Journal of Experimental Psychology:
Learning, Memory, and Cognition
2006, Vol. 32, No. 6, 1330–1340

0278-7393/06/$12.00 DOI: 10.1037/0278-7393.32.6.1330

Written Spelling to Dictation: Sound-To-Spelling Regularity Affects Both Writing Latencies and Durations

Marie Delattre and Patrick Bonin
Université Blaise Pascal

Christopher Barry
University of Essex

The authors examined the effect of sound-to-spelling regularity on written spelling latencies and writing durations in a dictation task in which participants had to write each target word 3 times in succession. The authors found that irregular words (i.e., those containing low-probability phoneme-to-grapheme mappings) were slower both to initially produce and to execute in writing than were regular words. The regularity effect was found both when participants could and could not see their writing (Experiments 1 and 2) and was larger for low- than for high-frequency words (Experiment 3). These results suggest that central processing of the conflict generated by lexically specific and assembled spelling information for irregular words is not entirely resolved when the more peripheral processes controlling handwriting begin.

Keywords: regularity, spelling to dictation, central and peripheral processes

The act of writing a spoken word to dictation involves both central processes concerned with retrieving, assembling, and selecting an orthographic representation (which we can call *spelling*) and peripheral processes concerned with the output and execution of orthographic codes (which we can call *writing*). This distinction between central and peripheral aspects of written production is supported by neuropsychological studies of varieties of acquired dysgraphias. In central dysgraphias (such as phonological, surface, and deep dysgraphia), the major impairment is to spelling, and the same patterns of impaired performance are seen irrespective of mode of output (such as writing, oral spelling, typing, etc.). In peripheral dysgraphias, the major impairment is to writing and can be specific to one mode of production output (e.g., there are patients who make errors in handwriting but not in oral spelling; Baxter & Warrington, 1986). This article is concerned with the relationship between the central processes of spelling and the peripheral processes of handwriting in literate French adults, and our experiments measured both the latency and duration of writing responses in dictation.

The dual-route model of spelling production (e.g., Ellis, 1982) proposes that two processing systems operate in parallel: a lexical route that retrieves spellings of known words from a memory store of word-specific knowledge and a nonlexical (or assembled) route that generates spellings using a process of sublexical sound-to-spelling conversion. The assembled spelling route would be efficient in languages whose orthographies have predictable or consistent orthographic-to-phonological correspondences (such as Turkish, Italian, and Japanese kana) but would be considerably less effective for English and French, whose orthographies are characterized by highly inconsistent relationships (e.g., the vowel /i:/ is spelled in many different ways in English words, as in *eel, tea, theme, thief, Keith, people, me, key, quay, ski,* etc.). There are many irregular and some almost arbitrarily spelled words in English (e.g., *pint, yacht*) and French (e.g., *fraise, monsieur*). The lexical route would work for all known words (irrespective of regularity) but could not provide spellings for new words or nonwords. The assembled route would work for nonwords but would often produce phonologically plausible errors (PPEs), particularly to irregular words, such as *yacht* (*YOT*) and *monsieur* (*MESSIEU*).

Evidence consistent with the dual-route model comes primarily from studies of the spelling performance of neuropsychological patients with acquired central dysgraphia (for reviews see Barry, 1994; Tainturier & Rapp, 2000). The separation of the dual routes is supported by the double dissociation between surface dysgraphia (e.g., Beauvois & Dérouesné, 1981; Hatfield & Patterson, 1983) and phonological dysgraphia (e.g., Shallice, 1981). Surface-dysgraphic people accurately spell more regular than irregular words (for which they make many PPEs) and are interpreted as having an impaired lexical route that forces overreliance on their preserved assembled route. Phonological-dysgraphic people have a marked impairment of nonword spelling but have relatively preserved word spelling and are interpreted as having an impaired assembled route but an intact lexical route.

Although the lexical and assembled spelling routes are proposed to be separate, there are at least two lines of evidence to suggest that they interact at some level in normal spellers. First, observation of spelling errors in free writing (e.g., Ellis, 1979; Hotopf, 1980) suggests that assembled spelling plays some role in writing; people sometimes make PPEs (e.g., *Ver-knickers ayfasia*) and may produce different alternative spellings on different occasions (which suggests that not all errors reflect inaccurate spelling

Marie Delattre and Patrick Bonin, Laboratoire de Psychologie Sociale et Cognitive, Centre National de la Recherche Scientifique (Unité Mixte de Recherche 6024), Université Blaise Pascal, Clermont-Ferrand, France; Christopher Barry, Department of Psychology, University of Essex, Colchester, United Kingdom.

Correspondence concerning this article should be addressed to Patrick Bonin, Laboratoire de Psychologie Sociale et Cognitive, Université Blaise Pascal, 34 Avenue Carnot, Clermont-Ferrand, France 63037. E-mail: Patrick.Bonin@srvpsy.univ-bpclermont.fr

knowledge). Second, there is experimental evidence showing lexical influence on assembled spelling; there are lexical priming effects on nonword spelling (e.g., Barry & Seymour, 1988; Campbell, 1983; Perry, 2003). For example, the nonword /vi:m/ is more likely to be spelled as *VEAM* after hearing the word *team*, as *VEEM* after the word *deem*, and as *VEME* after the word *theme*.

Dual-route models of spelling have been expressed in symbolic terms (e.g., Barry, 1994) but also as more interactive (Rapp, Epstein, & Tainturier, 2002) and connectionist (Houghton & Zorzi, 2003) models. Although single-route models of spelling have been proposed (e.g., Brown & Loosemore, 1994; Bullinaria, 1997; Olson & Caramazza, 1994), Houghton and Zorzi (2003) have argued that these are currently unable to account for the full range of empirical data. It is not crucial for our current purposes to determine which of these general architectures is to be ultimately preferred, but any successful model of spelling must account for the ability both to retrieve lexically specific spelling knowledge (to correctly spell irregular words and homophones) and to assemble plausible spellings of new words and nonwords. How do the two spelling routes or processing operations come together to produce correct performance in normal adult written production? Is it the case that one generally "drives" spelling (perhaps by being faster or more reliable), or is there some level of interaction (cooperation or competition) between the outputs of the two routines? The experiments to be reported here study written production when there is conflict between lexical and assembled spelling knowledge for words with low-probability (or irregular) spelling-to-sound associations.

The primary purpose of the present study was to investigate how such conflict engendered by irregular words might carry over to affect peripheral processes in writing. The functional relationship between central and peripheral processes is an important general issue in language production research. In the study of spoken word production, Kello, Plaut, and MacWhinney (2000) and Damian (2003) have made the distinction between "cascaded" and "staged" processing architectures. Damian argued that if response or articulatory durations of words, which are assumed to reflect the operation of peripheral speech-execution processes, are unaffected by manipulations designed to tap central processes (such as semantic activation and phonological encoding), then the preceding central processing must be completed before spoken responses are initiated. In this situation, the processing would be classified as staged. However, if articulatory durations are affected by manipulations designed to operate at central levels, then the processing would be classified as cascaded, and central processing could still be operative after responses are initiated.

