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Do Phonological Codes Constrain the Selection of Orthographic Codes in Written Picture Naming?

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Sound-to-print consistency of picture labels was manipulated in five experiments to investigate whether phonological codes constrain the selection of orthographic codes in written picture naming. In Experiments 1 and 2, participants wrote down picture names which were inconsistent or consistent in the phono-orthographic mapping defined either at the level of the word unit, i.e., heterographic homophones versus nonhomophones (Experiment 1), or at the sublexical level (Experiment 2). In neither experiment did phonographic consistency affect written latencies. Although more errors were observed for inconsistent than for consistent picture names, the observation of a similar error pattern in an untimed written picture naming (control) task suggests that errors resulted from inaccurate orthographic knowledge. In Experiment 3, the position of the inconsistent units within the picture name (initial versus middle or final) was manipulated. The results indicated that only initial inconsistencies affected written latencies. Ruling out the hypothesis that this finding merely results from the fact that handwriting starts before the orthographic encoding of the word endings, Experiments 4 and 5 showed that middle or final inconsistencies influenced written latencies in a spelling-to-dictation task. The findings are discussed as suggesting that the build-up of orthographic activation from pictures is phonologically constrained through the sequential operation of sublexical conversion.

Key Words: phonology; orthography; semantic; written picture naming; spelling to dictation.

Any theory of spelling in writing must account for our ability to go from a to-be-named concept, e.g., *TABLE*, to the actual writing of the specific word form associated with the concept (the letters *t-a-b-l-e*). More precisely, it has to specify how orthographic codes which form the basis for the production of the actual letters are generated from semantic representations. According to the obligatory phonological mediation hypothesis, access to orthography depends on the prior retrieval of the phonological representations (Geschwind, 1969; Luria, 1970). This hypothesis (Rapp & Caramazza, 1997; Rapp, Benzing, & Caramazza, 1997) reflects the fact that spoken language precedes, ontogenetically and phylogenetically, written language (Scinto,

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1986). It is consistent both with observations of phonologically based spelling errors (Aitchinson & Todd, 1982), such as homophone substitutions (e.g., *there* for *their*) or phonologically plausible pseudoword production (e.g., *dirth* for *dearth*) and with our introspective experiences of the inner speech that accompanies writing (Hotopf, 1980). Two different versions of the obligatory phonological mediation hypothesis can be distinguished depending on the lexical or sublexical nature of the phono-orthographic associations. According to the lexical version, the semantic system first activates the target phonological form, which, in turn, activates the corresponding orthographic form (Miceli, Benvegnu, Capasso, & Caramazza, 1997). The sublexical version, which was the first to be proposed, assumes that writing requires the identification of the phonemes of the word and their arrangement in the correct order, followed by the recoding of each phoneme into its corresponding grapheme (Luria, 1970). However, such a procedure would be hopelessly inaccurate for English due to the ambiguity of phoneme–grapheme correspondences.

The obligatory phonological mediation hypothesis has been challenged by analyses of various patterns of performance exhibited by brain-damaged patients in written and spoken naming tasks. First, written performance in picture naming tasks can be relatively spared when compared to spoken performance even though the difficulties in spoken production cannot be ascribed to the articulatory processes (e.g., Assal, Buttet, & Jolivet, 1981; Bub & Kertesz, 1982; Rapp & Caramazza, 1997; Shelton & Weinrich, 1997). Second, some patients exhibit inconsistent lexical responses in their written and spoken productions in response to the same pictures (e.g., a correct written response and a spoken semantic error or the reverse or two distinct semantic errors as for the spoken response *church* and the written response *piano* to the stimulus *organ*[1]; Miceli et al., 1997; Miceli & Capasso, 1997; Miceli, Capasso, & Caramazza, 1999). According to the obligatory phonological mediation hypothesis, different semantic responses for the same trial in spoken versus written picture naming are not expected because phonology underlies both forms of language production.

To account for the neuropsychological data, the orthographic autonomy hypothesis (Miceli et al., 1997; Rapp & Caramazza, 1997; Rapp et al., 1997) assumes that the retrieval of orthographic codes does not obligatorily require prior access to phonology because activation from semantic representations propagates directly in parallel to orthographic and phonological word forms. However, although the neuropsychological data mentioned above favor the orthographic autonomy hypothesis, this does not rule out the possibility that, in normal writing, phonological information might combine with semantic specifications to constrain the selection of orthographic codes. Data favoring the orthographic autonomy hypothesis were observed in masked priming experiments with normals (Bonin, Fayol, & Peereman, 1998). In this technique, the visibility of the prime is reduced by using short prime durations and forward and backward masking. It was initially used by Ferrand, Grainger, and Segui (1994) to investigate spoken picture naming using nonword primes that were (1) homophonic with the target (pseudohomophone primes); (2) nonhomophonic with the target, although the orthographic overlap was the same as for pseudohomophones (orthographic primes); or (3) nonhomophones orthographically and phonologically unrelated to the picture name with the exception of the first letter(s) (control primes). The results showed that spoken picture naming was facilitated by pseudohomophone primes when compared to orthographic primes and control primes, with the latter two conditions giving rise to similar performance. Thus, spoken picture naming was facilitated by the preactivation of phonological representations, but not by the preactivation of orthographic information. In Bonin et al.'s study (1998), the same priming conditions were used but participants had to quickly write the names of pictures (a written picture naming task) instead of speaking them aloud. Orthographic priming effects were observed with prime expo-

[1] The example is from patient ECA (Miceli, Capasso, & Caramazza, 1999).

sure durations of 34 and 51 ms but not with a shorter exposure duration of 17 ms. In none of the experiments did homophony between primes and picture names yield an additional advantage. These findings were interpreted as support for the hypothesis that orthographic information is retrieved directly from semantics in written picture naming.

The goal of the present study was to assess further whether phonological information constrains orthographic encoding in written picture naming. In the experiments, the consistency of the mapping between the phonological and orthographic units (PO consistency) of picture labels was manipulated in a written picture naming task. The main prediction is that inconsistencies should hurt performance if phonological information contributes to orthographic encoding. In order to make clear the specific predictions examined in the experiments, we have outlined a model of written picture naming which builds in part on a recent proposal of Miceli et al. (1999). This model is depicted in Fig. 1.

As depicted in Fig. 1, when a target picture is presented, a first processing level consists of object identification which results in the activation of structural representations (Humphreys, Lamote, & Lloyd-Jones, 1995). These representations send activation to the semantic system. Activation then flows, in parallel, from semantic representations to phonological and orthographic word forms in the (output) phonological and orthographic lexicon respectively. Finally, activation propagates from orthographic word forms to the grapheme level where abstract representations corresponding to individual graphemes and their positions are specified.

Two different versions of the orthographic autonomy hypothesis were distinguished between by Miceli et al. (1997). According to the "lexical" version, phonological and orthographic word forms are directly linked to each other through lexical connections (arrow A in Fig. 1). The sublexical version holds that phonological and orthographic word forms are not directly connected to each other, but that they interact through sublexical connections between phonological and orthographic units (arrow B in Fig. 1). For instance, consider the to-be expressed concept *TABLE*. The lexical version holds that the orthographic word form *table* is directly activated from semantics and from the phonological word form /tɛblə/, whereas the sublexical version holds that the orthographic word form is activated from semantics and, indirectly, from the recoding of the individual phonemes of the phonological word form /tɛblə/ into their corresponding graphemes *t*+a+b+l+e. Analyses of errors exhibited by brain-damaged patients support the sublexical version of the orthographic autonomy hypothesis (Miceli et al., 1997; Miceli & Capasso, 1997; Miceli et al., 1999). Unlike patients who produce consistent lexical responses when naming and writing picture names, the patients who produce inconsistent responses also manifest impairments of the PO and/or the OP sublexical conversion procedures (Miceli et al., 1999). Hence, inconsistent responses arise when damage to the sublexical conversion procedure prevents interactions between orthographic and phonological word forms.

The primary goal of Experiments 1 and 2 was to investigate whether phonology constraints orthographic code activation in written picture naming. A secondary goal was to investigate whether the phonological contribution to the orthographic encoding of picture names is better characterized as resulting from lexical or sublexical associations. To that end, phono-orthographic (PO) consistency was manipulated at the lexical level in Experiment 1 and at the sublexical level in Experiment 2. In Experiment 1, the picture names were either heterographic homophones or nonhomophones (referred to as "controls") matched for consistency on subword units. In Experiment 2, the consistency of the picture names was manipulated at the level of subword units (mostly on the VC or V units). In both experiments, participants had to quickly write down the names of pictures presented on a computer screen.

Two different predictions can be derived from the general framework presented above. If orthographic and phonological word forms interact directly through lexical connections (arrow

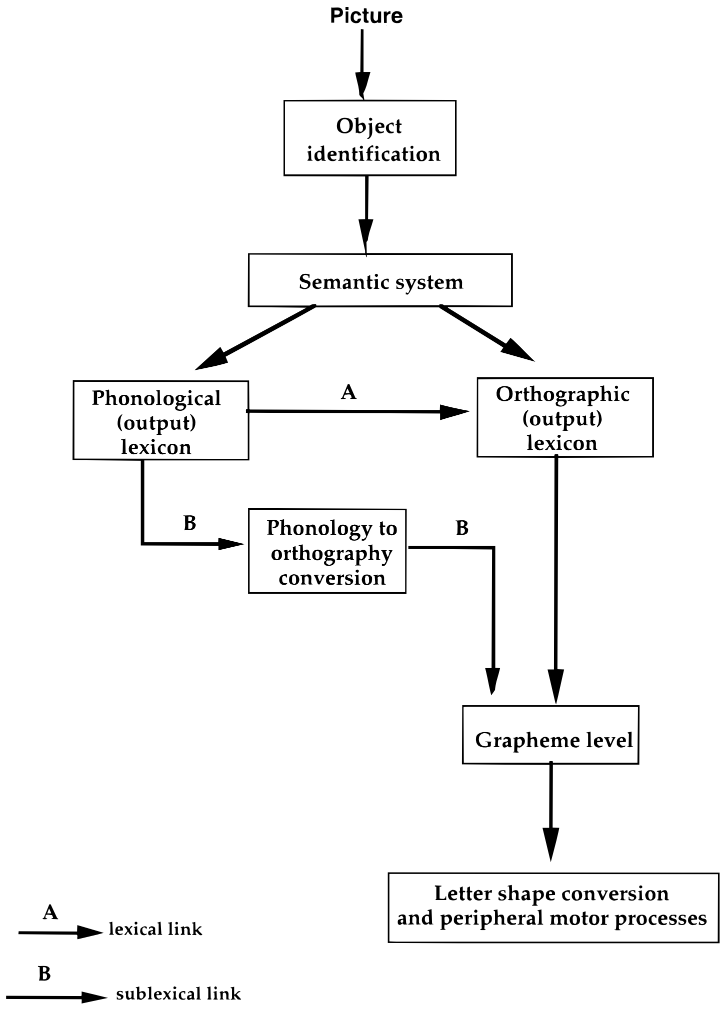

FIG. 1. Working model of written picture naming.

