudo-words on L2 $F_1(1, 20) = 2.20$; $F_2(1, 28) = 1.72$ and L3, $F_1(1, 20) = 2.10$; $F_2(1, 28) = 1.40$. But,

Table 1 Mean latency and standard deviation (in ms) for L1, L2 and L3 in Experiment 1

Latency	Words		Pseudo-words	
	2 syllables	4 syllables	2 syllables	4 syllables
L1				
M	1,341	1,340	1,852	2,145
SD	327	333	512	522
L2				
M	530	566	545	572
SD	101	123	119	134
L3				
M	537	560	542	571
SD	103	105	103	116

in L2 and L3, the number of syllables affected both word and pseudo-word production. Moreover, the interaction between lexicality and the number of syllables was not significant, $F_1 < 1$; $F_2 < 1$ for L2, and $F_1 < 1$; $F_2 < 1$ for L3. L2 was longer for four syllable words than for two syllable words, $F_1(1, 20) = 11.64$, $p < .01$; $F_2(1, 14) = 8.63$, $p < .05$. L3 yielded the same pattern of results, $F_1(1, 20) = 9.42$, $p < .01$; $F_2(1, 14) = 4.61$, $p < .05$. Furthermore, L2 was longer for four syllable pseudo-words than for two syllable pseudo-words, $F_1(1, 20) = 14.05$, $p < .01$; $F_2(1, 14) = 6.47$, $p < .05$. L3 yielded the same pattern of results, $F_1(1, 20) = 13.42$, $p < .01$; $F_2(1, 14) = 7.54$, $p < .05$. Thus, in L2 and L3 the latencies were longer for the four-syllable items than two-syllable items, irrespective of the item's lexicality. This reveals that writing movements are indeed modulated by the items' syllable structure. The syllabic complexity of a letter sequence therefore determines the complexity of the processes that are involved in movement preparation. Therefore, writing is not just an automatic activity of writing one letter after the other, as van Galen's (1991) model of handwriting production postulated. The following experiment further examines the effect of the number of syllables by reducing the difference in the number of syllable boundaries. In addition, we explored the word frequency effect, which is another classical effect observed in the psycholinguistic literature.

Experiment 2

The purpose of this experiment was to use other materials to replicate and generalize the results of Experiment 1 on words only. On one hand, we attempted to verify whether the number of syllables effect observed for L2 and L3 still occurred with two and three-syllable words rather than four-syllable words as in Experiment 1. The replication of the results of the preceding experiment with a smaller difference in number of syllables should indicate their robustness. On the other hand, since the previous experiment confirmed a classical psycholinguistic lexicality effect, in the present experiment we investigated word frequency effect, which is also a well-known and documented psycholinguistic effect. Thus, as in Experiment 1, we expected a word frequency effect for L1. Moreover, the number of syllables should affect L2 and L3.

Method

Participants

Twenty volunteer undergraduate students (15 women and 5 men) from the University of Poitiers participated in the experiment. They were all right-handed, native speakers of French and had normal or corrected-to-normal vision. Their mean age was 23;6.

Material

The corpus consisted of thirty-two seven-letter items: 16 high-frequency words and 16 low-frequency words (Appendix B). Each category had an equal number of two- and three-syllable words. The list thus included 8 high-frequency two-syllable words (e.g. *couloir*, hallway), 8 high-frequency three-syllable words (e.g. *cabinet*, closet), 8 low-frequency two-syllable words (e.g. *pochoir*, stencil) and 8 low-frequency three-syllable words (e.g. *vibrato*, vibrato). The two and three-syllable words were matched for lexical frequency and for the frequency of their syllabic constituents (see Table 2). An analysis of variance was conducted to make sure that neither lexical frequency nor syllable frequency differed across the four experimental conditions (Fs < 1).

Procedure and data analysis

The procedure and data analysis were the same as in Experiment 1.

Results and discussion

An analysis of variance (ANOVA) was conducted with latency number (L1, L2, L3), lexical frequency (low, high) and number of syllables (two, three syllables) as repeated factors. The reported F-values concern analysis by participants (F_1) and items (F_2). The productions with errors—one error on high-frequency words (0.3%) and four on low-frequency words (1.2%)—were discarded.