In studies of reading words aloud, the issue of whether articulation can begin before the computation of phonology has been concluded remains unsettled. Rastle, Harrington, Coltheart, and Palethorpe (2000) have argued that a word's phonology must be fully encoded before its articulation can begin. In contrast, Kawamoto, Kello, Jones, and Bame (1998) and Kawamoto, Kello, Higareda, and Vu (1999) favor the view that responses may be initiated on the basis of the phonological availability of a word's initial phoneme, and that phonological encoding of later portions of a word continues while the response is being executed (their *initial phoneme criterion*). Kello et al. (2000) argued that the speech production processing system can be flexible and that when task demands are increased, central effects can cascade to articulation. However, studies of word production using tasks that (unlike word naming) are necessarily semantically mediated have not produced clear support of the notion that central processes cascade to articulation (Damian, 2003; Meyer, 1990; Schriefers & Teruel, 1999). For example, Damian (2003) found no effects on response durations of central variables that did affect response latencies in picture–word interference and Stroop tasks, either with or without response deadlines, and he concluded that "articulation, as assessed by response duration, is never influenced by central cognitive processes once a response has been initiated" (p. 416).

The relationship between central processes of spelling and peripheral processes of writing has not been addressed experimentally. Part of this neglect is associated with the general paucity of studies that have used online paradigms and have measured reaction times of correct written production. Whereas research in word recognition has been informed by numerous studies of reading latencies, there are substantially fewer studies of written word production, and most of these have measured only spelling accuracy. Some studies of spelling have measured latencies, however; for example, Kreiner (1992) measured reaction times in a spelling probe task and Kreiner (1996) measured oral spelling latencies. Bonin and colleagues connected the contact pen of a graphics tablet to a computer and timed written naming latencies from the onset of a stimulus picture (e.g., Bonin, Chalard, Méot, & Fayol, 2002; Bonin & Fayol, 2000; Bonin, Fayol, & Chalard, 2001). In the task of writing spoken words to dictation, Bonin, Peereman, and Fayol (2001) found longer latencies for irregular rather than for regular French words, and Bonin and Méot (2002) found that this irregularity effect was larger for low- rather than for high-frequency words. However, these studies did not record the durations of written responses, which we will assume to be an index of the peripheral processes required for writing execution (much as articulatory durations have been assumed to index the peripheral processing of spoken word production). We shall follow previous studies by also assuming that writing latencies index more central processes involved in spelling. The examination of both writing latencies and durations represents the novel feature of the present study.

The major theoretical question addressed by the present study is whether the conflict between the outputs of the central lexical and assembled spelling routines for irregular words is fully resolved before the peripheral processes controlling writing execution begin. If this conflict is resolved, then we would expect there to be a regularity effect on written latencies but not on durations (and so central and peripheral processing would be staged). However, if a regularity effect were to be found on both written latencies and durations, then this would suggest that central processes continue to operate and affect performance after a written response has been initiated (and so processing would be cascaded). In these experiments, we also used a new variant of the writing-to-dictation task. Participants were required to write each target word three times in quick succession, and we recorded the latency of writing responses as well as both the duration of each written production and the delay between writings. This new procedure (which has not been used to study speech production) allowed an examination of the broad time course of any possible cascaded processing in writing. We reasoned that the durations of the second and third writings of words would reflect the processing associated with the execution of handwriting movements, whereas the duration of the first writing of an irregular word would reflect both writing execution and persisting time costs involved in resolving conflict generated by the two central spelling routines.

In all experiments, participants heard a spoken target word and had to write it down three times as quickly as possible. We recorded the following: (a) the latency to initiate the first writing of the word (measured from the onset of the spoken target word); (b) the pause between finishing the writing of the first word and the initiation of the second word, and the pause between the end of the second and the beginning of the third; (c) the duration of each writing response (i.e., the onset to offset time of each word's written production); and (d) spelling errors produced on the first written production only. In the analyses below, (a) and (b) were included together (and referred to as *latencies and pauses*).

Experiment 1

Participants heard spoken French words containing regular (or high-probability) and irregular (or low-probability) sound-to-spelling correspondences and had to write them down three times. We predicted that the latencies for the first writing response would be longer for irregular than for regular words, and also that there would be more errors made to the irregular words. The critical question was whether there would also be a sound-to-spelling regularity effect on the durations of written responses.

Method

Participants. Twenty psychology students at Blaise Pascal University (aged between 17 and 19 years, with a mean age of 18.3 years) participated in exchange for course credit. All were native speakers of French who reported no hearing deficits and had normal or corrected-to-normal vision.

Stimulus materials. The experimental stimuli were 19 regularly spelled words and 19 irregularly spelled French words. Regular words were those that had common phoneme-to-grapheme correspondences, and irregular words were those that contained at least one very low frequency phoneme-to-grapheme relationship, taken from Peereman and Content's (1999) LEXOP database for the sound-to-spelling consistency of French monosyllabic words. LEXOP provides the proportion of words in which phonological units are spelled in a particular way and considers the spelling of the initial consonant or consonant cluster (or onset), the vowel, the initial consonant(s) plus vowel (CV), the final consonant or consonant cluster (or coda), the terminal vowel plus consonant(s) (or rime), and the least consistent phoneme–grapheme correspondence. Furthermore, it provides measures for both type (or number of words) and token (or word-frequency adjusted) sound-to-spelling correspondences. As shown in Table 1, most of the inconsistencies occurred on the vowel, the coda, and the rime units; the two sets of words did not differ on the consistency of their onsets.

The two sets of words were matched for word frequency, age of acquisition (rated on a 5-point scale with 3-year age bands), the acoustic duration of the spoken word, number of phonological neighbors (from Peereman & Content, 1999), and diphone frequency (from the BRULEX database; Content, Mousty, & Radeau, 1990). In terms of their orthographic features, the two sets of words were matched for both bigram frequency (from Content & Radeau, 1988) and mean length in terms of number of letters. Unfortunately, it was difficult to precisely match the two sets for their number of phonemes or their *uniqueness point* (the point at which the initial sequence of phonemes is particular to that word and no other; Marcus & Frauenfelder, 1985), which might affect their initial auditory recognition. Stimulus words were recorded by a male speaker and digitized using 16-bit analog-to-digital conversion at a sampling rate of 44.1 kilohertz with the SoundEdit software on an Apple Macintosh computer. The statistical characteristics of the experimental words are given in Table 1 and a list of the words is given in Appendix A.

Apparatus. The experiment was run using SpellWrite II (Cottrell, 1999) on an Apple PowerMac computer. A Wacom A5 graphic tablet (Wacom, Krefeld, Germany) and a contact pen (Intuos2 Ink pen XP-110, Wacom) were used to record written latencies, pauses, and writing durations. The computer controlled the presentation of the words and recorded latencies and durations to the nearest millisecond. Philips SBC HP510 stereo headphones (Royal Philips Electronics, Amsterdam, The Netherlands) were used to present the stimuli.