A in Fig. 1), competition for selection between orthographic word forms should occur when, as it is the case for heterographic homophones, different orthographic word forms match a single phonological word form. Thus, because at least two orthographic forms are activated but only the intended one is to be selected, picture names which are homophones should yield a processing cost when compared to control picture names matched for sublexical consistency. Suppose, for instance, that the picture represents a *swan*, which corresponds to the French word *cygne*. Activation will first propagate, in parallel, from semantic representations to the phonological word form */siɲ/* and to the orthographic word form *cygne*. Because the French word *signe* is homophonic with the target word *cygne*, any subsequent phonological contribution in accessing orthographic specifications will lead to the activation of the orthographic word forms corresponding to *cygne* and *signe*. As two competing orthographic forms are activated, further processing must take place to permit the selection of the intended orthographic form. Thus, written latencies should be longer for homophonic targets than for controls. This prediction was tested in Experiment 1. In contrast, if orthographic and phonological word forms interact through sublexical links (arrow B in Fig. 1), then a processing cost is expected for picture names including inconsistent subword units. Indeed, PO inconsistencies of subword units should lead, through sublexical conversion, to the activation of incorrect alternative orthographic codes that will conflict with the orthographic activation coming directly from semantics. Hence, if orthographic and phonological word forms are connected through sublexical associations, written latencies should be longer for sublexically inconsistent targets than for consistent ones. This prediction was examined in Experiment 2.

EXPERIMENT 1: WRITING HETEROGRAPHIC HOMOPHONES FROM PICTURES

In Experiment 1, participants wrote down picture names that were either heterographic homophones or nonhomophones. To ensure that any difference in performance between the two sets of stimuli was not attributable to sublexical conversion, homophones and controls were matched for phono-orthographic consistency on subword units. If activation of orthographic word forms is partially determined by lexical phonology, then homophones should give rise to longer written latencies than controls.

In the written picture naming task used in Experiment 1 and in subsequent experiments, spelling errors can result either from the selection of an erroneous orthographic code among competing alternatives activated during processing ("performance" errors) or from incorrect lexical specifications of the word's orthography ("competence" errors). Therefore, a control spelling task was performed to examine whether spelling errors observed for each of the sets of stimuli used in the present study were better characterized as reflecting "competence" or "performance" errors. In the control spelling task, participants had to write down the names of the pictures with no time pressure. They were instructed to check and, if necessary, correct their responses. After spelling each word, participants had to rate their spelling for confidence on a 5-point scale. If the spelling errors observed in the speeded written picture naming experiments are true performance errors resulting from competition between alternative orthographic codes, the advantage of consistent items over inconsistent ones should reduce or disappear when the task allows more time for the participants to perform spelling checks and permits error correction. Indeed, although the prediction of similar numbers of errors for consistent and inconsistent items in the control task might be too strong and omits the fact that participants might skip the spelling check procedure for some words, it seems appropriate to assume that at least some of the errors will be detected and corrected. Consequently, the difference in error rates between consistent and inconsistent words should be smaller in the untimed writing task than in the speeded writing experiments. It follows, then, that the pattern of spelling errors observed in each speeded writing experiment should remain significant when the error scores obtained in the control task are introduced as a covariate. In contrast, if most of the spelling errors observed in the speeded experiments are true competence errors, which reflect incorrect lexical specifications of word orthography, then the same pattern of errors should occur in the speeded written picture naming and control tasks. Thus, the consistency effect in each speeded experiment should become insignificant when the error scores from the control writing experiment are entered as a covariate.

Differences in confidence ratings between consistent and inconsistent words are also expected if lexical orthographic representations for inconsistent words are less well specified than for consistent words. Participants who have stored inaccurate orthographic representations might be accustomed to "erroneous" spellings (especially for inconsistent words) and be unaware of their errors. As a result, they could be relatively confident about words produced erroneously. According to Holmes and Carruthers (1998), the more consistently university students produce particular misspellings, the more confident they are in their own productions. However, participants might, on average, be less confident about their spellings of inconsistent words because, for some of them at least, they are aware of the uncertainty of their orthographic knowledge.

A single independent group of participants performed the control spelling task for all the sets of stimuli used in Experiment 1 and the subsequent picture naming experiments. For each speeded picture naming experiment, the error data are presented together with the data obtained in the control spelling task for the corresponding sets of stimuli.

Method

Participants. Thirty psychology students from Blaise Pascal University (Clermont-Ferrand, France) were involved in the experiment. All were native speakers of French and had normal or corrected-to-normal vision.

Stimuli. The stimuli consisted of 44 line drawings. For half of them, the picture name had a heterographic homophone of higher frequency. For example, the picture name *cygne* (meaning *swan*) and the word *signe* (meaning *sign*) are heterographic homophones, with *signe* having a higher frequency of occurrence in print than *cygne*. For each picture name, the corresponding orthographic code was of low or medium frequency in print (less than 90 occurrences per million according to Imbs, 1971). The 22 pictures of the homophone condition were matched with 22 control pictures for which the picture names had no heterographic homophone. Hence, items in the control condition were consistent at the lexical level of the PO correspondences (whole-word level). However, by definition, the heterographic homophones carry sound-to-print inconsistencies both at the lexical and sublexical levels. For example, the PO correspondences between the phonological and the orthographic codes of the words *cygne* and *signe* are inconsistent at the sublexical level since each of the */s/* and */i/* phonological codes have two distinct orthographic renderings (*c* and *s*, *y* and *i*, respectively). Because the experiment focused on the phonology-to-orthography inconsistencies at the lexical level, picture names in the homophone and control conditions were matched for sublexical inconsistencies. The matching was performed using the LEXOP lexical database, which includes detailed lexical statistics on sound-to-print correspondences for French monosyllabic words (Peereman & Content, 1999).

Ideally, heterographic homophones and controls should be matched for both the spoken and written frequencies of the picture names. However, such a matching is impossible where heterographic and nonheterographic words are concerned. In the case of heterographic words, the spoken frequency of the word form corresponds to the pooled frequencies of the homophonic forms (e.g., the summed frequency of *cygne* and *signe*), but the written frequency is specific to the orthographic form of one of the homophones (e.g., *cygne*). Therefore, the nonheterographic controls consisted of line drawings whose names were matched for the written frequency of the orthographic forms. Note that the possible advantage afforded by the higher spoken frequency of the heterographic items works against the expected disadvantage related to heterography. In addition to word frequency and sound-to-print consistency, the picture names were matched as far as possible for number of letters and bigram frequencies. The phonological forms of the picture label were matched for number of phonemes. The orthographic similarity between the members of the homophonic pairs was relatively high (.62 according to the orthographic similarity index of Van Orden, 1987). The average picture name characteristics are presented in Table 1. Fifteen pictures were used as warm-ups. The pictures were taken from Snodgrass and Vanderwart (1980), children books (*Père Castor*), a dictionary (*Larousse*), and various clip-art libraries. The picture names are listed in Appendix 1.

Apparatus. The experiment was created with PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) and ran on a PowerMacintosh. A graphic tablet (Wacom tablet) and a contact pen (UP-401) were used to record written latencies.

Procedure. The participants were tested individually. During a preliminary phase, they had to learn the name associated with each of the pictures. Each picture was presented on the screen while its name was auditorily presented through headphones (Sennheiser HD 25 SP). The picture remained on the screen until the

TABLE 1

Characteristics of the Picture Names Used in Experiment 1

	Homophones	Non-homophones	*p* Values (*t* tests)
Number of letters	4.27	4.27	*ns*
Number of phonemes	2.86	2.82	*ns*
Log frequency[a]	1.08	1.14	*ns*
Log bigram frequency[b]	3.21	2.87	$<.01$
Onset (C1) consistency[c]	0.91 (0.88)	0.95 (0.95)	*ns* (*ns*)
Vowel (V) consistency[c]	0.53 (0.55)	0.60 (0.58)	*ns* (*ns*)
Coda (C2) consistency[c]	0.45 (0.47)	0.46 (0.51)	*ns* (*ns*)
C1V consistency[c]	0.51 (0.45)	0.61 (0.59)	*ns* (*ns*)
VC2 consistency[c]	0.19 (0.13)	0.27 (0.23)	*ns* (*ns*)

[a]Log word Frequency per 100 million from Imbs (1971).
[b]From Content and Radeau (1988).
[c]Values by Type (by Token in parentheses) as given by LEXOP (Peereman & Content, 1999).

participant pressed the spacebar. The participants were told to look carefully at each picture to learn its name and then, when they felt they knew its name, to press the spacebar to proceed to the next picture. The time taken to learn each picture together with its name was measured and recorded. To ensure that participants had correctly learned the names associated with the pictures, the experimenter tested them on several pictures selected randomly. The learning times were analyzed for each speeded written picture naming experiment but they did not provide supplementary information with regard to the pattern of results found in each experiment. For this reason, the results from the learning phases are not reported. The rationale for conducting this learning phase was that our production experiments required the selection of specific measurable responses, and in production there is often no easy way to get specific responses (Bock, 1996). Hence, "specified elicitation" is frequently used in spoken picture naming studies in order to reduce variability in the names used to refer to the pictures (e.g., Jescheniak & Levelt, 1994; Schriefers, Meyer, & Levelt, 1990; Starreveld & La Heij, 1995).

In the experimental phase, the participants were instructed that they had to quickly write down the name of each of the pictures presented on the screen. The distance between the computer screen and the participant was about 60 cm. The experimenter monitored the participants' responses and scored them for correctness. The entire session lasted about 60 min.

Each trial consisted of the following events: A ready signal ("*") was presented for 1000 ms followed, after a 200-ms delay, by the picture. Latencies were measured from picture onset until the initiation of the written response. The participants sat with the stylus right above the tablet so that the latency was the time required to make the initial contact with the tablet after picture onset. The picture was removed from the screen after the participant had initiated writing. The next trial was presented after an intertrial interval of 5000 ms.[2] The experiment began with 15 practice trials.

In the spelling control task, 30 additional participants, all native speakers of French, had to write down the names of pictures dispayed by a slide projector while hearing their names. All the pictures used in Experiments 1, 2, and 3 were presented. Participants were tested in groups of 10. Each picture was presented for a period of 10 to 15 s and participants were allowed to correct their spellings. They were also asked to rate their spellings for confidence on a 5-point scale ranging from *very confident* (5) to *unconfident* (1).

[2] This delay was determined on the basis of previous experiments (Bonin & Fayol, 2000; Bonin, Fayol, & Gombert, 1997, 1998; Bonin, Fayol, & Peereman, 1998).

Results

In Experiment 1, as in the following experiments, observations were discarded from the latency analyses when the participant did not remember the picture name or used a picture name other than the expected one, when a technical problem occurred, or when a word was misspelled. Moreover, latencies exceeding 2.5 standard deviations above the participant and item means were discarded (0.98% of the data) and considered as errors. Overall, 10.6% of the data were excluded. One item (*puits* meaning *well*) was removed from the latency analyses due to a high error rate (22 participants of 30 wrote it erroneously).