Table 3 presents L1, L2 and L3 values for high and low frequency words as a function of the number of syllables. As in Experiment 1, the latency was longer for L1 than L2, $F_1(1, 19) = 112.56$, $p < .001$; $F_2(1, 28) = 1{,}033{,}4$, $p < .001$, and L3, $F_1(1, 19) = 131.91$, $p < .001$; $F_2(1, 28) = 1{,}165.6$, $p < .001$. But, L2 and L3 did not differ significantly from each other, $F_1(1, 19) = 1.37$; $F_2(1, 28) = 2.25$. Also, and as expected, at L1 the interaction between lexicality and the number of syllables was not significant, $F_1(1, 19) = 1.14$; $F_2 < 1$. L1 was longer for low-frequency words than for high-frequency ones, $F_1(1, 19) = 49.77$, $p < .001$; $F_2(1, 28) = 22.55$, $p < .001$, both on two-syllable words, $F_1(1, 19) = 66.68$, $p < .001$; F_2(1,

Table 2 Mean word frequency (occurrences per million) and syllable frequency (occurrences per million) for high-frequency and low-frequency items

	High-frequency		Low-frequency	
	2 syllables	3 syllables	2 syllables	3 syllables
Mean frequency	150	151	0.18	0.19
Minimum frequency	51	46	0.04	0.08
Maximum frequency	416	481	0.38	0.34
Syllable frequency	2,177	2,186	1,970	1,958

Table 3 Mean latency and standard deviation (in ms) for L1, L2 and L3 in Experiment 2

Latency	High-frequency		Low-frequency	
	2 syllables	3 syllables	2 syllables	3 syllables
L1				
M	1,069	1,093	1,262	1,273
SD	287	266	345	347
L2				
M	536	559	544	560
SD	91	92	95	98
L3				
M	533	549	535	550
SD	93	101	92	99

14) = 17.06, $p < .001$, and on three-syllable words, $F_1(1, 19) = 34.14$, $p < .001$; $F_2(1, 14) = 7{,}90$, $p < .05$. This confirms the frequency effect and the classical idea of a direct orthographic lexicon retrieval modulated by word frequency (Goodman & Caramazza, 1986). It suggests that the activation level of the orthographic representations that are involved in writing is also modulated by word frequency. In L1, the number of syllables did not yield a significant effect, $F_1(1, 19) = 3.42$; $F_2 < 1$.

At L2 and L3, the interaction between frequency and the number of syllables was not significant, $F_1 < 1$; $F_2 < 1$ for L2, and $F_1 < 1$; $F_2 < 1$ for L3. There was no longer a frequency effect on L2, $F_1 < 1$; $F_2 < 1$, and L3, $F_1 < 1$; $F_2 < 1$. The latencies for L2 were shorter for two-syllable items than for three-syllable ones: $F_1(1, 19) = 21.89$, $p < .001$; $F_2(1, 28) = 5.13$, $p < .05$ for high frequency words and low frequency words, $F_1(1, 19) = 12.09$, $p < .01$; $F_2(1, 14) = 3.57$, $p = .08$. L3 yielded the same patter of results: $F_1(1, 19) = 24.93$, $p < .001$; $F_2(1, 28) = 4.89$, $p < .05$, for high-frequency words $F_1(1, 19) = 7.80$, $p < .05$; $F_2(1, 14) = 5.12$, $p < .05$, and low-frequency words, $F_1(1, 19) = 15.58$, $p < .001$. Thus, L2 and L3 were shorter for two-syllable words than for three-syllable ones, regardless of their frequency.

This experiment replicated the results of Experiment 1 and reinforced the number of syllables effect. This result is particularly relevant because it indicates that a mere one-syllable difference between the items is enough to change the way in which the writing system prepares the movements. Moreover, as expected, L1 varied inversely with word frequency. Thus, this experiment indicates the presence of a word frequency effect in written production that is characteristic of lexical retrieval.

In sum, Experiments 1 and 2 revealed that lexicality and word frequency affected the initial latency (L1). L1 therefore involves the activation of orthographic representations. Their activation level depends on word frequency. However, it is likely that the lexicality and word frequency effects only reflect processing in the encoding stage and not in movement preparation. The fact that L2 and L3 were only affected by the items' number of syllables reinforces this idea. L2 and L3 apparently involve processing that is independent of the orthographic lexicon and is sensitive to the number of syllables. The writing system would just "chunk" the letter strings into syllable units in order to keep the spelling in the graphemic buffer.

There are at least two possible explanations of why there was no number of syllables effect on words for L1. The first interpretation is that the variance on L1 is too high and it masks the number of syllables effect. The difference between the pseudo-words of two and four syllables for L1 was 293 ms whereas this difference was of 27 ms for L2. The second interpretation is that keeping the items active before subsequent productions requires one or more processes that are not involved in the initial production. Once an item is produced—and thus once it's graphemic representation has been activated (or constructed)—the processes that follow are likely to be different. The spellings retrieved or constructed before the first production would be kept active in the graphemic buffer while awaiting productions two and three.