Table 1
Statistical Characteristics of the Experimental Words Used in Experiment 1

Characteristic	Irregular	Regular	Difference
Onset consistency	0.99 (0.90)	0.97 (0.97)	*ns* (*ns*)
Vowel consistency	0.45 (0.43)	0.92 (0.99)	< .0001 (< .0001)
CV consistency	0.61 (0.57)	0.90 (0.89)	< .002 (< .01)
Coda consistency	0.53 (0.58)	0.85 (0.89)	< .002 (< .02)
Rime consistency	0.34 (0.29)	0.91 (0.97)	< .0001 (< .0001)
PO L	0.11	0.74	< .0001
BRULEX frequency	18.40	26.30	*ns*
Frantext frequency	11.70	19.90	*ns*
AoA ratings	2.25	2.09	*ns*
Number of letters	4.89	5.21	*ns*
Number of phonemes	3.16	3.74	$p = .02$
Uniqueness point	3.95	4.42	$p = .03$
Acoustic duration (ms)	687.00	693.00	*ns*
Acoustic duration from UP (ms)	635.00	669.00	*ns*
Log of diphone frequency	2.55	2.50	*ns*
Number of phonological neighbors	9.63	8.42	*ns*
Log of bigram frequency (BRULEX)	2.79	2.92	*ns*
Bigram frequency[a]	3,977.00 (4,760.00)	6,542.00 (6,022.00)	*ns*
Trigram frequency[a]	347.00 (542.00)	819.00 (952.00)	*ns*

Note. Orthographic consistency measures are from Peereman and Content (1999); the values are by type (and by token in parentheses). CV = consonant–vowel; PO L = phonology-to-orthographic consistency of the least phoneme–grapheme association; AoA = age of acquisition; UP = uniqueness point.
[a] From LEXIQUE 2 (New, Pallier, Brysbaert & Ferrand, 2004)

Procedure. Participants were tested individually. In each trial, the target word was presented aurally via headphones, and participants were required to write down the word three times as fast as possible on the graphic tablet using a contact pen (they were told to write a cross if they could not identify the stimulus). Participants had to write each word in cursive, lowercase script. As they were asked to write as they usually do, they were allowed to produce accents (e.g., pièce, crêpe) and to take the pen off the tablet (e.g., for dotting an *i* or crossing a *t*). Writing latencies were measured as the time between the onset of the stimulus word and the contact of the pen with the graphic tablet and were recorded automatically by the computer. Writing durations and the pauses between the second and third rewritings of the words were measured by the experimenter's inspection of the computer's time recordings of writing responses (i.e., response endpoints were determined "by hand"). The 38 experimental items (which were presented in a random order) were preceded by 10 practice trials.

Results

Observations were discarded from the analyses if a word was not identified, was crossed out or misspelled, or if a technical problem occurred. Times longer than two standard deviations above the participant and item means were also excluded from the analyses (2.8% and 1.4% of the latency and duration data). Overall, 8.9% of the latency data and 7.6% of the duration data were excluded. Table 2 presents the mean written latencies, pauses, and writing durations.

Analyses of variance were performed on both the participant means (F_1) and the item means (F_2). Word type (irregular vs. regular) was a within-factor in the analysis by participants and a between-factor in the analysis by items. Production sequence (first, second, and third writings) was a within-factor in both analyses. The conventional level for statistical significance of $p < .05$ was adopted throughout.

Latencies and pauses. There were reliable main effects of regularity, $F_1(1, 19) = 13.290$, $MSE = 3{,}594.23$, $p < .05$; $F_2(1, 32) = 10.519$, $MSE = 4{,}378.74$, $p < .05$, and production sequence, $F_1(2, 38) = 394.8$, $MSE = 16{,}258.48$, $p < .001$; $F_2(2, 64) = 1583.7$, $MSE = 3{,}424.91$, $p < .001$. Latencies were longer to irregular than to regular words, and the latency to begin the first writing was longer than the pause between subsequent writings. It is important to note that the interaction between regularity and production sequence was also significant, $F_1(2, 38) = 6.11$, $MSE = 3{,}772.52$, $p < .05$; $F_2(2, 64) = 8.31$, $MSE = 3{,}424.91$, $p < .05$. Post hoc Newman–Keuls tests revealed that the regularity effect was larger (and only reliable) in the first (95 ms) writings rather than in the second (13 ms) and third (12 ms) writings.

Writing durations. There were reliable effects of regularity, $F_1(1, 19) = 57.01$, $MSE = 3{,}566.43$, $p < .001$; $F_2(1, 32) = 4.03$, $MSE = 7{,}430.00$, $p = .053$, and production sequence, $F_1(2, 38) = 9.690$, $MSE = 8{,}866.04$, $p < .001$; $F_2(2, 64) = 35.197$, $MSE = 2{,}165.40$, $p < .001$. Writing durations were longer for irregular than for regular words and for the first production than for the two subsequent productions. The interaction between regularity and production sequence was also significant, $F_1(2, 38) = 9.64$, $MSE = 1{,}191.77$, $p < .001$; $F_2(2, 64) = 4.19$, $MSE = 2{,}165.40$, $p < .05$. As can be seen from Table 2, the difference between the irregular and regular words was larger for the first (120 ms) than for the two subsequent written productions (72 ms and 54 ms); post hoc tests showed that the irregularity effect was reliable for each written production.

Spelling errors. As participants were not explicitly told that they were allowed to correct their spelling during the second and third production, only the errors on the first production were analyzed (and are reported in Table 2). More errors were made to irregular than to regular words, $F_1(1, 19) = 25.81$, $MSE = 0.002$, $p < .001$; $F_2(1, 32) = 5.59$, $MSE = 0.011$, $p < .05$. When we analyzed only the PPE errors, the regularity effect was significant only on participants, $F_1(1, 19) = 21.87$, $MSE = 0.0011$, $p < .001$; $F_2(1, 32) = 2.78$, $MSE = 0.0100$, *ns*.

Discussion

Experiment 1 found that both writing latencies and durations were longer for irregular than for regular French words. The difference on latencies—which we took to index central spelling processes—replicates the results of previous research (Bonin & Méot, 2002; Bonin, Peereman, Fayol, 2001) and shows that irregular words require more time for some resolution of the conflict between lexical and sublexically assembled spelling information before a writing response may be initiated. The difference on durations—which we took to index peripheral writing processes—suggests that the spelling conflict engendered for irregular words is not fully resolved before a written response is executed. This is a novel result and shows that there is a cascaded relationship between the central processes of spelling and the peripheral processes of writing. The regularity effect found for writing durations cannot be due solely to peripheral orthographic factors (e.g., the possible slower production of rarer letter combinations), as the irregular and regular words were matched for bigram frequency (and, indeed, also for trigram frequency as taken from the LEXIQUE database; New, Pallier, Ferrand, & Matos, 2001) as well as for number of letters. The fact that the difference between the writing durations for irregular and regular words, although larger on the first writing response, was also found to be reliable for the second and third writings further shows that the spelling conflict persists for some time.

Table 2
Latency and Pause, Writing Duration (ms), and Spelling Error Rates as a Function of Regularity and Production Sequence in Experiment 1

	Regular			Irregular		
Variable	First	Second	Third	First	Second	Third
Latency and pause	974	324	318	1069	336	331
Duration	1736	1684	1685	1856	1756	1739
Errors (%)	0			5		

However, an alternative explanation of the results may be possible. The participants could see their own written responses and so may have engaged in a kind of spelling checking procedure from the ongoing visual trace of their writing (and, for the subsequent writings, from inspection of what they had just written). As irregular words might be spelled in more ways than regular words, it is possible that they would take more time to check confidently. To test this possibility and to explore the effect of online visual monitoring of writing, we presented participants in Experiment 2 with the same words and had them perform the same dictation task as in Experiment 1, but a change in procedure ensured that they did not actually see what they wrote (they were also told that they were allowed to correct their spelling during the second and/or the third production). If the difference between the writing durations of irregular and regular words found in Experiment 1 was due only to possible online visual checking, then no such effect should be seen in Experiment 2, in which writing durations without visual feedback might be seen to provide a "purer" measure of graphemic execution.