Analyses were performed on written latencies and on errors with Homophony condition (homophonic labels; control labels) as the main factor. ANOVAs were conducted separately with participants and items as random factors. Mean latencies were 1219 ms for homophones and 1230 ms for controls. The 11-ms difference was not reliable, both $F < 1$, and the trend was in the direction opposite to the expected effect.[3]

In this experiment as well as in the following ones, three different kinds of analyses were conducted on the errors: (1) all error types included; (2) spelling errors and homophone substitutions only; and (3) spelling errors only. All these analyses were carried out either with items having an error rate greater than 50% removed or with the whole set of items. For the sake of conciseness, only the analyses performed on the whole set of errors and corresponding to the items used in the latency analyses are reported for each experiment, except when the different analyses led to different outcomes. In such cases, the other analyses are also presented. The effect of homophony was significant, $F_1(1, 29) = 24.63$, $MSE = .0069248$, $p < .001$; $F_2(1, 41) = 11.67$, $MSE = .0104668$, $p < .01$, with homophonic labels causing more errors (14.6%) than controls (3.9%). The effect was also reliable when both spelling and homophone substitution errors were counted as errors, but it failed to reach significance in the by-item analysis when only spelling errors were considered, $F_1(1, 29) = 5.22$, $MSE = .0011757$, $p = .05$; $F_2(1, 41) = 1.31$, $MSE = .0032527$, $p = .25$.

A qualitative analysis performed on the errors on homophonic labels revealed that most of the errors were spelling errors (34.78%) and homophone substitution errors (44.57%). The remaining errors corresponded to cutoff values (5.43%), responses using a label other than the intended one (9.78%), no response (3.26%), and spelling corrections by the participants (2.17%).

Untimed Written Picture Naming Task. More spelling and homophone substitution errors were observed for the homophonic labels (15%) than for the control labels (1.81%), $F_1(1, 29) = 75.66$, $MSE = .0034447$, $p < .001$; $F_2(1, 42) = 10.11$, $MSE = .0189141$, $p < .01$. When the error data from the control task were used as a covariate in the analysis of the errors of Experiment 1, the difference between the two word sets no longer reached significance.

Homophonic labels were given a slightly lower confidence score (4.73) than controls (4.88). The homophony effect on confidence ratings was significant by participants, $F_1(1, 29) = 19$, $MSE = .0181201$, $p < .001$, and marginally significant by items, $F_2(1, 42) = 3.36$, $MSE = .0751130$, $p = .073$.

Discussion

Contrary to the prediction, control labels were not produced significantly faster than homophonic labels, although an effect on errors was observed. An important finding was that numerous errors consisted of homophone substitutions. At first, this observation could be interpreted as evidence of phonological involvement in written picture naming. Accordingly, the phonological word form corresponding to a homophonic target would be activated from semantics and activation would then spread to its different related orthographic forms. For example, the concept *verre* (meaning *glass*) would activate the phonological word form /vɛr/ which, in turn, would activate the orthographic

[3] An additional analysis using log bigram frequency as a covariate was carried out because we were concerned that the higher frequency of bigram units (by token counts) for homophones than for nonhomophones might have weakened the expected homophone effect. The results did not reveal significant effects of bigram frequency and homophony.

word forms *verre*, *vers*, and *ver*. Such errors might reflect true “performance” errors and would follow from erroneous selection of the nonintended orthographic form. One problem with this hypothesis is that it is unclear why written latencies were not affected by consistency. It might be that our decision to consider very long latencies as errors led to the elimination of latency differences between homophones and controls. However, the percentage of excluded items did not statistically differ across conditions (0.79 and 1.21% for the homophones and controls, respectively) and the homophone effect was still nonsignificant when these very long responses were included in the latency analyses (1241 versus 1265 ms for the homophones and controls respectively). Finally, the fact that similar patterns of spelling and homophone substitution errors were observed in the speeded writing task and the control writing task suggests that most of the errors on inconsistent words were competence errors resulting from inaccurate orthographic knowledge. Therefore, the differences in error rates between consistent and inconsistent words in Experiment 1 cannot be readily taken as evidence of phonological involvement in written picture naming.

The apparent lack of competion between homophones during processing seems to contrast with recent findings for visual word recognition. One possibility is that the frequency of the homophone mates was not high enough as compared to the frequency of the target homophones to truly compete for selection. Indeed, Pexman, Lupker, and Jared (2001) found that, in lexical decision, the homophone effect was retricted to low-frequency homophones having high-frequency mates. A close examination of our stimuli revealed, however, that this was the case in Experiment 1, with the frequency of the homophone mates being higher and statistically different ($p < .001$) from the frequency of the homophone targets (log frequency of 2.33 and 1.08 respectively). Another possibility is that the failure to observe a homophony effect for written latencies results from the fact that homophones and controls were matched for sublexical inconsistencies. Hence, similar interferences in orthographic code selection could have occurred for both categories of items. In Experiment 2, PO consistency was defined at the sublexical level. If this explanation is correct, we should observe significant effects of sublexical inconsistencies for both latencies and errors in Experiment 2.

EXPERIMENT 2: WRITING SUBLEXICALLY CONSISTENT AND INCONSISTENT WORDS FROM PICTURES

In Experiment 2, we examined whether PO inconsistencies at the sublexical level affect written performance. In addition to the consistency factor, word frequency was manipulated. In the word recognition literature, consistency effects are more easily obtained on low-frequency words than high-frequency words (Seidenberg, 1985; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; but see Content, 1991; Jared, 1997). Thus, consistency effects in written picture naming could be confined to low-frequency picture names. Such a prediction makes sense because, according to the sublexical version of the orthographic autonomy hypothesis, the phonology-to-orthography conversion procedure is assumed to act slowly (Miceli, personal communication) and to lag behind the activation of phonological word forms. For high-frequency picture names, the selection of the appropriate orthographic form could occur before the involvement of the PO conversion procedure. Conversely, because activation of the orthographic word form is slower for low than for high-frequency picture names, the PO conversion should have more time to develop and could consequently constrain the selection of orthographic word forms. Hence, consistency should influence both latencies and errors, especially for low-frequency picture names.

Method

Participants. Thirty psychology students from the same pool as Experiment 1 were recruited. None of them had participated in the previous experiment. All were native speakers of French and had normal or corrected-to-normal vision.

Stimuli. Eighty line drawings were used. For half of them, the picture name was a frequent word, whereas for the remaining half it was a low-frequency word. Of the low- and high-frequency items, half were sublexically inconsistent and half were consistent.

As in the previous experiment, the items were selected from the LEXOP lexical database (Peereman & Content, 1999). In Experiment 2 and in the following experiments, sound-to-print consistency was defined at the level of the onset, vocalic, and coda units, as well as at the level of onset+vowel and vowel+coda (rime) units. Manipulation of consistency involving larger units rather than the phoneme–grapheme correspondences was preferred for two reasons. First, there are several instances in French in which the inconsistency of phoneme-to-grapheme relations decreases or disappears when the adjacent context is taken into account. For example, the phoneme */k/* has multiple orthographic renderings (*qu*, *c*, *k*, and *ch*) but consistency is nearly maximal when the phoneme */k/* is followed by */R/* as in the word "*crime*" ("*Christian*" and "*krypton*" are two exceptions). In other cases, positional information is also critical. For example, Tainturier (1997) mentioned the case of the French vowel */O/*, which is generally transcribed with "*o*" (as in the word "*moto*") except when occurring at the word final where the "*au*" and "*eau*" graphemes are very usual (as in "*râteau*"). Thus, defining consistency on the basis of phoneme–grapheme associations might have resulted in the inclusion of words that are inconsistent at the phoneme level, but are highly consistent when the adjacent context is also considered. A second reason motivating our preference for considering contextual information when selecting consistent and inconsistent words is that recent data (Pacton, Fayol, & Perruchet, 2001) clearly indicate that the surrounding context of a phoneme partially determines the way children spell nonwords (see also Pacton, Perruchet, Fayol, & Cleeremans, in press). In Experiment 2, most of the inconsistencies occurred on the vowel (V) and the final vowel-consonant (VC rime) units. Among high- and low-frequency words, labels were matched as far as possible for number of letters and phonemes. The average picture name characteristics are presented in Table 2. Sixteen additional pictures were used as warm-ups. The pictures were taken from the same pool as in Experiment 1. The picture names are listed in Appendix 2.

Apparatus and procedure. These were identical to those used in Experiment 1.

Results

As in Experiment 1, latencies above 2.5 standard deviations from the participant and item

TABLE 2

Characteristics of the Picture Names Used in Experiment 2

	HF-Inc	HF-Con	*p* Values (*t* tests)	LF-Inc	LF-Con	*p* Values (*t* tests)
Number of letters	4.95	4.95		4.95	4.95	
Number of phonemes	3.30	3.90	.06	3.50	3.60	*ns*
Log frequency[a]	3.88	3.90	*ns*	2.65	2.63	*ns*
Log bigram frequency[b]	3.15	2.94	<.05	3.06	2.82	<.01
Onset (C1) consistency[c]	0.94 (0.92)	0.96 (0.95)	*ns* (*ns*)	0.71 (0.70)	0.96 (0.97)	<.05 (=.01)
Vowel (V) consistency[c]	0.47 (0.48)	0.91 (0.97)	<.01 (<.01)	0.49 (0.44)	0.91 (0.98)	<.01 (<.01)
Coda (C2) consistency[c]	0.57 (0.57)	0.86 (0.94)	<.01 (<.01)	0.68 (0.60)	0.85 (0.93)	*ns* (<.01)
C1V consistency[c]	0.54 (0.63)	0.91 (0.96)	<.01 (<.01)	0.42 (0.33)	0.85 (0.88)	<.01 (<.01)
VC2 consistency[c]	0.34 (0.34)	0.82 (0.93)	<.01 (<.01)	0.46 (0.34)	0.90 (0.96)	<.01 (<.01)

Note. HF = high frequency words; LF = low frequency words; Con = Consistent; Inc = Inconsistent.
[a]Log word Frequency per 100 million from Imbs (1971).
[b]From Content and Radeau (1988).
[c]Values by Type (by Token in parentheses) as given by LEXOP (Peereman & Content, 1999).

means were excluded and considered as errors (0.67–1.16% for consistent and inconsistent HF words respectively; 1–0.98% for consistent and inconsistent LF words). Overall, 7.25% of the data were excluded from the latency analyses. Moreover, in the latency analyses, three items ("*hyène*," "*seau*," and "*serpe*") were discarded because more than half the participants wrote them incorrectly.