To decide between these two interpretations, it is necessary to dissociate the duration of visual encoding from that of motor programming. In other words, it is likely that the lexicality and frequency effects are in fact located in the item encoding stage and not when preparing its production. The next two experiments were designed to dissociate the effects of these two processing stages.

Experiment 3

This experiment aims at dissociating the encoding processes from the movement programming processes. To do so, we used a delayed copy paradigm that is often used in pronunciation tasks (Andrews, 1992; Morrison & Ellis, 1995). The participant encodes the item and then pronounces it after an auditory signal. This procedure thus dissociates the visual encoding processes—measured as the time between stimulus presentation and the signal—from articulatory programming (the time between the signal and the response). In our experiment, the participants had to write the stimulus after a start signal instead of pronouncing it. Visual encoding could therefore be dissociated from movement preparation before the first production. To compare the three latencies, the delayed copying also concerned the following two productions. The participants had to start writing the item for the second and third time after an auditory signal. If orthographic representations only affect the encoding processes, L1 should be affected by the number of syllables and not by lexicality. In contrast, if orthographic representations also modulate the movement preparation process, L1 should still be affected by lexicality. L2 and L3—which only reflect information retention in the graphemic buffer- should only be sensitive to the number of syllables, as in Experiments 1 and 2 (Fig. 3).

Method

Participants

The participants were twenty-four native speakers of French who were students at the University of Poitiers. There were 20 women and 4 men. Their mean age was 24;7 and all had normal or corrected-to-normal vision.

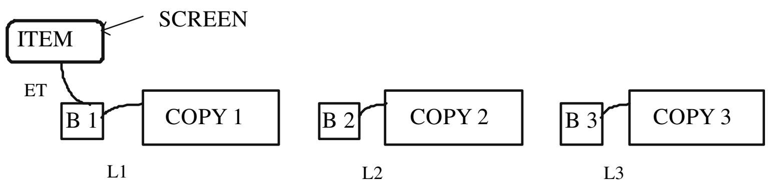

Fig. 3 Delayed production procedure

Material

The material was the same as in Experiment 1.

Procedure

The experimental device and procedure were the same as in Experiment 1 and 2. The differences are in the timing of the procedure (Fig. 3). The participant puts the pen point on the start box and the item appeared in the centre of the screen. After reading the item, the participant placed the pen on box 1 (B1) of the sheet and the item immediately disappeared from the screen. After a given temporal interval (450 ms + a random duration ranging from 0 to 250 ms), a 800-Hz beep indicated that the participant had to start his/her first production. The reason for the random short delay between pen contact and the start signal was to prevent the participant from anticipating the start signal. Once the first production was finished, the participant put the pen on box 2 (B2). After another delay—also of fixed and random duration—a second signal indicated the start of the second production. Finally, the pen was placed on box 3 (B3) and a third signal indicated when it was time to start producing the item for the third and last time. The distance between boxes B1, B2, and B3 and the three writing boxes were equal so avoid latency differences caused by differences in the distance to cover. The participants did six practice items before starting the experiment.

Data analysis

We measured the time to read each item (encoding time or ET) as the temporal interval between the display of the item on the screen and pen contact in B1. The three writing latencies (L1, L2, and L3) concerned the time lapses between the onset of each start signal and pen contact in the corresponding writing box.

Results and discussion

Two ANOVAs were conducted. The first one concerns ET, with lexicality (word, pseudo-word) and number of syllables (two, four syllables) as repeated factors. The second concerns latencies, with production number (L1, L2, L3), lexicality (word, pseudo-word), and the number of syllables (two, four syllables) as repeated factors. The reported F-values concern analysis by participants (F_1) and items (F_2). The productions with errors—one copying error on words (0.26%) and four copying errors on pseudowords (1.04%)—were discarded.