Experiment 2

Method

Participants. Twenty psychology students at Blaise Pascal University (aged between 18 and 20 years, with a mean age of 19.3 years) participated. All were native speakers of French with no reported hearing deficit and had normal or corrected-to-normal vision. None had participated in Experiment 1.

Stimulus materials. The same words used in Experiment 1 were used again, but four additional words were added. The controls remained the same with these four words included.

Procedure. The procedure was the same as in Experiment 1 except that participants used a pen that did not produce a visual record of their writings, and they were explicitly informed that they were allowed to correct their spelling in the second and/or third production.

Results

Overall, 11.8% of the latency data and 10.2% of the duration data were excluded following application of the same criteria as used in Experiment 1. Table 3 presents the mean written latencies, pauses, and writing durations.

Latencies and pauses. The main effects of regularity, $F_1(1, 19) = 28.83$, $MSE = 905.16$, $p < .001$; $F_2(1, 36) = 4.58$, $MSE = 8{,}192.76$, $p < .05$, and production sequence, $F_1(2, 38) = 326.70$, $MSE = 15{,}415.03$, $p < .001$; $F_2(2, 72) = 759.16$, $MSE = 6{,}595.79$, $p < .001$, were significant, as was the interaction between the two variables, $F_1(2, 38) = 59.676$, $MSE = 466.51$, $p < .001$; $F_2(2, 72) = 4.440$, $MSE = 6{,}595.79$, $p < .05$. Post hoc tests showed that the regularity effect was reliable on the first writing (91 ms) but not on the second (4 ms) and third (−6 ms) writings.

Writing durations. The main effect of regularity was significant in the analysis by participants, $F_1(1, 19) = 12.53$, $MSE = 4{,}864.17$, $p < .05$, but not by items, ($F_2 < 2.5$). There was a significant main effect of production sequence, $F_1(2, 38) = 11.230$, $MSE = 4{,}192.3$, $p < .001$; $F_2(2, 72) = 16.436$, $MSE = 3{,}469.0$, $p < .001$, and a significant interaction between production sequence and regularity, $F_1(2, 38) = 8.50$, $MSE = 1{,}883.43$, $p < .001$; $F_2(2, 64) = 8.92$, $MSE = 3{,}469.00$, $p < .001$; post hoc tests showed that the regularity effect was significant on the first (90 ms) and second writing (31 ms) but not on the third (14 ms).

Errors. The regularity effect was significant by participants, $F_1(1, 19) = 22.21$, $MSE = 0.00427$, $p < .001$, but not by items, ($F_2 < 1$); there were more errors to irregular (13.0%) than to regular (4.2%) words. When we analyzed only PPE errors, there were more made to irregular (8.8%) than to regular (0.4%) words, but the regularity effect only reached significance in the analysis by participants, $F_1(1, 19) = 21.87$, $MSE = 0.001$, $p < .001$; $F_2(1, 32) = 2.78$, $MSE = 0.010$, $p = .12$. There was no interaction between regularity and production sequence (Fs < 1).

Discussion

The results of Experiment 2 were remarkably similar to those of Experiment 1. Indeed, for writing latencies, the pattern of results was exactly the same in both experiments: There was an effect of regularity on the latency of the first written response, and there was no reliable effect on pauses between responses. For written durations, there were very similar patterns: There was a main effect of regularity and an interaction between regularity and production sequence, such that the difference between irregular and regular words was larger for the first than for subsequent productions. The only difference was that post hoc tests showed that the regularity effect was reliable for all three writings in Experiment 1, but was reliable only for the first and second writings in Experiment 2. There was therefore no major change in the results by removing the availability of visual feedback, which we reasoned should assist any possible visual spelling checking procedure. We accept that other possible spelling checking mechanisms (such as some form of imagery- or rehearsal-guided checks) might conceivably be unaffected by the removal of online visual feedback. However, as people normally write to leave a visual trace and can see what they produce, we feel that such alternatives may be less likely (or less important) than one directly informed by online visual monitoring. The regularity effects found on writing durations in both Experiments 1 and 2 must therefore be due to the spelling conflict cascading to affect writing execution.

In Experiments 1 and 2, the stimulus words tended to be of medium word frequency. In the word-reading literature, a number

Table 3
Latency and Pause, Writing Duration (ms), and Spelling Error Rates as a Function of Regularity and Production Sequence in Experiment 2

	Regular			Irregular		
Variable	First	Second	Third	First	Second	Third
Latency and pause	870.00	295.00	308.00	961.00	299.00	302.00
Duration	1836.00	1802.00	1865.00	1926.00	1833.00	1879.00
Errors (%)	1.05	0.05	0.05	9.70	8.40	8.40

Table 4
Statistical Characteristics of the Experimental Words Used in Experiment 3

Characteristic	High-frequency words			Low-frequency words		
	Irregular	Regular	Diff	Irregular	Regular	Diff
Onset consistency	0.96 (0.92)	0.98 (1.00)	*ns* (*ns*)	0.84 (0.82)	0.97 (1.00)	*ns* (.05)
Vowel consistency	0.21 (0.22)	0.92 (0.98)	< .01 (< .01)	0.40 (0.39)	0.92 (0.98)	< .01 (< .01)
CV consistency	0.41 (0.64)	0.91 (0.96)	< .01 (< .01)	0.62 (0.65)	0.87 (0.89)	< .01 (< .05)
Coda consistency	0.55 (0.57)	0.84 (0.92)	< .01 (< .01)	0.43 (0.41)	0.88 (0.97)	< .01 (< .01)
Rime consistency	0.21 (0.47)	0.94 (0.96)	< .01 (< .01)	0.23 (0.21)	0.97 (1.00)	< .01 (< .01)
PO L	0.11	0.64	< .01	0.13	0.65	< .01
Log BRULEX frequency	4.30	4.10	*ns*	2.50	2.70	*ns*
Log Frantext frequency	2.00	1.80	*ns*	0.61	0.71	*ns*
AoA ratings	2.37	2.27	*ns*	3.64	3.07	*ns*
Number of letters	5.00	5.00	*ns*	5.00	5.00	*ns*
Number of phonemes	3.70	3.55	*ns*	3.65	3.65	*ns*
Uniqueness point	4.30	4.50	*ns*	4.20	4.20	*ns*
Acoustic duration (ms)	783.00	783.00	*ns*	783.00	784.00	*ns*
Acoustic duration from uniqueness point (ms)	700.00	774.00	*ns*	687.00	695.00	*ns*
Log diphone frequency	2.82	2.63	*ns*	2.66	2.63	*ns*
Number of phonological neighbors	8.85	11.40	*ns*	8.65	7.50	*ns*
Log bigram frequency (BRULEX)	3.00	3.00	*ns*	2.90	2.70	*ns*
Bigram frequency[a]	3,112.00 (7,161.00)	6,864.00 (5,988.00)	$p = .012$ (*ns*)	2,715.00 (3,124.00)	3,174.00 (3,696.00)	*ns* (*ns*)
Trigram frequency[a]	406.00 (737.00)	367.00 (733.00)	*ns* (*ns*)	258.00 (305.00)	467.00 (467.00)	*ns* (*ns*)

Note. Orthographic consistency measures are from Peereman and Content (1999); the values are by type (and by token in parentheses). CV = consonant–vowel; PO L = phonology-to-orthographic consistency of the least phoneme–grapheme association; AoA = age of acquisition.
[a] From LEXIQUE 2 (New, Pallier, Brysbaert & Ferrand, 2004)

of studies have shown that spelling-to-sound regularity effects are larger for low- than for high-frequency words (e.g., Monaghan & Ellis, 2002; Seidenberg, Waters, Barnes, & Tanenhaus, 1984). An interaction between word frequency and sound-to-spelling regularity has also been found in surface dysgraphic spelling accuracy (Goodman & Caramazza, 1986; Rapp et al., 2002) as well as in normal written latencies (Bonin & Méot, 2002). In Experiment 3, we examined written latencies and durations for a set of words that varied both sound-to-spelling regularity and word frequency orthogonally. The experiment aimed to determine whether the regularity effect on writing durations observed in Experiments 1 and 2 would be moderated by word frequency.