ANOVAs were conducted with Frequency (high frequency vs low frequency) and Consistency (consistent vs inconsistent) as main factors. As Table 3 shows, written responses were faster for high-frequency names than for low-frequency names, $F_1(1, 29) = 50.76$, $MSE = 1762.44$, $p < .001$; $F_2(1, 73) = 10.24$, $MSE = 5707.61$, $p < .01$. The main effect of consistency was not reliable, both $F < 1$. The interaction between the two factors was marginally significant by participants, $F_1(1, 29) = 3.48$, $MSE = 1545.35$, $p = .072$, but not significant by items, $F_2 < 1$. Similar results were obtained when latencies exceeding 2.5 standard deviations were included in the latency analyses.[4]

In the error analyses, the main effect of frequency was significant, $F_1(1, 29) = 22.31$, $MSE = .0026166$, $p < .001$; $F_2(1, 73) = 10.08$, $MSE = .0036999$, $p < .01$. The main effect of consistency was marginally significant by participants, $F_1(1, 29) = 3.53$, $MSE = .0036711$, $p = .07$, and failed to reach significance by items, $F_2(1, 73) = 2.24$, $MSE = .0036999$, $p = .14$. The interaction between the two factors was not significant in both analyses, both $F < 1$. When only spelling and homophonic substitution errors were considered, the effects of frequency, $F_1(1, 29) = 17.94$, $MSE = .0013102$, $p < .001$; $F_2(1, 73) = 12.66$, $MSE = .0011855$, $p < .001$, and of consistency, $F_1(1, 29) = 10.96$, $MSE = .0012446$, $p < .01$; $F_2(1, 73) = 7.35$, $MSE = .0011855$, $p < .01$, were significant. The interaction between frequency and consistency was significant by participants, $F_1(1, 29) = 4.68$, $MSE = .0013761$, $p < .05$, and marginally significant by items, $F_2(1, 73) = 3.47$, $MSE = .0011855$, $p = .07$ (exactly the same pattern of results was obtained when spelling errors only were considered).

When errors were analyzed with the full set of items, frequency and consistency effects were significant on both analyses as was the interaction effect between the frequency and consistency factors. Planned comparisons revealed that the consistency effect was marginally significant for high-frequency names by participants and not significant by items, but it was significant by both participants and items for low-frequency names.

Untimed written picture naming task. The effects of frequency, $F_1(1, 29) = 37.06$, $MSE = .0036789$, $p < .001$; $F_2(1, 76) = 12.75$, $MSE = .0064403$, $p < .001$, and consistency, $F_1(1, 29) = 45.99$, $MSE = .0028196$, $p < .001$; $F_2(1, 76) = 12.09$, $MSE = .0064403$, $p < .001$, were significant, as was the interaction between the two factors, $F_1(1, 29) = 43.04$, $MSE = .0028619$, $p < .001$; $F_2(1, 76) = 11.46$, $MSE = .0064403$, $p < .01$. More errors were observed for low-frequency inconsistent words (13.31%) than for the other categories of targets (HF-Consistent: 0%; HF-Inconsistent: 0.16%; LF-Consistent: 0.33%), $F_1(1, 29) = 42.85$, $MSE = .0090788$, $p < .001$; $F_2(1, 76) = 36.29$, $MSE = .0064403$, $p < .001$. As was the case in Experiment 1, the differences between the sets of stimuli in Experiment 2 were not significant when the error data from the untimed writing task were entered as covariates in the error analysis.

Confidence ratings were affected by both frequency, $F_1(1, 29) = 31.07$, $MSE = .0207644$, $p < .001$; $F_2(1, 76) = 10.69$, $MSE = .0402500$, $p < .01$, and consistency, $F_1(1, 29) = 34.36$, $MSE = .0140057$, $p < .001$; $F_2(1, 76) = 7.97$, $MSE = .0402500$, $p < .01$. The interaction effect was significant, $F_1(1, 29) = 35.74$, $MSE = .0138247$, $p < .001$; $F_2(1, 76) = 8.18$, $MSE = .0402500$, $p < .01$. A slightly lower confidence score was given to LF-Inconsistent items (4.71) than to the other categories of items (HF-Consistent: 4.99; HF-Inconsistent: 4.99; LF-Consistent: 4.97), $F_1(1, 29) = 35.13$, $MSE = .045919$, $p < .001$; $F_2(1, 76) = 26.72$, $MSE = .040250$, $p < .001$.

[4] As in Experiment 1, an additional analysis using bigram frequency as a covariate was performed because the sets of stimuli were not perfectly matched for bigram frequency. The pattern of results remained the same.

TABLE 3

Mean Latencies (in Milliseconds) and Percentages of Errors for Sublexically Consistent and Inconsistent Picture Names in Experiment 2

High-frequency names		Low-frequency names	
Inconsistent	Consistent	Inconsistent	Consistent
1102.9 (4.0)	1092.0 (2.3)	1144.2 (8.82)	1160.0 (6.3)

Discussion

Experiment 2 failed to show longer written latencies for sublexically inconsistent items than for consistent ones. Although the consistency effect was not significant when all error types were included, consistency had a clear effect when only spelling and homophone substitutions were considered. As mentioned under Experiment 1, the more numerous spelling and homophonic substitution errors on inconsistent items might result from the inaccurate lexical specification of orthographic forms since the control written picture naming task showed a similar pattern of spelling and homophonic substitution errors.

Hence, as far as written latencies are concerned, Experiments 1 and 2 do not provide evidence for the hypothesis that phonological codes can constrain the selection of orthographic codes by means of lexical (Experiment 1) or sublexical links (Experiment 2). It is possible, however, that participants initiate writing as soon as the first letter or the first grapheme of the to-be-written target becomes available for output. Given that most inconsistencies were carried out by the final part of the items (V or VC), the lack of a consistency effect on latencies could be due to the fact that the resolution of inconsistencies took place during the actual physical production of the first letters or graphemes. The processing cost associated with this resolution process would therefore remain undetected in an analysis of the written onset latencies. The next experiment addressed this issue.

EXPERIMENT 3: MANIPULATING THE SERIAL POSITION OF THE INCONSISTENT UNITS

It has been claimed that speech production can be initiated before the full phonological encoding of the word (Bachoud-Lévi, Dupoux, Cohen, & Mehler, 1998; Cortese, 1998; Kawamoto, Kello, Jones, & Bame, 1998; Schriefers & Teruel, 1999). Although this hypothesis was not confirmed by the electropalatographic study reported by Rastle, Harrington, Coltheart and Palethorpe (2000), the possibility of a similar assumption for written productions needs to be considered seriously. Indeed, first written responses are even slower than spoken ones, and it might thus be the case that handwriting starts before the full orthographic encoding of the target. Second, unlike consonants which cannot be pronounced in isolation, letters can be written in isolation. We are not claiming that complex relations do not exist between letters in written productions, but that individual segments are more easily produced in isolation in written than in spoken productions. In fact, there is some evidence that linguistic processes are involved during the actual handwriting movements (Orliaguet & Boë, 1993) as well as during typing movements (Gentner, Larochelle, & Grudin, 1988). For example, Orliguet and Boë (1993) showed that applying grammatical rules in order to resolve spelling uncertainties had an effect on writing execution. Hence, it seems plausible that participants initiate writing as soon as a stable pattern of activation over word-initial orthographic units is attained. This hypothesis leads to the prediction that written latencies should be affected when words are initially inconsistent because it takes longer to reach stability over orthographic units for initially inconsistent words than for consistent words.

A different hypothesis is that the sublexical PO conversion procedure underlying written production proceeds sequentially. Following Jared and Seidenberg's (1990) finding, it has been observed that, in printed word naming, early orthography-to-phonology inconsistencies are more damaging to reading performance than late inconsistencies (Coltheart & Rastle, 1994; Content, 1991; Content & Peereman, 1992; Cortese, 1998; Rastle & Coltheart, 1999). These results have been accounted for by assuming that grapheme-to-phoneme correspondence rules are applied sequentially, from left to right (but see, for example, Ans, Carbonnel, & Valdois, 1998; Plaut, McClelland, Seidenberg, & Patterson, 1996, for alternative interpretations). The variation of the consistency effect as a function of the serial position of the inconsistent unit was attributed to the fact that, as time proceeds, the phonological code of the word has a better chance of being lexically addressed so that it can drive naming. Similarly, in written production, the sublexical conversion of phonological to orthographic units might operate sequentially. As a result, only initial phonological units would have time to be converted into orthographic codes before response production, and consistency would affect written production only in the case of initial inconsistent units. Indeed, in such a case a conflict arises because the sublexical process and the "semantic–lexical" procedure lead to the activation of incongruent orthographic codes. For example, for the target *phoque* (/fɔk/), the semantic–lexical procedure will support the correct *ph* grapheme, whereas the *f* grapheme will be activated through sublexical conversion since it corresponds to the most frequent orthographic rendering of /*f*/. As this conflict must be resolved before writing begins, written latencies should be longer for initially inconsistent targets than for consistent ones. In the case of word-final inconsistencies, as the semantic constraints develop over time, the correct orthographic pattern of activation will be settled before completion of the sublexical conversion procedure. Consequently, the response will occur before sublexical conversion of the final inconsistent units.

In Experiment 3, the picture names were either mostly inconsistent on their initial part (initial consonant or vowel) or mostly inconsistent on their middle or final part (vowel or vowel-consonant units). Each type of inconsistent item was compared to sets of consistent items (referred to as control items in the following). If handwriting movements can start as soon as the first part of the target is available for output, written latencies should be longer for initially inconsistent items than for control items. The same prediction holds if the PO conversion procedure operates sequentially. Conversely, both hypotheses predict that consistency should not affect written latencies for middle or final inconsistent items (as found in Experiment 2).

Method

Participants. Thirty-six psychology undergraduate students from the same pool as in the previous experiments were involved. None of them participated in the previous experiments.

Stimuli. Ninety-two line drawings were used. Twenty-three picture names were inconsistent on their initial part (on the onset, the onset+vowel, or the initial vowel units, see Table 4 for the detailed characteristics of the stimuli). They were matched as closely as possible with twenty-three control items on the initial letter or letter stroke, number of letters, number of phonemes, number of syllables, log frequency, and bigram frequency.

Twenty-three picture names inconsistent on their middle or final part, but not on their initial part, were matched as closely as possible with an additional set of 23 consistent picture names for initial letter or letter stroke, number of letters, number of syllables, log frequency, and bigram frequency. However, these two sets of items differed significantly on the number of phonemes. The average picture name characteristics appear in Table 4. Eight pictures not used as stimuli served as warm-ups.

The pictures were taken from the same pool as Experiment 1. The picture names are listed in Appendix 3.

Apparatus and procedure. These were identical to Experiment 1.