Visual encoding time

Table 4 presents the mean encoding times and latencies for words and pseudo-words as a function of the number of syllables. The analysis revealed that encoding time was shorter for words than for pseudo-words, $F_1(1, 23) = 121.76$, $p < .001$; $F_2(1, 28) = 183.22$, $p < .001$. The difference between two and four-syllable items was also significant, $F_1(1, 23) = 54.10$, $p < .001$; $F_2(1, 28) = 10.61$, $p < .01$, as was the interaction between lexicality and the number of syllables, $F_1(1, 23) = 20.38$, $p < .001$; $F_2(1, 28) = 5.91$, $p < .05$. The number of syllables effect was significant for pseudo-words, $F_1(1, 23) = 48.29$, $p < .001$; $F_2(1, 14) = 10.39$, $p < .01$, but not for words, $F_1(1, 23) = 1.77$; $F_2 < 1$. A lexicality effect was found for two-syllable items, $F_1(1, 23) = 91.84$, $p < .001$; $F_2(1, 14) = 101.99$, $p < .001$, and four-syllable items, $F_1(1, 23) = 112.83$, $p < .001$; $F_2(1, 14) = 91.35$, $p < .001$.

Latencies

L1 was longer than L2 and L3, $F_1(1, 23) = 25.71$, $p < .001$; $F_2(1, 28) = 269.62$, $p < .001$. The interaction between lexicality and latencies was significant, $F_1(2, 46) = 4.81$, $p < .02$; $F_2(2, 56) = 5.77$, $p < .01$. For L1, the difference between

Table 4 Mean latency and standard deviation (in ms) for ET, L1, L2 and L3 in Experiment 3

Latency	Words		Pseudo-words	
	2 syllables	4 syllables	2 syllables	4 syllables
ET				
M	1,591	1,639	2,308	2,674
SD	407	489	605	688
L1				
M	787	788	812	842
SD	132	145	145	152
L2				
M	707	725	718	751
SD	127	138	136	142
L3				
M	724	755	731	772
SD	141	156	139	160

words and pseudo-words was significant, $F_1(1, 23) = 16.69$, $p < .001$; $F_2(1, 28) = 17.05$, $p < .001$. This difference was still significant on L2 and L3, but only in the by-participants analysis, $F_1(1, 23) = 4.62$, $p < .05$; $F_2(1, 28) = 3.64$. for L2; $F_1(1, 23) = 4.45$, $p < .05$; $F_2(1, 28) = 1.86$ for L3.

For L1, although the interaction between the number of syllables and lexicality was not significant, $F_1(1, 23) = 2.12$; $F_2(1, 28) = 2.74$, a number of syllables effect did occur on pseudo-words, $F_1(1, 23) = 5.52$, $p < .05$; $F_2(1, 14) = 7.37$, $p < .05$, but not on words, $F_1 < 1$; $F_2 < 1$. For L2 and L3, the number of syllables effect was significant, $F_1(1, 23) = 18.65$, $p < .001$; $F_2(1, 28) = 9.13$, $p < .01$, for L2, $F_1(1, 23) = 11.49$, $p < .01$; $F_2(1, 28) = 18.70$, $p < .001$, for L3. However, the number of syllables and lexicality did not interact, $F_1(1, 23) = 2.02$; $F_2 < 1$, for L2, $F_1 < 1$; $F_2 < 1$ for L3, since the number of syllables effect was significant on both words, $F_1(1, 23) = 6.13$, $p < .05$; $F_2(1, 14) = 2.49$, for L2, $F_1(1, 23) = 7.23$, $p < .01$; $F_2(1, 14) = 6.80$, $p < .05$, for L3 and pseudo-words, $F_1(1, 23) = 15.63$, $p < .001$; $F_2(1, 14) = 7.74$, $p < .01$, for L2, $F_1(1, 23) = 9.29$, $p < .01$; $F_2(1, 14) = 12.14$, $p < 0.01$, for L3.

In this experiment we dissociated the visual encoding time from the time required by the spelling processes in L1. The results of Experiment 1 revealed that L1 was affected by the item's lexicality and that the number of syllables effect occurred on pseudo-words only. Experiment 3 yielded analogous effects on visual ET. These are classical results obtained in research on lexical access. The processing time is longer for pseudo-words than words.

The main point addressed here was whether the effects observed on L1 of Experiment 1 would be replicated even when suppressing the encoding time. The results of Experiment 3 revealed that despite the dissociation of the visual encoding process from the spelling processes, L1 remained significantly longer than the other two. L1 still depended on the item's lexicality and the number of syllables effect only occurred on pseudo-words. Therefore, these results indicate that L1 requires a certain kind of processing that is not included in the other two. The lexicality effect, as in Kandel et al. (2006), suggests that the activation of the orthographic representations at the spelling module takes place before the initiation of the written production. It follows that the absence of an entry in the orthographic lexicon (i.e. pseudo-words) increases the latency. The syllabic effect on pseudo-words indicates that even when there is no orthographic representation of the letter string, the system parses it into syllable-sized chunks.