Experiment 3

Method

Participants. Nineteen psychology students at Blaise Pascal University (aged between 18 and 21 years, with a mean age of 19.8 years) participated. All were native French speakers with no reported hearing deficit and had normal or corrected-to-normal vision. None had participated in the previous experiments.

Stimulus materials. There were 80 experimental words: 20 high-frequency regular words, 20 high-frequency irregular words, 20 low-frequency regular words, and 20 low-frequency irregular words. The statistical characteristics of the stimuli are shown in Table 4, and a full list of words is given in Appendix B.

The words were selected from the LEXOP lexical database (Peereman & Content, 1999) using the same criteria as in Experiments 1 and 2, and the inconsistencies concerned the spelling correspondences of the vowel or rime. For each frequency level, the irregular and regular words were matched for the lexical variables of frequency and rated age of acquisition; the phonological properties of acoustic duration, uniqueness point, diphone frequency, and number of phonological neighbors; and the orthographic properties of bigram frequency and number of letters. Stimulus words were recorded by a female speaker and digitized using 16-bit analog-to-digital conversion at a sampling rate of 44.1 kilohertz with the SoundEdit software on an Apple Macintosh computer.

Procedure. The procedure was the same as that of Experiment 1, and so participants were able to see what they had written.

Results

The application of the criteria as used in Experiment 1 resulted in the removal of 19.8% of the latency data and 13.8% of the duration data.[1] One item (the irregular word *kyste*) was excluded from the analyses as more than half of the participants wrote it erroneously. Table 5 presents the mean written latencies, pauses, and writing durations in each condition.

The variables of regularity and frequency were within-factors in the analyses by participants and between-factors by items. Production sequence was a within-factor in both analyses.

[1] It may concern readers that rather high proportions of data were excluded. However, when the raw (i.e., untrimmed) data were analyzed, we found essentially the same pattern of results. For latencies, there were no differences. For writing durations, the main effect of frequency and the Regularity × Frequency interactions were not significant by items (but were by participants).

Table 5
Latency and Pause, Writing Duration (ms), and Spelling Error Rates as a Function of Word Frequency, Regularity, and Production Sequence in Experiment 3

	Regular			Irregular		
Variable	First	Second	Third	First	Second	Third
High-frequency words						
Latency and pause	824.00	251.00	277.00	869.00	259.00	277.00
Duration	1845.00	1803.00	1861.00	1895.00	1832.00	1894.00
Errors	0.00	0.00	0.00	0.79	0.54	0.53
Low-frequency words						
Latency and pause	842.00	254.00	278.00	942.00	286.00	296.00
Duration	1849.00	1769.00	1820.00	2096.00	1900.00	1939.00
Errors	0.79	0.79	0.79	20.80	19.20	15.50

Latencies and pauses. There were reliable main effects of regularity, $F_1(1, 18) = 36.256$, $MSE = 64{,}845.99$, $p < .001$; $F_2(1, 75) = 25.850$, $MSE = 79{,}096.04$, $p < .001$, word frequency, $F_1(1, 18) = 26.85$, $MSE = 30{,}772.66$, $p < .001$; $F_2(1, 75) = 14.26$, $MSE = 43{,}619.77$, $p = .001$, and production sequence, $F_1(1, 36) = 499.94$, $MSE = 18{,}053.13$, $p < .001$; $F_2(2, 150) = 3215.22$, $MSE = 2{,}961.35$, $p < .001$. The interaction between regularity and frequency was also significant, $F_1(1, 18) = 11.09$, $MSE = 14{,}971.79$, $p < .05$; $F_2(1, 75) = 6.80$, $MSE = 20{,}796.58$, $p < .05$; the difference between irregular and regular words was larger for low- (100 ms) than for high-frequency (45 ms) words. The interaction between regularity and production sequence was significant, $F_1(2, 36) = 35.16$, $MSE = 617.54$, $p < .001$; $F_2(2, 150) = 8.74$, $MSE = 2{,}961.39$, $p < .001$, as was the interaction between frequency and production sequence, $F_1(2, 36) = 10.41$, $MSE = 672.42$, $p < .05$; $F_2(2, 150) = 3.46$, $MSE = 2{,}961.35$, $p < .05$. There was no three-way interaction between regularity, frequency, and production sequence, $F_1(2, 36) = 1.43$, *ns* ($F_2 < 1$). Post hoc tests revealed only that the regularity effect was reliable for the first production sequence only.

Writing durations. The main effect of regularity was reliable by participants, $F_1(1, 18) = 41.35$, $MSE = 13{,}287$, $p < .001$, but not quite by items, $F_2(1, 75) = 2.71$, $MSE = 225{,}509$, *ns*. The main effect of production sequence was reliable, $F_1(2, 36) = 9.63$, $MSE = 17{,}071.87$, $p = .001$; $F_2(2, 150) = 61.79$, $MSE = 2{,}910.40$, $p < .001$, but the main effect of word frequency was not, $F_1(1, 18) = 2.73$, $MSE = 15{,}273.37$, *ns* ($F_2 < 1$). The interaction between word frequency and regularity was significant by participants but not by items, $F_1(1, 18) = 21.94$, $MSE = 8{,}998.92$, $p < .001$; $F_2(1, 75) = 1.08$, *ns*. Production sequence interacted with both regularity, $F_1(2, 36) = 14.28$, $MSE = 1{,}955.58$, $p < .001$; $F_2(2, 150) = 11.43$, $MSE = 2{,}910.40$, $p < .001$, and word frequency, $F_1(2, 36) = 14.21$, $MSE = 3{,}474.48$, $p < .001$; $F_2(2, 150) = 19.82$, $MSE = 2{,}910.40$, $p < .001$; the difference between the times taken to write irregular and regular words was larger on the first (148 ms) than on the subsequent writings (80 ms and 76 ms), and the difference between the times taken to produce high- and low-frequency words was larger on the first (103 ms) than on the subsequent writings (17 ms and 2 ms). It is important to note that the three-way interaction was also significant, $F_1(2, 36) = 11.38$, $MSE = 1{,}222.47$, $p < .05$; $F_2(2, 150) = 6.17$, $MSE = 2{,}910.40$, $p < .05$. As can be seen from Table 5, the greater regularity effect for low- than for high-frequency words was most pronounced for the first writing response. Post hoc tests showed that the difference between regular and irregular words was reliable for both high- and low-frequency words on the first writing; for the second and third writings, the regularity effect was significant by participants only for high-frequency words and reliable in both analyses for low-frequency words.