Results

As in the previous experiments, data above 2.5 standard deviations from the participant and item means were discarded from the latency

TABLE 4

Characteristics of the Picture Names Used in Experiment 3

	Initial inconsistencies			Final inconsistencies		
	Inconsistent	Control	*p* Values (*t* tests)	Inconsistent	Control	*p* Values (*t* tests)
Number of letters	5.22	5.26	*ns*	4.96	5.22	*ns*
Number of phonemes	3.74	4.26	*ns*	3.17	3.87	<.01
Number of syllables	1.39	1.39	*ns*	1.04	1.04	*ns*
Log frequency[a]	2.87	2.98	*ns*	3.12	3.00	*ns*
Bigram frequency[b]	1107.39	994.39	*ns*	1046.60	1092.90	*ns*
Onset (C1)	0.17	0.94	<.01	0.98	0.97	*ns*
consistency[c]	(0.23)	(0.88)	(<.01)	(0.99)	(0.97)	(*ns*)
Vowel (V)	0.59	0.91	<.01	0.46	0.92	<.01
consistency[c]	(0.61)	(0.96)	(<.01)	(0.44)	(0.98)	(<.01)
Coda (C2)	0.65	0.83	0.09	0.53	0.86	<.01
consistency[c]	(0.64)	(0.92)	(<.05)	(0.52)	(0.90)	(<.01)
C1V consistency[c]	0.26 (0.26)	0.82 (0.82)	<.01 (<.01)	0.57 (0.56)	0.89 (0.91)	<.01 (<.01)
VC2 consistency[c]	0.39 (0.33)	0.83 (0.93)	<.01 (<.01)	0.27 (0.22)	0.92 (0.98)	<.01 (<.01)

[a]Log word frequency per 100 million from Imbs (1971).
[b]From Content and Radeau (1988).
[c]Values by type (by token in parentheses) as given by LEXOP (Peereman & Content, 1999).

analyses (1.17% of the data). Two items ("*puits*" and "*luth*") were also discarded from the latency analyses due to a high error rate. Overall, 9.24% of the data were excluded from the latency analyses. For the error analyses, the criteria defined in the previous experiments were applied.

The ANOVAs were performed with Word Type (inconsistent vs consistent) and Position (initial vs final) as factors. Mean latencies and error rates are presented in Table 5.

For the latency data, the main effect of Position was significant by both participants and items, $F_1(1, 35) = 22.67$, $MSE = 6146.47$, $p < .001$; $F_2(1, 86) = 10.07$, $MSE = 7608.46$, $p < .01$. The main effect of Word Type was significant by participants, $F_1(1, 35) = 25.52$, $MSE = 2002.61$, $p < .001$, and marginally significant by items, $F_2(1, 86) = 3.28$, $MSE = 7608.46$, $p = .073$. Also, the interaction between Position and Word Type was significant by participants, $F_1(1, 35) = 15.21$, $MSE = 3519.917$, $p < .001$, and marginally significant by items, $F_2(1, 86) = 3.24$, $MSE = 7608.46$, $p = .075$. More importantly, planned comparisons revealed that the consistency effect (+76 ms) was significant for both participants and items for initial items, $F_1(1, 35) = 30.45$, $MSE = 3436.60$, $p < .001$; $F_2(1, 86) = 6.68$, $MSE = 7608.46$, $p < .05$, and virtually absent (−1 ms) for final items, both $F < 1$.

For errors, the main effect of Position was significant by participants only, $F_1(1, 35) = 6.95$, $MSE = .0017160$, $p < .05$; $F_2(1, 86) = 1.11$, $MSE = .0066731$, $p = .29$. The main effect of Word Type was significant by both participants and items, $F_1(1, 35) = 35.72$, $MSE =$

TABLE 5

Mean Latencies (in Milliseconds) and Percentages of Errors as a Function of Consistency and Position of the Inconsistency (Experiment 3)

Initial position		Final position	
Inconsistent	Consistent	Inconsistent	Consistent
1229.4 (12.9)	1153.1 (4.3)	1128.6 (9.5)	1129.5 (4.1)

.0049334, $p < .001$; $F_2(1, 86) = 16.48$, MSE = .0066731, $p < 001$. The interaction between Position and Word Type was significant by participants, $F_1(1, 35) = 4.29$, MSE = .0020885, $p < .05$, but not significant by items, $F_2 < 1$. Planned comparisons indicated that the consistency effect was significant by both participants and items for initial items, $F_1(1, 35) = 38$, MSE = .0034829, $p < .001$; $F_2(1, 86) = 12.67$, MSE = .0066731, $p < .001$, as well as for final items, $F_1(1, 35) = 14.93$, MSE = .0035390, $p < .001$; $F_2(1, 86) = 4.83$, MSE = .0066731, $p < .05$.

Untimed written picture naming task. The main effect of Position was significant by participants, $F_1(1, 29) = 5.80$, MSE = .0010864, $p < .05$, but not by items, $F_2 < 1$. The main effect of Word Type was significant by both participants and items, $F_1(1, 29) = 63.34$, MSE = .0030094, $p < .001$; $F_2(1, 88) = 11.45$, MSE = .0127580, $p < .01$. The interaction between Position and Word Type was significant by participants, $F_1(1, 29) = 6.59$, MSE = .0009560, $p < .05$, but not by items, $F_2 < 1$. Planned comparisons indicated that errors were more numerous for initial inconsistent items (6.81%) than for consistent controls (0.28%), $F_1(1, 29) = 28.16$, MSE = .0022652, $p < .001$; $F_2(1, 88) = 3.84$, MSE = .0127580, $p < .05$, and also more numerous for middle or final inconsistent items (9.71%) than for consistent controls (0.28%), $F_1(1, 29) = 78.29$, MSE = .0017002, $p < .001$; $F_2(1, 88) = 7.99$, MSE = .0127580, $p < .01$. As in the previous experiments, the consistency effect on spelling and homophone substitution errors failed to reach significance when the error data from the control task were introduced as covariates. Finally, for confidence scores, only the main effect of Word Type was significant, $F_1(1, 29) = 16.17$, MSE = .0305179, $p < .001$; $F_2(1, 88) = 10.13$, MSE = .0373452, $p < .01$. Planned comparisons indicated that initial inconsistent words were given a slightly lower confidence score (4.84) than their consistent controls (4.94), but the difference was only marginally significant by both participants and items, $F_1(1, 29) = 3.70$, MSE = .0382428, p = .064; $F_2(1, 88) = 2.90$, MSE = .0373452, p = .091. The spelling confidence score for middle or final inconsistent items (4.82) was significantly lower than for the consistent controls (4.98), $F_1(1, 29) = 41.38$, MSE = .0092128, $p < .001$; $F_2(1, 88) = 7.83$, MSE = .0373452, $p < .01$.

Discussion

Experiment 3 showed that initial inconsistency, but not middle or final inconsistency, of picture names had a detrimental effect on written latencies. The observation of a consistency effect suggests that orthographic encoding is influenced by phonology. Additionally, the results suggest that the PO sublexical conversion process works serially from left to right or that writing starts before the full orthographic encoding of the target, therefore allowing final inconsistencies to be resolved during handwriting. Before providing a more detailed account of these findings (see General Discussion), we investigate, in Experiments 4 and 5, why middle or final inconsistencies did not affect written picture naming latencies.

EXPERIMENT 4. WRITING CONSISTENT AND INCONSISTENT WORDS FROM AUDITORY PRESENTATIONS

One striking aspect of Experiments 2 and 3 was that middle or final sublexical consistency (i.e., consistency defined at the level of V or VC units) did not influence the time taken to initiate writing. This result contrasts with the well-documented finding that the characteristics of body–rime correspondences influence the speeded naming of printed letter strings (e.g., Glushko, 1979; Jared, McRae, & Seidenberg, 1990; Peereman & Content, 1997) as well as with the observation that rime–body consistency affects written spelling-to-dictation (Peereman, Content, & Bonin, 1998). In Experiment 3, we proposed that final inconsistencies do not affect written latencies either because the initiation of written production occurs as soon as the beginning of the word has been orthographically encoded or because the PO sublexical conversion procedure works sequentially. The purpose of Experiment 4 was to disentangle these two interpretations by exploring whether final consistency effects can be found in a spelling-to-dictation task.

According to the dual-route theory of spelling to dictation (Kreiner, 1992; Kreiner & Gough, 1990; Margolin, 1984; Véronis, 1988, see Barry, 1994 for a synthesis), skilled spellers have two routes at their disposal: A lexical route, which retrieves the spellings of known words from an orthographic lexicon, and a nonlexical, route (or assembly route), which builds the spellings of words through a sublexical sound-to-spelling conversion process (Barry, 1994). In Kreiner's (1996) parallel-interactive model, both routes are involved in parallel to compute a spelling pattern but they differ in their processing time course. The route that wins the race can trigger the spelling response. For high-frequency words, the lexical route usually provides the correct spelling before the nonlexical route has finished its computation. For low-frequency words, however, since the lexical route for such words is slower than for high-frequency words, both routes overlap in time and thus deliver competing responses when the word carries sublexical inconsistencies. Since the resolution of the competition takes time, low-frequency inconsistent words are expected to yield longer response latencies than consistent words.

Two different predictions can be put forward regarding the effect of final inconsistent units on spelling-to-dictation latencies. Suppose that the writing act is initiated before the complete encoding of the word-end. In such a case, one would predict that, as observed in written picture naming, only initial inconsistencies should impair responses. Indeed, according to this hypothesis, the main determinant of writing onset latencies is the time required for the orthographic encoding of the first letters. The null effect of final inconsistencies on written latencies in written picture naming should therefore be replicated in spelling to dictation. Alternatively, the hypothesis of a sequential PO conversion procedure leads one to predict a greater positional effect in written picture naming than in spelling to dictation because of the stronger involvement of semantic constraints in written picture naming than in spelling to dictation. In written picture naming, because semantics quickly plays a dominant role and drives orthographic encoding, the influence of PO conversion would be confined to the beginning of the words. In spelling to dication, the less important influence of semantic constraints (and the early involvement of phonology) would give the PO conversion procedure a greater chance to act on most parts of the word. Hence, supposing that the PO conversion procedure proceeds sequentially, semantic and lexical constraints are more likely to cause the activation of the correct orthographic codes before completion of the PO procedure in written picture naming than in spelling to dictation. As a result, the consistency effect which was absent in written picture naming for middle or final inconsistencies should appear in spelling to dictation.

In Experiment 4, participants had to write the spellings of auditorily presented words which differed in the consistency of the vowel or the rime units. Word frequency was also manipulated. Half of the participants had to write the spellings of words as quickly as possible immediately after their auditory presentation (immediate writing task) and the remaining half were asked to delay overt writing until a response signal occurred several hundred milliseconds after word presentation (delayed writing task). The delayed writing task was included to assess potential differences resulting from the triggering of the contact pen when initial letters are not matched across stimulus sets. This was particularly important in Experiment 4 because, unlike Experiment 3, it was not possible to match the stimulus categories for the initial letters.

Method

Participants. Sixty psychology students taken from the same pool as in the previous experiments participated in Experiment 4. They had no known hearing deficit. Thirty students took part in the immediate writing task and 30 in the delayed writing task. None of them had participated in the previous experiments.

Material. The target words consisted of 20 high-frequency consistent words, 20 high-frequency inconsistent words, 20 low-frequency consistent words, and 20 low-frequency inconsistent words. The word stimuli were selected from the LEXOP lexical database (Peereman & Content, 1999).

Most of the inconsistencies were carried by the vowel (V) or the rime unit (VC). The mean phono-orthographic consistency of C1, V, C2, C1V, and VC2 appears in Table 6 together with the mean log frequency, number of phonemes, number of letters, number of phonological neighbors, and log bigram frequency. For each frequency level, the consistent and inconsistent words were matched for the number of letters. The target words were recorded by a female speaker and digitized using 16-bit analog-to-digital conversion at a sampling rate of 44.1 with the SoundEdit software on a Macintosh computer. Auditory length durations, position of the uniqueness point (Marslen-Wilson & Welsh, 1978), and auditory length durations at the uniqueness point also appear in Table 6. The stimulus words are provided in Appendix 4.