In Experiments 1 and 2, L2 and L3 were no longer subject to a lexicality effect but rather to a systematic effect of the number of syllables, regardless of item lexicality or frequency. This suggests that after the activation of the spelling process, the graphemic buffer keeps the sequence in memory such that the "reactivation" of the spelling process is no longer necessary on later productions. This interpretation accounts for the latency decrease between the first production and the next two. We replicated this decrease in Experiment 3. However, for this hypothesis to be confirmed there must not be a lexical effect on L2 and L3. The information must be kept active in the graphemic buffer in the same way, regardless of the lexicality of the item. But in contrast to what was observed in Experiment 1, the lexical effect found on L1 was still significant on L2 and L3 in the by-participants analysis, although it was not as strong. The only difference between the procedures used in Experiments 1 and 3 was the addition of a start signal before each production, which increased the time lapse between two productions. The significant lexical effect observed before productions 2 and 3 in Experiment 3 could therefore be due to the temporal interval between the two productions, which may have caused the orthographic trace to deteriorate. In this case, the spelling process would have to be activated again, as earlier on the first production. The aim of Experiment 4 was to test this hypothesis.

Experiment 4

To test whether the lexical effect found on L2 and L3 in Experiment 3 resulted from the additional temporal interval introduced by the procedure, we manipulated the delay of the start signal. Waiting may cause deterioration of the item's trace in the graphemic buffer, resulting in the need to rely again on a spelling retrieval process. We thus introduced a short and long delay before the signal that preceded the third production. For the long delay, L3 and L1 should be subject to (a) a lexical effect for words, thereby confirming the existence of a lexical retrieval stage, and (b) a number of syllables effect for pseudo-words. In contrast, for the short delay, L3 should only be affected, as in Experiments 1 and 2, by the number of syllables. Lexicality should no longer have an impact, since the graphemic representation would be kept in the buffer.

Method

Participants

Twenty-five native French speakers, students at the University of Poitiers, participated in the experiment. There were 21 women and 4 men. Their mean age was 23;7 and they all had normal or corrected-to-normal vision.

Material

The items were the same as in Experiment 1.

Procedure

The device was the same as in Experiment 1 and the procedure was like Experiment 3. The delay on productions 1 and 2 consisted in a fixed 450 ms duration and a random duration ranging from 0 to 250 ms. The delay before the third production was either short (450 ms) or long (1,000 ms). The participants produced the set of 32 items twice: once with the short delay and once with the long delay. The presentation of the items and their association with the two delays were counterbalanced.

Results and discussion

Two ANOVAs were conducted. The first one concerned ET, with lexicality (word, pseudo-word) and number of syllables (two, four syllables) as repeated factors. The second concerns production latencies, with production number (L1, L2, L3), delay before the third production (long, short), lexicality (word, pseudo-word), and the number of syllables (two, four syllables) as repeated factors. The reported F-values concern analysis by participants (F_1) and items (F_2). The participants made two copying errors on words (0.26%) and seven copying errors on pseudo-words (0.88%). This data were excluded from the analyses.

Visual encoding time

Visual encoding time was affected by lexicality (see Table 5), $F_1(1, 24) = 153.8$, $p < .001$; $F_2(1, 28) = 98.67$, $p < .001$, and number of syllables, $F_1(1, 24) = 76.56$, $p < .001$; $F_2(1, 14) = 9.47$, $p < .01$. The interaction between lexicality and the number of syllables was also significant, $F_1(1, 24) = 89.40$, $p < .001$; $F_2(1, 14) = 6.69$, $p < .05$. The lexical effect occurred on two-syllable items, F_1(1,

Table 5 Mean latency and standard deviation (in ms) for ET, L1, L2 and L3 in Experiment 4. L3– is the latency with the short delay, and L3+ is the latency with the long delay

Latency	Words		Pseudo-words	
	2 syllables	4 syllables	2 syllables	4 syllables
ET				
M	1,312	1,326	1,716	2,024
SD	251	289	408	448
L1				
M	782	783	805	821
SD	146	140	143	151
L2				
M	715	734	727	755
SD	138	124	125	137
L3–				
M	750	761	747	774
SD	127	122	120	134
L3+				
M	765	772	773	811
SD	127	122	120	134

24) = 85.78, $p < .001$; $F_2(1, 14) = 52.63$, $p < .001$, as well as four-syllable items, $F_1(1, 24) = 193.4$, $p < .001$; $F_2(1, 14) = 52.69$, $p < .001$. The number of syllables effect was only significant for pseudo-words, $F_1(1, 24) = 98.31$, $p < .001$; $F_2(1, 14) = 9.32$, $p < .01$, and not words, $F_1(1, 24) = 3.05$; $F_2 < 1$. These results are consistent with Experiment 3.