Errors. The main effect of regularity was significant, $F_1(1, 18) = 27.85$, $MSE = 0.0112$, $p < .001$; $F_2(1, 75) = 23.01$, $MSE = 0.0141$, $p < .001$, as was the interaction between word frequency and regularity, $F_1(1, 18) = 27.08$, $MSE = 0.0073$, $p < .001$; $F_2(1, 75) = 13.08$, $MSE = 0.0141$, $p = .001$. Most errors were made to low-frequency irregular words. In an analysis of only PPE errors, there were main effects of regularity, $F_1(1, 18) = 57.08$, $MSE = 0.00839$, $p < .001$; $F_2(1, 75) = 15.709$, $MSE = 0.02360$, $p < .001$, and frequency, $F_1(1, 18) = 52.769$, $MSE = 0.0094$, $p < .001$; $F_2(1, 75) = 16.378$, $MSE = 0.0236$, $p < .001$, as well as a significant interaction between the two variables, $F_1(1, 18) = 55.140$, $MSE = 0.0075$, $p < .001$; $F_2(1, 75) = 13.477$, $MSE = 0.0236$, $p < .001$. Finally, the three-way interaction between production sequence, word frequency, and regularity was significant by participants, $F_1(2, 36) = 33.12$, $MSE = 0.0032$, $p < .001$, and just failed to reach significance by items, $F_2(2, 150) = 2.90$, $p = .058$. This interaction indicated that there were more errors on low-frequency irregular words, especially in the first and second production sequences.

Discussion

Experiment 3 replicated the results of Bonin and Méot (2002) for writing latencies—the sound-to-spelling regularity effect was larger for low- than for high-frequency words. It is important to note that the same form of this interaction was also found for the writing durations of the first writing response (and, although not consistently reliable, showed the same trend for the second and third writings). These novel results, which were found for different stimuli than those used in Experiments 1 and 2, show that the regularity effects on both latencies and durations are robust and generalize to different samples of words (as only 12.5% of regular words and 7.5% of irregular words used in Experiment 3 were also used in Experiment 1).

The interaction between regularity and frequency for writing latencies can be interpreted in terms of how information provided by the lexical and assembled spelling routines effectively combines to influence spelling production. If we assume that word frequency affects the ease of lexical retrieval (such that low-frequency words are slower to activate and/or have weaker activations), then the influence of the assembled spelling process (which operates independently of lexical characteristics of individual words) will be larger for low-frequency words. Houghton and Zorzi's (2003) connectionist dual-route model simulates this interaction rather well (see their Simulations 7 and 8), and they claim that Bullinaria's (1997) single-route model does not. The fact that we found the same interaction for both writing latencies and durations provides clear support for a cascaded processing architecture.

The results of Experiment 3 show that the combined effects of sound-to-spelling regularity and the lexical variable of word frequency influence the central processes of spelling that then cascade to the peripheral processes of writing execution. The conflict generated by the different spellings provided by the assembled and lexical routines for irregular words continues to exert an influence even after handwriting is initiated. However, there was no main effect of word frequency on writing durations, and inspection of the interaction between regularity and frequency showed that there was only a small (23 ms) and unreliable effect of word frequency on the writing durations of regular words. This may suggest that it is only the unresolved conflict concerning the spelling of irregular words that cascades to affect writing execution; variables that simply affect the ease of retrieving a spelling (such as frequency) appear not to necessarily cascade in the same fashion.

General Discussion

In three experiments, participants heard spoken words and had to write each word three times in quick succession. In each experiment, we found that the latencies to initiate the first writing response were reliably slower for irregular than for regular words when matched for frequency and other variables. Experiment 2 showed that this regularity effect was unaffected by the removal of a visual trace of the written response, and Experiment 3 showed that it was larger for low- than for high-frequency words.

In all three experiments, we found that the writing durations of the first response in the sequence of three were longer for irregular than for regular words when matched for length and bigram frequency. The regularity effect on writing durations also persisted, albeit in a diminished form, to subsequent writings of the words; it was reliable for all three writings in Experiment 1 and for the first and second, but not the third, writing in Experiment 2. In Experiment 3, the regularity effect was reliable for all three writings of low-frequency words. As writing durations have not been studied systematically before, these results are both novel and have important theoretical implications for the nature of the functional relationship between central and peripheral processes in the generally underresearched area of the accurate production of written language.

The absence of visual feedback while writing seemed to have no major effect on performance. When, in Experiment 2, participants were unable to see what they had written, the pattern of results was essentially identical to that found in Experiment 1, as there were regularity effects on both latency and durations. Furthermore, there was no systematic main effect of experiment; a comparison of Tables 2 and 3 shows that mean latencies were a little faster and the overall durations were somewhat longer in Experiment 2 than in Experiment 1, which we can only attribute to between participant variability. However, the results of Experiment 2 firmly rule out the possibility that the regularity effects found on written response durations reflect the operation of a purely visual spelling checking or verification strategy while writing is being executed.

The major theoretical motivation for our study was to examine written production when there is conflict between the spellings of irregular words proffered by the lexical and the assembled spelling routes of dual-route models (or the competing constraints of lexically specific and sublexically generated spelling information in single-route models) and to address the specific (and previously unstudied) question of whether this conflict would affect the durations of handwritten responses. To recapitulate the logic of our study, we assumed that latencies to begin writing reflect central spelling processes (and especially those associated with conflict resolution), whereas writing durations of words reflect subsequent peripheral processes controlling handwriting execution. Adapting Damian's (2003) logic mutatis mutandis from speech to writing, we reasoned that if writing durations are affected by conflict generated by the two central spelling routines for irregular words, then processing would be cascaded. This would suggest that prior central processing would not need to be completed before handwritten responses are initiated but could continue while writing is underway. However, if writing durations are not affected by conflict generated by irregular words, then processing would be staged. This would suggest that central processing is concluded (i.e., the conflict must be fully resolved) before handwritten responses begin to be executed (and so there would be underlying discrete processing stages of spelling and writing).

Our results clearly show that central spelling and peripheral writing processes are cascaded: The processing of the conflict engendered by central spelling routines for irregular words appears not to be concluded before the peripheral processes controlling writing execution begin. We found that the effects of the spelling conflict carry over to affect the time to produce handwritten responses. Furthermore, this carry-over effect was rather protracted, as it reliably affected all three writings of words in Experiment 1 and all three writings of low-frequency irregular words in Experiment 3. These results show that resolution of spelling conflict has a rather long time course of between 5 and 7 s from the onset of the auditory stimulus word to the writing of the third response in the sequence (i.e., after a particular spelling has been chosen and written twice). Thus, when we talk of conflict resolution, this must be taken to mean the consequences of the processing that results in a particular spelling being selected and programmed for handwriting execution. It is the time cost of processing the conflict (which involves making a spelling decision) that cascades to affect subsequent writing times. Of course, some spelling decisions must be made before any handwriting can commence (e.g., for words with inconsistently spelled initial sounds, as in *knit* and *gnat*), although the French irregular words used here had "regular" spellings of their first phoneme.

Damian (2003) claimed that articulation durations of spoken responses are "never influenced by central cognitive processes once a response has been initiated" (p. 416). For writing, a different picture clearly emerges, as our results demonstrate that the central processing of spelling conflict for irregular words continues to influence the time taken to execute handwritten responses while they are actually being produced. There are a number of reasons why the functional organization of central and peripheral processes might be different for phonological and orthographic word production. Compared with speech, spelling is mastered later in life and is used less often (even by the most prolific of writers) and sometimes with less confidence. Accurate spelling appears to be more "costly" than speaking (Bourdin & Fayol, 2002). Whereas speakers strive for fluency, this may be less important in writing, and writing takes longer to produce than speech. It might therefore be argued that there is more scope for cascaded processing in writing than in speaking. Furthermore, the durations of some spoken words (and especially their vowels) represent a crucial property of their identity (as in the contrast between *ship* and *sheep*, for example), whereas whether one takes a long or a short time to actually write a word conveys no meaning at all.