Apparatus. The same apparatus as in the previous experiments was used.

Procedure. The participants were tested individually. The experimental session started with 20 practice trials. In the immediate writing task, each trial began with a visual ready signal (*) presented for 1000 ms at the center of a computer screen. It was followed, 200 ms later, by the auditory stimulus word presented through headphones. The intertrial interval was 5 s. The participants were required to write the stimulus as fast as possible on the graphic tablet using a contact pen. They were told to write a cross when the stimulus was not identified. After responding, participants were instructed to concentrate on the center of the screen. The time elapsing between the onset of the auditory word and the contact of the pen with the graphic tablet was recorded by the computer. In the delayed writing task, the main change in procedure was that participants had to wait for a response cue (a "?????" signal) before writing the word. The target word was presented auditorily and followed by an empty screen for a random delay interval of 1200, 1300, 1400, or 1500 ms. The cue was then presented and the time until the onset of the participant's response was measured. After completion of the experimental session, the participants completed a subjective frequency rating task. They were given booklets including all the stimulus words. Six squares were printed in front of each word. The first square was labeled "unknown" and the last one "very frequent." The participants were asked to rate each word for its frequency in *spoken* language by putting a cross in the square corresponding to their choice. Ratings were converted to numerical values ranging from 1 (*unknown*) to 6 (*very frequent*).

Results

Written latencies longer than 2.5 standard deviations above participant and item means were excluded from the analyses (0.37% of the data in both the immediate and delayed writing tasks), as were words unknown to the participants (1.41 and 5.5% in the immediate and delayed writing task respectively). Over both tasks, seven items were discarded [*flair* (*scent*), *rouge* (*red*), *rêve* (*dream*), *rich* (*rich*), *rôle* (*role*), *kyste* (*cyst*), and *suaire* (*shroud*)], because they produced error rates higher than 50%.[5] In the delayed writing task, anticipatory responses (2.1%) were also excluded. Overall, 11.83% and 13.29% of the data in the immediate and delayed writing task respectively were excluded from the latency analyses. Mean written latencies and error rates are presented in Table 7. Analyses were performed on written latencies and on errors with Task, Frequency, and Consistency as factors.

For latencies, the Frequency effect was significant, $F_1(1, 58) = 28.67$, $MSE = 2655.9$, $p < .001$; $F_2(1, 69) = 8.21$, $MSE = 5743.75$, $p < .01$, as was the effect of Consistency, $F_1(1, 58) = 50.95$, $MSE = 2742$, $p < .001$; $F_2(1, 69) = 15.07$, $MSE = 5743.75$, $p < .001$. The effect of Task was also significant, $F_1(1, 58) = 48.41$, $MSE = 141875$, $p < .001$; $F_2(1, 69) = 961.08$, $MSE = 4475.97$, $p < .001$. More importantly,

[5] Four items (*riche*, *rouge*, *rêve*, and *rôle*) seem to have been misheard by most of the participants, a problem that is not unusual in auditory experiments (e.g., Hamburger & Slowiaczek, 1996). The remaining three items were excluded because they were very frequently misspelled and too few correct responses remained.

TABLE 6

Characteristics of the Word Stimuli Used in Experiment 4

	Low-frequency words			High-frequency words		
	Inc	Con	*p* Values (*t* tests)	Inc	Con	*p* Values (*t* tests)
Log word frequency[a]	2.5	2.7	*ns*	4.3	4.1	*ns*
Number of phonemes	3.65	3.65	*ns*	3.70	3.55	*ns*
AL duration (ms)	782.5	783.7	*ns*	783.4	782.8	*ns*
Position of UP (number of phonemes)	4.2	4.2	*ns*	4.3	4.5	*ns*
AL duration at the UP (ms)	686.75	694.50	*ns*	699.55	774	*ns*
Number of letters	5.0	5.0	*ns*	5.0	5.0	*ns*
Number of phonological neighbors	8.65	7.50	*ns*	8.85	11.40	*ns*
Log bigram frequency[b]	2.9	2.7	*ns*	3.0	3.0	*ns*
Onset (C1) consistency[c]	0.84	0.97	*ns*	0.96	0.98	*ns*
	(0.82)	(1.0)	(=.05)	(0.92)	(1.0)	(*ns*)
Vowel (V) consistency[c]	0.40	0.92	<.01	0.21	0.92	<.01
	(0.39)	(0.98)	(<.01)	(0.22)	(0.98)	(<.01)
Coda (C2) consistency[c]	0.43	0.88	<.01	0.55	0.84	<.01
	(0.41)	(0.97)	(<.01)	(0.57)	(0.92)	(<.01)
C1V consistency[c]	0.62	0.87	<.01	0.41	0.91	<.01
	(0.65)	(0.89)	(<.05)	(0.64)	(0.96)	(<.01)
VC2 consistency[c]	0.23	0.97	<.01	0.21	0.94	<.01
	(0.21)	(1.0)	(<.01)	(0.47)	(0.96)	(<.01)

Note. Con = consistent; Inc = inconsistent; UP = uniqueness point; AL = auditory length.
[a]Log word frequency per 100 million from Imbs (1971).
[b]From Content and Radeau (1988).
[c]Values by type (by token in parentheses) as given by LEXOP (Peereman & Content, 1999).

both the Frequency X Task and the Consistency X Task interactions were reliable, $F_1(1, 58) = 11.60$, $MSE = 2655.9$, $p < .01$; $F_2(1, 69) = 5.72$, $MSE = 4475.97$, $p < .05$, and $F_1(1, 58) = 16.81$, $p < .001$, $MSE = 2742$, $p < .0$; $F_2(1, 69) = 6.67$, $MSE = 4475.97$, $p < .05$, respectively. These interactions indicated that both the consistency effect and the frequency effect were stronger in the immediate than in the delayed writing task. Planned comparisons indicated that the frequency effect was significant in immediate, $F_1(1, 58) = 38.36$, $MSE = 2655.90$, $p < .001$; $F_2(1, 69) = 8.14$, $MSE = 8734.39$, $p < .01$, but not in delayed writing, $F_1(1, 58) = 1.90$, $MSE = 2655.88$, $p = .17$; $F_2(1, 69) = 1.10$, $MSE = 1485.32$, $p = .30$. The consistency effect was significant in both the immediate, $F_1(1, 58) = 63.14$, $MSE = 2742$, $p < .001$; $F_2(1, 69) = 12.48$, $MSE = 8734.40$, $p < .001$, and delayed writing, $F_1(1, 58) = 4.61$, $MSE = 2742$, $p < .05$; $F_2(1, 69) = 4.96$, $MSE = 1485.32$, $p < .05$. A post hoc analysis was therefore performed to de-

TABLE 7

Mean Latencies (in Milliseconds) and Percentages of Errors as a Function of Frequency and Consistency (Experiment 4)

	High-frequency words		Low-frequency words	
	Inconsistent	Consistent	Inconsistent	Consistent
Immediate spelling	1055.6 (2.0)	993.3 (0.9)	1125.6 (10.9)	1037.9 (0.5)
Delayed spelling	714.7 (3.3)	697.3 (2.6)	730.8 (11.8)	707.1 (3.5)

termine whether the consistency effect was still significant in immediate writing when the delayed written latencies were entered as covariates. This analysis revealed that the main effects of consistency and of frequency were still significant, as were the consistency effects for high- and low-frequency words.

The analyses on the error data indicated reliable effects of Frequency, $F_1(1, 58) = 40.32$, $MSE = .0024080$, $p < .001$; $F_2(1, 76) = 9.87$, $MSE = .0177898$, $p < .01$, and Consistency, $F_1(1, 58) = 51.64$, $MSE = .0025755$, $p < .001$; $F_2(1, 76) = 11.68$, $MSE = .0177898$, $p < .001$. Due to numerous response anticipations, errors were more numerous in delayed than in immediate writing, $F_1(1,58) = 7.01$, $MSE = .0038748$, $p < .05$; $F_2(1, 76) = 17.29$, $MSE = .0012153$, $p < .001$. Only the Frequency X Consistency interaction effect was significant, $F_1(1, 58) = 27.84$, $MSE = .0030832$, $p < .001$; $F_2(1, 76) = 9.62$, $MSE = .0177898$, $p < .01$. Planned comparisons indicated that for high-frequency words, the consistency effect was not significant, $F_s < 1$, whereas it was significant for low-frequency words, $F_1(1, 58) = 47.14$, $MSE = .0045873$, $p < .001$; $F_2(1, 76) = 21.26$, $MSE = .0177898$, $p < .001$. For spelling errors, the same pattern of results was found except that the main effect of Task was not significant, $F_s < 1$.

Subjective frequency ratings. Mean subjective frequency ratings were as follows: 5.06 and 5.15 for high-frequency consistent and inconsistent words respectively and 3.72 and 3.63 for low-frequency consistent and inconsistent words respectively. The only effect of note was that Frequency had a reliable effect on ratings, $F_1(1, 59) = 524.34$, $MSE = .2348157$, $p < .001$; $F_2(1, 76) = 114.75$, $MSE = .3576626$, $p < .001$. An additional analysis indicated a reliable correlation of .79 between log objective frequency and subjective frequency ratings. Thus, word classification on the basis of subjective frequency ratings for spoken language was in agreement with word classification based on objective frequency in printed material.

Discussion

The data gathered in the immediate writing task are straightforward. Both consistency and word frequency influenced written latencies but these two factors did not interact. For the error data, frequency and consistency effects were observed, as was an interaction between the two factors. In the delayed writing task, consistency effects were observed for written latencies but additional analyses showed that they were reduced compared to the immediate writing task. For errors, the same pattern of results as was found for immediate writing was observed.

The consistency effect observed in latencies in delayed writing might result either from differences in contact pen triggering (different initial letters) between consistent and inconsistent items, or from differences in the ease of generating the graphic motor program. Although this result suggests that part of the consistency effect observed in immediate writing might have a similar source, consistency had a stronger effect in immediate than in delayed writing. Hence, it is likely that the effect observed in immediate writing reflects additional difficulties resulting from the inconsistency of the mapping between phonological and orthographic units.[6] This finding thus replicates the previous observation that writing latencies for words which mainly include final inconsistencies are longer than for consistent words in spelling to dictation (Peereman et al., 1998).

In contrast to the written latencies, the pattern of errors was analogous in immediate and delayed writing. Moreover, the number of spelling errors was almost identical in immediate ($N = 46$) and in delayed spelling ($N = 45$). Also, in both tasks, most of the errors were phonologically based (92% in both tasks). The similar error patterns in the two tasks suggests that most of the errors in the immediate writing task were not due to incorrect sublexical mappings between phonological and orthographic units. Indeed, in such a case, a smaller consistency effect would have been expected in delayed writing because the delay between the stimulus word and the “go” signal should, on average, have permitted the establishment

[6] The delayed writing task could be influenced by consistency if one supposes that, on some occasions, the response was not fully prepared before the “go” signal appeared.

of more correct orthographic representations. Alternatively, the similarity of the error data in both tasks is compatible with our previous assumption that errors essentially result from inaccurate spelling knowledge for low-frequency inconsistent words.