Latencies preceding the three productions

Figure 4 presents the mean latencies for L1, L2 and L3, as a function of the delay (long or short) preceding L3. The effect of the production number was significant, $F_1(2, 48) = 15.19$, $p < .001$; $F_2(2, 62) = 139.7$, $p < .001$, both for the short delay, $F_1(2, 48) = 16.15$, $p < .001$; $F_2(2, 62) = 75.86$, $p < .001$, and for the long delay, $F_1(2, 48) = 12.42$, $p < .001$; $F_2(2, 62) = 75.17$, $p < .001$.

L2 was significantly shorter than L1, for both the short delay, $F_1(1, 24) = 27.00$, $p < .001$; $F_2(1, 31) = 136.9$, $p < .001$, and long delay, $F_1(1, 24) = 35.48$, $p < .001$; $F_2(1, 31) = 214.9$, $p < .001$. L3 was significantly higher than L2, both when the delay was short, $F_1(1, 24) = 6.96$, $p < .05$; $F_2(1, 31) = 31.67$, $p < .001$, and long, $F_1(1, 24) = 18.67$, $p < .001$; $F_2(1, 31) = 75.15$, $p < .001$. The magnitude of the increase was bigger for the long delay (see Fig. 4), as reflected by the significant interaction between the production number (2 or 3) and the delay, $F_1(1, 24) = 11.32$, $p < .01$; $F_2(1, 31) = 16.55$, $p < .001$.

For L1, the difference between words and pseudo-words was significant, $F_1(1, 24) = 22.12$, $p < .001$; $F_2(1, 28) = 12.74$, $p < .001$ and the number of syllables was not significant, $F_1(1, 24) = 2.25$; $F_2(1, 28) = 1.40$. For L2, the lexical effect remained significant but only in the by-participants analysis, $F_1(1, 24) = 15.46$,

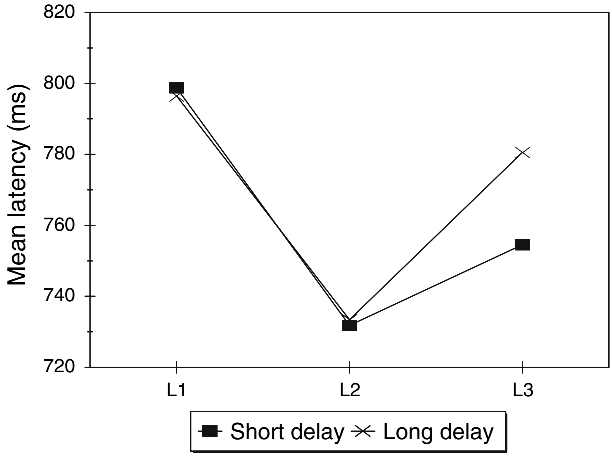

Fig. 4 Mean latency (in ms) before the three productions, for the short and long delays

$p < .001$; $F_2(1, 28) = 3.38$ and the number of syllables did have an impact on L2, $F_1(1, 24) = 22.82$, $p < .001$.; $F_2(1, 28) = 6.39$, $p < .02$.

For the long delay on L3, the lexical effect persisted, $F_1(1, 24) = 8.44$, $p < .01$; $F_2(1, 28) = 4.69$, $p < .05$ and the effect of the number of syllables was still significant, $F_1(1, 24) = 10.25$ $p < .01$; $F_2(1, 28) = 4.69$ $p < .05$. In this case, the interaction between lexicality and the number of syllables was significant, but only in the by-participants analysis, $F_1(1, 24) = 11.50$, $p < .01$; $F_2(1, 28) = 2.14$. The number of syllables effect occurred on pseudo-words, $F_1(1, 24) = 14.02$, $p < .001$; $F_2(1, 14) = 6.87$ $p < .05$, but not on words, $F_1(1, 24) = 1.31$; $F_2 < 1$. For the short delay on L3, the lexical effect was not significant, $F_1(1, 24) = 1.89$; $F_2(1, 28) = 1.69$. The number of syllables effect was however significant, $F_1(1, 24) = 10.69$, $p < .01$; $F_2(1, 28) = 7.65$, $p < .01$. The interaction between the lexicality and the number of syllables was not significant, $F_1(1, 24) = 1.58$; $F_2 < 1$, and the number of syllables affected both words, $F_1(1, 24) = 5.44$, $p < .05$; $F_2(1, 14) = 5.90$, $p < .05$, and pseudo-words, $F_1(1, 24) = 7.02$, $p < .05$; $F_2(1, 14) = 5.22$, $p < .05$.