Our demonstration that the central processing of spelling cascades to peripheral writing processing is consistent with the findings of Orliaguet and Boë (1993). In their study, participants listened to French sentences and were required to write down a target word from them. Among the targets were ambiguous, homographic words such as *vers* (*toward* or *worms*), where the spelling of one sense depended on the application of a grammatical rule, which was pluralization in this case (*ver* + *s*). Their results showed that the additional linguistic load from the application of a grammatical rule had an effect on both reaction times and writing movement times, which suggests that some grammatical processing is realized online and in parallel with the execution of handwriting. This interesting (but rather small-scale) study raises a number of issues that require further research (such as the role and nature of morphological processing in spelling), but it shows, as we have, that central processes do cascade to affect writing durations.

We have shown that there is cascaded processing for writing words. For irregular words, there will be conflict between lexically specific spelling information (e.g., *theme* = *THEME*) and alternatives provided by sublexical assembled spelling (e.g., *theme* = *THEAM, THEEM, THIEM,* or *THEME*). Such conflict might operate at a number of different levels in the overall system. It necessarily operates at the level of the selection of a particular spelling to produce (and it may also be that people continue to consider alternative spellings while actually writing the one selected). However, it is also possible that all activated spellings coactivate their associated motor execution programs, which then compete. Certainly, more detailed investigation of the microdynamics of writing production (e.g., the study of hesitations between letters, or even subletter strokes, at different positions relative to the inconsistently spelled segments of words) will be required for definitive answers to such detailed questions, although we note that such an enterprise would be rather difficult for cursive (i.e., normal) handwriting as assessed in the experiments reported here. However, our finding that regularity affected the latency to produce the first writing of a word but had no reliable effect on the pauses between the three writings of each word suggests that activated graphemic motor patterns do not compete at the level of their repeated initiation.

There are three other theoretical possibilities to consider concerning our observed regularity effect on writing durations. First, it might be argued that the effect arose due to some confounded characteristic of the irregular and regular words. What might such confounds be? They are certainly not the lexical variables of frequency or age of acquisition, both of which have been claimed to affect writing latencies, as the two sets of words were matched for these variables. There was also no confound with peripheral or "local" orthographic effects, such as the possibility that writing less-frequent letter combinations is retarded compared with more-frequent letter sequences, as our regular and irregular words were matched for both bigram and trigram frequency (as well as for number of letters). Currently, we can think of no other possible confounds. Second, it might be argued that we have only shown that spelling conflict cascades to affect the peripheral processes of writing. Would there also be cascaded processing for words in which there is no (or less) conflict or for central processing that is simply slow rather than involving conflict resolution? Gentner, Larochelle, and Grudin (1988) found that typing performance was affected by word frequency, but in Experiment 3, we found no reliable effect of frequency on writing durations for regular words, which might suggest that the speed of retrieving lexical information may not necessarily cascade to writing. However, it is pertinent to note that if assembled spelling operates in a fashion that generally provides more than one possible spelling (e.g., /i:/ = *EE* or *EA* or *E-E*, or /k/ = *C* or *K*) as Barry and Seymour (1988) suggest, then there would always be some degree of spelling conflict for words in orthographies such as English and French. Third, it might be argued that the task we have used—namely writing each word three times—imposed a high cognitive load on writing that had the effect of making cascaded processing more likely. This possibility is also relevant to considerations of the difference between cascaded processing in speech and writing, and we note that we are aware of no studies of spoken-word production that have used repeated articulations. For speech production, Kello et al. (2000) argued that central effects can cascade to articulation when task demands are increased. Although writing the same word three times may not appear to be excessively taxing, it is possible that it is more demanding than writing only one word. To test this, we repeated our Experiment 1 with 20 new participants who were required simply to write each word only once, and we replicated the pattern of results found for the first writing response reported earlier: There were reliable effects of regularity on both latencies and durations. This shows that central spelling processes cascade to affect writing durations for even a light cognitive load.

To conclude, we have shown that conflict produced by central spelling processes cascades to affect peripheral writing processes. This is an important and novel finding that provides a key constraint on modeling writing to dictation. Our study has shown that written spelling latencies and writing durations are slower for irregular than for regular words. These results can be interpreted within the dual-route model by proposing that there is conflict between the outputs of the lexical and assembled spelling routes that takes time to resolve and that the central processing of this conflict then cascades to affect the peripheral processes of handwriting.

References

Barry, C. (1994). Spelling routes (or roots or rutes). In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of spelling: Theory, process and intervention* (pp. 27–49). Chichester, United Kingdom: Wiley.

Barry, C., & Seymour, P. H. K. (1988). Lexical priming and sound-to-spelling contingency effects in nonword spelling. *Quarterly Journal of Experimental Psychology, 40A,* 5–40.

Baxter, D. M., & Warrington, E. K. (1986). Ideational agraphia: A single case study. *Journal of Neurology, Neurosurgery, and Psychiatry, 49,* 369–374.

Beauvois, M.-F., & Dérouesné, J. (1981). Lexical or orthographic agraphia. *Brain, 104,* 21–49.

Bonin, P., Chalard, M., Méot, A., & Fayol, M. (2002). The determinants of spoken and written picture naming latencies. *British Journal of Psychology, 93,* 89–114.

Bonin, P., & Fayol, M. (2000). Writing words from pictures: What representations are activated and when? *Memory & Cognition, 28,* 677–689.

Bonin, P., Fayol, M., & Chalard, M. (2001). Age of acquisition and word frequency in written picture naming. *Quarterly Journal of Experimental Psychology, 54A,* 469–489.

Bonin, P., & Méot, A. (2002). Writing to dictation in real time in adults: What are the determinants of written latencies? In S. P. Shohov (Ed.), *Advances in psychology research* (Vol. 16, pp. 139–165). New York: Nova Science Publishers.

Bonin, P., Peereman, R., & Fayol, M. (2001). Do phonological codes constrain the selection of orthographic codes in written picture naming? *Journal of Memory and Language, 45,* 688–720.

Bourdin, B., & Fayol, M. (2002). Even in adults, written production is still more costly than oral production. *International Journal of Psychology, 37,* 219–222.

Brown, G. D. A., & Loosemore, R. P. W. (1994). Computational approaches to normal and impaired spelling. In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of spelling: Theory, process, and intervention* (pp. 319–335). Chichester, United Kingdom: Wiley.

Bullinaria, J. A. (1997). Modeling reading, spelling, and past tense learning with artificial neural networks. *Brain and Language, 59,* 236–266.

Campbell, R. (1983). Writing nonwords to dictation. *Brain and Language, 19,* 153–178.

Content, A., Mousty, P., & Radeau, M. (1990). BRULEX: Une base de données informatisée pour le français écrit et parlé [BRULEX: A lexical database for written and spoken French]. *L'Année Psychologique, 90,* 551–566.

Content, A., & Radeau, M. (1988). Données statistiques sur la structure orthographique du français [Statistical data on French orthographic structure]. *Cahiers de Psychologie Cognitive, 8,* 399–404.

Cottrell, D. (1999). *SpellWrite II.* Unpublished manuscript, James Cook University, Townsville, Queensland, Australia.