The finding that final inconsistencies affect immediate written latencies in spelling to dictation but not in written picture naming appears difficult to reconcile with the claim that writing starts before the orthographic encoding of the word-end. In contrast, this observation seems in agreement with the hypothesis that phono-orthographic conversion is a sequential procedure. The crucial difference between the two tasks is that semantic constraints are more likely to quickly dominate phonological constraints in the activation of orthographic codes from pictures than in the case of spoken words, therefore making it less likely that sublexical conversion will process sequentially up until the end of the word.

Given the assumption of differential processing time- courses for the lexical and the sublexical processes in spelling to dictation, larger consistency effects were anticipated for low- frequency words than for high-frequency ones. However, the finding that high- and low-frequency words were similarly affected by sublexical consistency parallels recent findings reported by Jared (1997) on printed word naming. Jared (1997) showed that consistency effects emerge for high-frequency words when their lexical neighborhood characteristics matched those of low-frequency words. When the number of frequent words, including the same body–rime correspondence as the target (friendly neighbors), and the number of frequent words, including the same body but with a different pronunciation (enemies), were appropriately matched across the two word frequency categories, similar consistency effects were observed. We therefore further examined the neighborhood characteristics of the stimulus words to assess whether differences existed between high- and low-frequency words in terms of the number of friends and enemies. Unlike in Jared's (1997) study, computations were performed on the phonological-to-orthographic correspondences. Both high- and low-frequency inconsistent words had a small number of friends (4 and 4 respectively) and a large number of enemies (16 and 15 respectively). The summed frequency of friends was 433 (per million) and 234 for high- and low-frequency inconsistent words respectively, and the summed frequency of enemies was 557 and 488 for high- and low-frequency inconsistent words respectively (as in Jared, neighbors with frequencies greater than 1000 were truncated to 1000). Thus, the similarity of neighborhood characteristics, essentially for frequency of enemies, between high- and low-frequency inconsistent words might account for the finding of robust consistency effects for both high- and low-frequency words in the spelling-to-dictation task. However, further studies are needed to investigate the relationship between neighborhood characteristics and spelling-to-dictation performance in greater details.

EXPERIMENT 5: A FURTHER LOOK AT THE FINAL CONSISTENCY EFFECT IN SPELLING TO DICTATION

Even though Experiment 4 replicated the finding that final inconsistencies impair written performance in spelling to dictation (Peereman et al., 1998), the comparison with the null consistency effect on written picture naming latencies (Experiment 3) is weakened by the fact that different items were used in Experiments 3 and 4. Therefore, in Experiment 5, we aimed at replicating the final consistency effect in spelling to dictation using items from Experiment 3. In addition, using items from Experiment 3 allowed us to test whether initial inconsistencies also affect spelling to dictation. Such an effect is expected given that phonology is assumed to play a dominant role right from the early stages of processing. However, whether the expected consistency effect for middle or final inconsistencies in spelling to dictation, is similar in size to the consistency effect for initial inconsistencies is a question that cannot be answered a *priori*. Indeed, different predictions can be made as a function of the supposed time course of the PO conversion procedure and of the semantic or lexical influence on orthographic encoding. Similar size effects are expected if semantic or lexical constraints do not occur early enough relative to the PO conversion procedure, but a smaller consistency effect for middle or final inconsistencies can be predicted if semantic or lexical information influences orthographic encoding before completion of the PO conversion procedure. Our main prediction, however, is that irrespective of whether the consistency effect differs in size across positions, inconsistencies of middle or final units should be more detrimental in spelling to dictation than in written picture naming.

Method

Participants. Thirty psychology students from the same pool as in the previous experiments were involved in Experiment 5. None of them had participated in the previous experiments.

Material. Four categories of words were used in Experiment 5: Initial Inconsistent items (II), Initial Control items (IC), Final Inconsistent items (FI), and Final Control items (FC). The stimulus words corresponded to the labels of the pictures used in Experiment 3, except that eight homophonic words were replaced by nonhomophonic words (these eight nonhomophonic words are presented in brackets in Appendix 3). This change was necessary because homophonic words would have induced spelling uncertainties when presented auditorily. Furthermore, 12 items used in Experiment 3 were replaced to ensure that the sets of stimuli were matched for the same variables as those described for Experiment 4 (these items are marked with an "*" in Appendix 3). The percentage of items common to both experiments was 78%. As in Experiment 3, II and FI items were matched as closely as possible with consistent items (IC and FC respectively) on the initial letter or letter stroke. Given this matching, a delayed spelling task was not included. The average word characteristics are presented in Table 8.

Apparatus and procedure. These were identical to those used in Experiment 4.

Results

As in the previous experiments, data above 2.5 standard deviations from the participant and item means were discarded from the latency analyses (0.54% of the data). Application of the criteria defined in Experiment 4 led to the exclusion of 6.58% of the data from the latency analyses. For the error analyses, the criteria defined in the previous experiments were applied. In contrast to the previous experiments, no item was excluded from the analyses. Mean latencies and error rates are presented in Table 9.

ANOVAs were performed with Word Type (inconsistent vs consistent) and Position (initial vs final) as factors. For the latency data, the effect of Word Type was significant, $F_1(1, 29) = 120.34$, $MSE = 2558.60$, $p < .001$; $F_2(1, 76) = 19.53$, $MSE = 10661.14$, $p < .001$. The effect of Position was not significant, $F_1(1, 29) = 1.75$, $MSE = 2795.15$, $p = .19$; $F_2 < 1$. The interaction between Position and Word Type was also not significant, both F_1 and $F_2 < 1$. As Table 9 shows, the consistency effect for initial words (+102 ms) was nearly identical to that for final words (+100 ms). Planned comparisons indicated that the Word type effect was significant for initial items, $F_1(1, 29) = 60.26$, $MSE = 2609$, $p < .001$; $F_2(1, 76) = 10.04$, $MSE = 10661.10$, $p < .01$, as well as for final items, $F_1(1, 29) = 61.92$, $MSE = 2433.8$, $p < .001$; $F_2(1, 76) = 9.49$, $MSE = 10661.10$, $p < .01$.

As far as errors are concerned, the effect of Word Type was reliable, $F_1(1, 29) = 33.65$, $MSE = .0059454$, $p < .001$; $F_2(1, 76) = 11.60$, $MSE = .0114956$, $p < .01$. The effect of Position, F_1 and $F_2 < 1$, and the interaction between Word Type and Position were not significant, $F_1(1, 29) = 1.17$, $MSE = .0025690$, $p = .29$; $F_2 < 1$. Planned comparisons indicated that the Word type effect was significant for initial items, $F_1(1, 29) = 29.19$, $MSE = .0043175$, $p < .001$; $F_2(1, 76) = 7.31$, $MSE = .0114956$, $p < .01$, as well as for final items, $F_1(1, 29) = 18.36$, $MSE = .0041968$, $p < .001$; $F_2(1, 76) = 4.47$, $MSE = .0114956$, $p < .05$. In the case of spelling errors, the effect of Position and the interaction between the two factors were significant in the participant analysis only. Word type had a reliable effect in both analyses. Planned comparisons revealed that the consistency effect was significant by participants but marginally significant by items.

TABLE 8

Characteristics of the Word Stimuli Used in Experiment 5

	Initial inconsistencies			Final inconsistencies		
	Inconsistent	Control	*p* Values (*t* tests)	Inconsistent	Control	*p* Values (*t* tests)
Word frequency[a]	2.93	2.94	*ns*	3.05	3.06	*ns*
Number of phonemes	4.10	4.05	*ns*	3.25	3.70	*ns*
AL duration (ms)	697.8	696.6	*ns*	698.2	697.1	*ns*
Position of UP (number of phonemes)	3.90	4.55	*ns*	4.00	4.40	=.065
Number of letters	5.35	5.05	*ns*	4.95	5.15	*ns*
Number of phonological neighbors	4.95	6.40	*ns*	9.20	8.25	*ns*
Bigram frequency[b]	951.21	1216.10	*ns*	837.31	921.45	*ns*
Onset (C1) consistency[c]	0.18	0.94	<.01	0.99	0.97	*ns*
	(0.28)	(0.87)	(<.01)	(0.99)	(0.97)	(*ns*)
Vowel (V) consistency[c]	0.63	0.91	<.01	0.43	0.93	<.01
	(0.66)	(0.97)	(<.01)	(0.41)	(0.99)	(<.01)
Coda (C2) consistency[c]	0.79	0.81	*ns*	0.57	0.84	<.01
	(0.80)	(0.91)	(*ns*)	(0.61)	(0.89)	(<.05)
C1V consistency[c]	0.28	0.82	<.01	0.59	0.91	<.01
	(0.29)	(0.84)	(<.01)	(0.57)	(0.90)	(<.01)
VC2 consistency[c]	0.64	0.84	<.10	0.34	0.91	<.01
	(0.62)	(0.93)	(<.05)	(0.29)	(0.98)	(<.01)

Note. UP = uniqueness point; AL = auditory length.
[a]Log word frequency per 100 million from Imbs (1971).
[b]From Content and Radeau (1988).
[c]Values by type (by token in parentheses) as given by LEXOP (Peereman & Content, 1999).

Discussion

The data replicated the previous observation (Experiment 4; Peereman et al., 1998) that written latencies were longer when the stimulus words included a final inconsistent unit. Moreover, this effect was obtained using most of the stimulus words that produced no effect in written picture naming (Experiment 3). The hypothesis that, in general, the spelling-to-dictation task magnifies the consistency effect can be rejected since effects of similar magnitude for initial inconsistencies were observed in spelling to dictation and written picture naming. A post hoc analysis carried out on the latencies for the set of items used in both Experiments 3 and 5 confirmed that the initial consistency effect did not significantly differ between the two tasks (112 and 88 ms in spelling to dictation and written picture naming respectively), whereas final inconsistencies influenced latencies in spelling to dictation (+88 ms) but not in written picture naming (+7 ms).

The observation that final inconsistencies have an effect on written latencies in spelling to

TABLE 9

Mean Latencies (in Milliseconds) and Percentages of Errors as a Function of Consistency and Position of the Inconsistency (Experiment 5)

Initial position		Final position	
Inconsistent	Consistent	Inconsistent	Consistent
1280.4 (11.8)	1178.1 (2.7)	1266.6 (9.8)	1166.3 (2.7)

dictation does not support the assumption that writing begins as soon as the initial letter has been encoded. To account for the influence of initial but not final inconsistencies in written picture naming (Experiment 3), we proposed that semantic influence on orthographic encoding quickly develops when writing words from pictures, therefore allowing final inconsistencies to be resolved before production. We predicted that, because semantics should be less involved in spelling to dictation than in written picture naming, final inconsistencies could affect written latencies in spelling to dictation. This prediction was confirmed by the data. The additional finding of no greater latency cost for initial than for final inconsistencies in spelling to dictation contrasts with the documented finding of a position of inconsistency effect in reading aloud (Coltheart & Rastle, 1994; Rastle & Coltheart, 1999). However, as we noted in the introduction to Experiment 5, the observation of effects of similar magnitude for initial and final inconsistencies is not incompatible with the assumption of a sequential PO conversion procedure if the lexical or semantic influence on orthographic encoding is too slow to prevent sublexical conversion of the entire word. Consequently, for both initial and final inconsistencies, the correct spelling of the word will conflict with the output of the sublexical procedure. Although we acknowledge that the hypothesis of a parallel PO conversion procedure might also account for the results in spelling to dictation, this hypothesis seems more difficult to reconcile with the position effect observed in written picture naming. Whether position effects can be found in spelling to dictation is an issue which deserves further investigation. It is possible, for example, that our stimulus words were not long enough (in terms of the number of phoneme-to-grapheme correspondences) to give rise to a position effect or that the nature of the inconsistencies used in initial position and in middle or final position are not fully comparable. The most important finding from Experiment 5, however, is that the middle or final inconsistencies which did not impair written picture naming caused longer latencies in spelling to dictation.