Unlike Experiment 1, Experiment 3 yielded a lexical effect on L2 and L3. We hypothesized that the persistence of this lexical effect could be due to the supplementary time between the two productions during which the participant had to wait for the start signal. This delay may have caused the reactivation of the spelling process so that orthographic information could be kept in memory. Experiment 4 tested this explanation with a short or long temporal interval before the start signal. As expected, when the delay before L3 was short, as in Experiment 1, there was no significant lexical effect. The opposite pattern resulted with the long delay. When the delay before the third production was long, the lexical effect occurred on L3. This result provides an initial explanation for the differences observed between Experiments 1 and 3. In Experiment 1, the participants produced the item three times, one after the other. In Experiment 3, they had to wait for a signal between each production. The persistence of the lexical effect on the latencies for productions 2 and 3 in Experiment 3 may thus be explained by the impact of the delay of the start signal. Similarly, the number of syllables effect, observed on words and pseudo-words in Experiment 1 and on pseudo-words only in Experiment 3, can also be explained by this additional waiting period. Indeed, for a short delay, the two-syllable item latencies were shorter than the four-syllable ones, for words and pseudo-words alike. For a long delay, this effect only occurred on pseudo-words. So when the time lapse between two productions was short enough, the graphemic representation could be kept in the graphemic buffer without requiring re-access to the lexical entry. Therefore, the only remaining effect was the number of syllables, but keeping the spelling information in the graphemic buffer turned out to be highly sensitive to time. It therefore seems that an item's spelling can be kept active only for a relatively short period. Once this period is over, the spelling process must be implemented again to avoid deterioration of the memory trace.

General discussion

The four experiments examined how the syllable structure of a word affects the timing of written production. The results revealed that the number of syllables only affected pseudo-word production in L1. In contrast, L2 and L3 increased as a function of the number of syllables, both for word and pseudo-word production. The study also aimed at investigating how the activation of orthographic representations affects the time course of movement preparation. Lexicality and word frequency only affected L1, but not L2 and L3. L1 was shorter for word production than for pseudo-words (Experiment 1). The latencies were longer for low frequency words than for high frequency words (Experiment 2). Furthermore, the lexicality effect persisted in L1 even when production initiation was delayed (Experiments 3 and 4).

The number of syllables effect for pseudo-words in L1 suggests that when the items do not activate an orthographic representation in the lexicon, the letter strings are chunked into syllables. The pseudo-word is in fact written as a series of processes that recall each of the syllable units. This segmentation/recomposition procedure seems to be more time consuming than the processes that are involved when writing words. The number of syllables effect is also significant in L2 and L3, not only for pseudo-words, but also for words. This suggests that words are also segmented into their syllable constituents after the activation of the orthographic representation. Keeping a word in memory as a series of syllables would facilitate the recall during the preparation of the writing movements. This idea is supported and reinforced by the fact that the number of syllables effect is even present when the words only differ by one syllable (Experiment 2).

Theses results are in agreement with neuropsychological and experimental data. Case studies of patients with a graphemic buffer disorder (Baxter & Warrington, 1987; Caramazza & Miceli, 1990; Zesiger & de Partz, 1997) indicate that the recall of orthographic information is indeed regulated by the syllable structure of words. It seems that the storage of orthographic information in the graphemic buffer—once lexical access has occurred for words and chunking has taken place for pseudo-words—is achieved via a rehearsal process, which is sensitive to the processing load (measured in number of syllables). Furthermore, the results are consistent with Kandel et al.'s (2006) research and provide supplementary information on the way syllables modulate the written production of words and pseudo-words. The syllable structure of the word constrains the temporal course of handwriting.

It should be pointed out that the characteristics of the syllable-sized unit used during written production remain uncertain. The number of syllables effect is due to a rehearsal process achieved via phonological mediation (Nolan & Caramazza, 1983), which would make it a phonological syllable. However, this interpretation conflicts with a remark proposed by Barry (1994): If the graphemic buffer uses a rehearsal system based on a phonological representation, then phonological errors could appear when this system is activated. Indeed, French has many irregularities between phonemes and graphemes, and often, the phonological representation is not sufficient to retrieve the correct spelling (Catach, 1995). Moreover, in a delayed naming study with the same items than in Experiment 1, the number of syllables effect was not significant (Lambert, 1999). Given that phonological errors were never found in the present study, the graphemic buffer seems to take advantage of a dual-encoding process: (1) phonological encoding (as suggested by the number of syllables effect); and (2) orthographic encoding to avoid production errors. Dual encoding enables the retention of information, both for a rather long time (phonological information) and in an efficient way (orthographic information).