Damian, M. (2003). Articulatory duration in single-word speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 416–433.

Ellis, A. W. (1979). Slips of the pen. *Visible Language, 13,* 265–282.

Ellis, A. W. (1982). Spelling and writing (and reading and speaking). In A. W. Ellis (Ed.), *Normality and pathology in cognitive functions* (pp. 113–143). New York: Academic Press.

Gentner, D. R., Larochelle, S., & Grudin, J. (1988). Lexical, sublexical, and peripheral effects in skilled typewriting. *Cognitive Psychology, 20,* 524–548.

Goodman, R. A., & Caramazza, A. (1986). Dissociation of spelling errors in written and oral spelling: The role of allographic conversion in writing. *Cognitive Neuropsychology, 3,* 179–206.

Hatfield, F. M., & Patterson, K. E. (1983). Phonological spelling. *Quarterly Journal of Experimental Psychology, 35A,* 451–468.

Hotopf, W. H. N. (1980). Slips of the pen. In U. Frith (Ed.), *Cognitive processes in spelling* (pp. 287–307). New York: Academic Press.

Houghton, G., & Zorzi, M. (2003). Normal and impaired spelling in a connectionist dual-route architecture. *Cognitive Neuropsychology, 20,* 115–162.

Kawamoto, A. H., Kello, C. T., Higareda, I., & Vu, J. V. Q. (1999). Parallel processing and initial phoneme criterion in naming words: Evidence from frequency effects on onset and rime duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 362–381.

Kawamoto, A. H., Kello, C. T., Jones, R., & Bame, K. (1998). Initial phoneme versus whole-word criterion to initiate pronunciation: Evidence based on response latency and initial phoneme duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 862–885.

Kello, C. T., Plaut, D. C., & MacWhinney, B. (2000). The task-dependence of staged vs. cascaded processing: An empirical and computational study of Stroop interference in speech production. *Journal of Experimental Psychology: General, 129,* 340–361.

Kreiner, D. S. (1992). Reaction time measures of spelling: Testing a two-strategy model of skilled spelling. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 765–776.

Kreiner, D. S. (1996). Effects of word familiarity and phoneme-grapheme polygraphy on oral spelling time and accuracy. *Psychological Record, 46,* 49–70.

Marcus, S. M., & Frauenfelder, U. H. (1985). Word recognition–uniqueness or deviation? A theoretical note. *Language and Cognitive Processes, 1,* 163–169.

Meyer, A. S. (1990). The time course of phonological encoding in language production: The encoding of successive syllables. *Journal of Memory and Language, 29,* 524–545.

Monaghan, J., & Ellis, A. W. (2002). What exactly interacts with spelling-sound consistency in word naming? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 183–206.

New, B., Pallier, C., Brysbaert, M., & Ferrand, L. (2004). LEXIQUE 2: A new French lexical database. *Behavior Research Methods, Instruments, & Computers, 36,* 516–524.

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). Une base de données lexicales du français contemporain sur internet: LEXIQUE [A lexical database of contemporary French on the Internet: LEXIQUE]. *L'Année Psychologique, 101,* 447–462.

Olson, A., & Caramazza, A. (1994). Representations and connectionist models: The NETspell experience. In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of spelling: Theory, process, and intervention* (pp. 337–363). Chichester, United Kingdom: Wiley.

Orliaguet, J-P., & Boë, L. J. (1993). The role of linguistics in the speed of handwriting movements: Effects of spelling uncertainty. *Acta Psychologica, 82,* 103–113.

Peereman, R., & Content, A. (1999). LEXOP: A lexical database providing orthography-phonology statistics for French monosyllabic words. *Behavior Research Methods, Instruments, & Computers, 31,* 376–379.

Perry, C. (2003). Priming the rules of spelling. *Quarterly Journal of Experimental Psychology, 56A,* 515–530.

Rapp, B., Epstein, C., & Tainturier, M.-J. (2002). The integration of information across lexical and sublexical processes in spelling. *Cognitive Neuropsychology, 19,* 1–29.

Rastle, K., Harrington, J., Coltheart, M., & Palethorpe, S. (2000). Reading aloud begins when the computation of phonology is complete. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 1178–1191.

Schriefers, H., & Teruel, E. (1999). Phonological facilitation in the production of two-word utterances. *European Journal of Cognitive Psychology, 11,* 17–50.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behavior, 23,* 383–404.

Shallice, T. (1981). Phonological agraphia and the lexical route in writing. *Brain, 104,* 412–429.

Tainturier, M.-J., & Rapp, B. (2000). The spelling process. In B. Rapp (Ed.), *The handbook of cognitive neuropsychology* (pp. 263–289). Philadelphia, PA: Psychology Press.

(*Appendixes follow*)

Appendix A

The Stimulus Words Used in Experiments 1 and 2

Irregular	Regular
clown (clown)	cloche (bell)
bombe (bomb)	bouche (mouth)
diè se (sharp)	douche (shower)
fraise (strawberry)	film (film)
gland (acorn)	gourde (water bottle)
dauphin (dolphin)	urne (urn)
lynx (lynx)	louche (soup ladle)
næ ud (knot)	niche (kennel)
plante (plant)	poule (hen)
plat (dish)	prune (plum)
tronc (trunk)	tarte (pie)
tasse (cup)	tigre (tiger)
noix (walnut)	moto (motorbike)
loup (wolf)	loupe (magnifying glass)
lampe (lamp)	mouche (fly)
peigne (comb)	poche (pocket)
pull (pullover)	plume (feather)
tank[a] (tank)	torche[a] (torch)
raie[a] (ray)	ruche[a] (beehive)

Note. English translations are given in parentheses.
[a] Presented in Experiment 2, but not in Experiment 1.

Appendix B

The Stimulus Words Used in Experiment 3

High frequency		Low frequency	
Irregular	Regular	Irregular	Regular
train (train)	poche (pocket)	bêche (spade)	fugue (running away from home)
type (type)	lune (moon)	zèle (zeal)	bave (dribble)
froid (cold)	larme (tear)	crêpe (pancake)	prune (plum)
frère (brother)	monde (world)	dièse (sharp)	bribe (scrap)
pièce (room)	crise (crisis)	flair (scent)	crabe (crab)
cœur (hear)	riche (rich)	flash (flash)	louve (she-wolf)
oeuvre (work)	double (double)	gendre (son-in-law)	charte (charter)
grosse (big)	proche (near)	glaire (glair)	torche (torch)
femme (women)	ligne (line)	gland (acorn)	digue (dam)
règle (ruler)	libre (free)	kyste (cyst)	bulbe (bulb)
membre (member)	pointe (point)	moelle (marrow)	pioche (pick)
fils (son)	juge (judge)	môme (kid)	luge (sledge)
prêtre (priest)	bouche (mouth)	phoque (seal)	poutre (beam)
neige (snow)	bonne (maid)	plomb (lead)	biche (doe)
rêve (dream)	page (page)	pull (pullover)	ours (bear)
style (style)	nuage (cloud)	score (score)	niche (kennel)
plein (full)	rouge (red)	snack (snack)	arche (arch)
plaire (to please)	mouche (fly)	suaire (shroud)	fougue (heat)
rôle (role)	mode (fashion)	tank (tank)	tube (tube)
sens (direction)	arme (weapon)	zinc (zinc)	tige (trunk)

Note. English translations are given in parentheses.

Received May 20, 2005
Revision received January 30, 2006
Accepted April 4, 2006 ■