However, an alternative interpretation could be proposed. The number of syllables effect may not be a manifestation of phonological mediation but of orthographic encoding. Some data indeed suggests the existence of a grapho-syllable. The notion of grapho-syllable has been established in terms of grapheme organization (cf. Badecker, 1996). According to this view, the syllable is determined not phonologically but orthographically and the graphemic buffer may serve to cue grapho-syllabic boundaries (Caramazza & Miceli, 1990). As children acquire written language, grapho-syllabic representations may develop in a system that is independent of phonology but is subject to the same constraints. It is likely that the number of syllables effect reflects a grapho-syllable processing. If we assume the existence of a grapho-syllable, then it is also necessary to conceive the presence of a rehearsal system specific to the graphemic buffer. This hypothesis was already proposed by Annoni, Lemay, de Mattos Pimenta, and Roch Lecours in 1998. These authors hypothesized the existence of a “graphemic loop” to explain the performance of an agraphic patient who made more errors in delayed copying than in direct copying.

The other relevant results of this series of experiments concern the lexicality and word frequency effects that appeared in L1. These effects annulled the number of syllables effect. L1 therefore involves a process of direct orthographic representation activation that is independent of the number of syllables and that precedes the processes involved in movement preparation. The lexicality effect appeared with the activation of the orthographic representations of words and the non activation of the letter strings that constituted the pseudo-words. This is in line with the results observed in Experiment 2, where L1 was longer for low frequency words than for high frequency ones. It provides further understanding of the writing process, since it indicates that word frequency determines the level of activation of the orthographic representation, which in turn affects the timing of movement initiation.

By dissociating the effects of visual encoding and written production in Experiments 3 and 4, we provided evidence for a new effect which, to our knowledge, has never been reported in the literature. This effect concerns the temporary nature of the trace stored in the graphemic buffer. The introduction of a delay between productions 1 and 2 and between productions 2 and 3, made the lexicality effect reappear. As for L1, the durations of L2 and L3 were affected by the lexical status of the item when the delay was long. This effect was investigated more thoroughly in Experiment 4. The lexicality effect appeared with between-production intervals of 1,000 ms and not with intervals of 450 ms. This suggests that orthographic information can only be kept in the graphemic buffer for short temporal intervals. After a certain time, the trace of the graphemic pattern seems to deteriorate and the rehearsal is no longer possible to ensure the recall of the letter string. The exact duration of the temporal period should, of course, be determined in future experiments. When the delay goes beyond a certain threshold the trace disappears (or deteriorates), so another lexical retrieval operation needs to be conducted. This idea is supported by the fact that (1) the lexicality effect reappeared for L2 in Experiment 3 and for L3 in Experiments 3 and 4; and (2) the lack of number of syllables effect on words but not pseudo-words.

In conclusion, the results of the four experiments reported in this paper provide evidence supporting the role of the syllable in word writing. The number of syllables modulates the time course of handwriting production. The way the rehearsal process proceeds in the graphemic buffer requires further investigation. In particular, we should determine whether it relies on dual encoding or works through a grapho-syllable.

Appendices

Appendix A Items used in Experiments 1, 3, and 4

2-syllable words	4-syllable words	2-syllable pseudo-words	4-syllable pseudo-words
fonction	activité	coutrait	écitanal
tourment	humanité	grantion	hutofari
fragment	économie	conchant	cumalité
concours	original	deurtion	osécomie
couchant	facilité	tourtion	minotité
prochain	totalité	granment	covinima
portrait	humilité	porcours	acgifata
grandeur	sécurité	foncment	rivitécu

Appendix B Items used in Experiment 2

2-syllable high-freq.	3-syllable high-freq.	2-syllable low-freq.	3-syllable low-freq.
couloir	cabinet	tournis	antivol
progrès	théorie	miction	savarin
tableau	horizon	verseur	crétacé
courant	énergie	pochoir	embargo
conseil	qualité	compost	vibrato
combien	univers	sabreur	humérus
journal	naturel	pendard	calumet
instant	général	couvain	sédatif

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