Experiment 5 also showed a consistency effect on errors (though the effect was marginally significant in the item analysis when spelling errors only were considered). Moreover, contrary to written latencies, the error pattern did not vary as a function of task (for the set of items used in both Experiments 3 and 5 respectively, II: 9–8%; IC: 1.17–1.21%; FI: 5.33–5.42%; FC: 0.17–0.49%). As suggested for Experiment 3, the observation of a similar pattern of errors in the untimed written picture naming task suggests that most errors are "competence" errors (as opposed to "performance" errors) due to erroneous orthographic specifications of words in the participant's mental lexicon.

GENERAL DISCUSSION

A growing body of evidence from neuropsychological case studies and also from experiments with normal participants (Bonin, Fayol, & Gombert, 1997, 1998; Bonin et al., 1998) supports the hypothesis that written picture naming does not require obligatory phonological mediation. However, although the orthographic autonomy hypothesis states that orthographic codes can be directly accessed on the basis of semantic information, it does not preclude the possibility that phonology might constrain the selection of orthographic codes in written picture naming through lexical or sublexical connections between phonological and orthographic codes. The purpose of the present study was to determine whether phonology influences the selection of orthographic codes in speeded written picture naming.

The findings from our five experiments are straightforward. Experiment 1 examined whether consistency, defined at the lexical level, affected written picture naming performance. Homophonic picture names for which at least two orthographic lexical forms correspond to a single phonological form were compared with nonhomophonic control picture names. Homophonic picture names resulted in more errors than control names, but consistency did not affect written latencies. However, although word sets contrasted on lexical consistency, they were matched for sublexical consistency. Hence, in Experiment 2, we examined whether differences in latencies and errors emerged when consistency was defined at the level of subword units. Again, we found that both high- and low-frequency inconsistent words gave rise to more errors than consistent words, while no reliable effect was observed on written latencies. Because spelling inconsistencies were generally located at the word endings, the failure to observe a consistency effect on latencies might have resulted either from the sequential processing of the PO sublexical conversion or from the fact that it is possible to initiate writing as soon as the beginning of the word is orthographically specified. We therefore manipulated the position of the inconsistent unit in Experiment 3. The critical finding was that picture labels that were inconsistent in the initial unit gave rise to longer response latencies than matched consistent controls. Thus, evidence for phonological constraints in written picture naming was found, consistent with the primary goal of the present study.

Experiments 4 and 5 were designed to examine why consistency affected written picture naming latencies only in the case of initial inconsistent units. The data led us to reject the hypothesis that the absence of a consistency effect on latencies for word-final inconsistent items resulted from writing initiation before the orthographic encoding of the word-end. Indeed, unlike in the written picture naming task (Experiments 1–3), both initial and final inconsistencies affected written latencies when the targets were presented auditorily. The data were interpreted in terms of the differential involvement of semantic influence in the two tasks in the determination of orthographic activation and by assuming that sublexical mappings between phonological and orthographic units proceed sequentially.

A finding in all of the experiments was that the error data did not mirror the latency data. In Experiments 1 and 2, consistency effects on errors appeared in the absence of effects on latencies, and in Experiment 3, the position of the inconsistent unit affected latencies but not errors. Finally, in Experiment 4, the consistency effect on latencies was larger in immediate spelling than in delayed spelling, but the effect on errors did not differ across conditions. Interestingly, although consistency effects were observed for errors, the nature of the errors and the magnitude of the effects were similar to those observed in a control study consisting of an untimed written picture naming task. Thus, it is likely that the larger number of errors for inconsistent items in Experiments 1–3 resulted from incorrect orthographic representations in the lexicon and not from orthographic competition during processing.

Modeling Written Picture Naming

Within the theoretical framework outlined in the Introduction, and depicted in Fig. 1, the consistency effect on written latencies strongly suggests that activation at the grapheme level is constrained by phonology. It is assumed that graphemic encoding occurs as a result of direct activation of graphemes from semantics as well as through the PO sublexical conversion procedure (arrow B in Fig. 1). As soon as enough information is available at the grapheme level, it is transmitted for further processing dedicated to letter-shape encoding and peripheral motor processes. To account for the finding that consistency influences written latencies only in the case of initial inconsistencies, we suggest that phonology constrains grapheme activation through a sublexical conversion procedure working sequentially from left to right. Final inconsistencies do not affect written latencies because a full specification of orthographic codes is attained through activation from semantics before sublexical conversion of the word-end. Consequently, for inconsistent units, competition between lexical and sublexical codes occurs only when words are initially inconsistent. Hence, as in the oral reading of printed words (Coltheart & Rastle, 1994; Content, 1991; Content & Peereman, 1992; Cortese, 1998; Rastle & Coltheart, 1999), the position of the inconsistent unit within the word determines the consistency effect in writing words from pictures.

Such an account led us to predict that consistency effects for final units could emerge when the semantic influence on orthographic code activation arises too slowly to prevent the sublexical conversion of the whole word. As we suggested, the spelling-to-dictation task is less likely to be dominated by semantic constraints than the written picture naming task. On the one hand, the production of picture labels necessarily requires access to semantics since the relations between pictorial representations and words are entirely arbitrary. On the other hand, phonological information is involved from the very beginning in spelling to dictation. Hence, the relative contribution of semantic information and of the sublexical conversion procedure in orthographic encoding should differ in the two tasks (see Cutting & Ferreira, 1999 for a related discussion concerning spoken word production from pictures or auditorily presented words). Consequently, semantic information is more likely to quickly dominate orthographic code selection when the stimulus is a picture than when it corresponds to an auditorily presented word. In spelling to dictation, final inconsistencies were therefore expected to affect written latencies because the absence of strong semantic constraints allows the sublexical PO conversion of whole words. As discussed above, the observation that the size of the consistency effect did not vary as a function of the position of inconsistent units in spelling to dictation might seem intriguing in the light of the data reported for reading words aloud (Coltheart & Rastle, 1994; Rastle & Coltheart, 1999). However, as pointed out above, the lack of any significant modulation of the consistency effect as a function of the position of inconsistency might be ascribed to differences in the nature and the degree of the inconsistencies. Also, the relative contribution of lexical and sublexical processes might differ in naming printed words aloud and in writing spoken words. The sequential nature of speech might be particularly important since it allows the sublexical process to operate on each incoming phoneme and before selection of the word entry in the mental lexicon. If the sublexical procedure is more likely to process the whole word in spelling to dictation than in naming printed words aloud, then a greater level of conflict between lexical and sublexical information can be expected for word final inconsistent units. Although further work is necessary to understand these differences across tasks, this aspect of the data does not undermine our general claim that orthographic encoding from pictures is influenced by sublexical phonology delivered sequentially.

Although a full characterization of the PO sublexical process is beyond the scope of the present study, two main questions need to be addressed. The first issue concerns the nature of the sublexical units on which the sublexical conversion procedure operates. Although associations between phonemes and graphemes have often been considered as a valuable candidate, larger units such as phoneme groups or syllables have also been proposed (e.g., Tainturier, 1997). Recent observations, that in French, the spelling of the /*O*/ phoneme is contextually dependent might indicate sound-to-print associations on large units (Pacton et al., in press, 2001). However, it remains unclear whether the influence of context on spelling should be viewed as resulting from the use of contextually sensitive sublexical associations or as a consequence of the pooling of orthographic hypotheses derived from simple, noncontextual associations and word knowledge activated in the mental lexicon. For example, Rapp et al. (in press) have recently proposed that the sublexical and lexical processes integrate information at a grapheme level. These two processes are thought to “vote for” or activate their candidate graphemic codes. In the undamaged system, the lexical source of activation prevails, identifiable either in terms of a stronger vote produced by the lexical system and/or in terms of feedback connections between the grapheme and orthographic levels which may serve to stabilize and amplify the lexical contribution. As Fig. 1 shows, in our modeling of written picture naming we have also endorsed the idea that both the PO sublexical conversion and the semantic-lexical processes feed into a common grapheme level. The exact characterization of the competition that takes place at this level is, however, a matter for future empirical studies and/or simulations.

A related question is whether graphemes map to multiple phonemes or only to the most frequent one. For example, Baxter and Warrington (1987) have suggested that only a single idiosyncratic mapping should be represented. In constrast, Goodman and Caramazza (1986) have proposed that multiple phoneme-to-grapheme mappings are represented for each phoneme, e.g., /*k*/ → *c*, *k*, *qu*. Evidence from analyses of spelling errors by brain-damaged patients (e.g., Goodman & Caramazza, 1986; Sanders & Caramazza, 1990) and normals (Barry & Seymour, 1988) has revealed a huge variability in the spelling of the same phoneme sequences. This strongly suggests that a single grapheme option is not encoded for each phoneme. These data are more compatible with the hypothesis that the sublexical conversion procedure encodes the full range of the phoneme-to-grapheme associations of the language. The selection among the possible mapping options for each phoneme would then be based on the frequency with which they occur in the language, as evidenced by the strong correlation between the distribution of spellings produced for a given phoneme and the actual distribution of spellings in the language for that phoneme (Goodman & Caramazza, 1986; Sanders & Caramazza, 1990).

Spelling Errors and Homophonic (or Quasihomophonic) Substitution Errors

Spelling errors and homophone substitution errors have often played a central role in modeling written production. The spelling errors exhibited by brain-damaged patients and the so-called "slips of the pen" (Ellis, 1982) occasionally produced by normal writers have been frequently taken as evidence for the involvement of phonology in writing (Aitchison & Todd, 1982). In all of our three picture writing experiments, there were more spelling errors on inconsistent items than on consistent ones. Moreover, most of the spelling errors resulted in phonologically plausible pseudowords (e.g., *tank*: *tanque*, *tanck*, etc.). For example, in Experiment 3, 92% of errors on initial inconsistent words consisted of phonologically plausible pseudowords (almost exactly the same percentage was observed for final inconsistent words: 89%). A straightforward interpretation would be that errors reflect on-line competition between alternative orthographic codes for inconsistent items. For instance, the inconsistent word *phoque* would result in more errors than the consistent word *table* due to the fact that, for the former item, there are two orthographic alternatives that match the initial sound /*f*/ (*ph* / *f*) and at least three for the rime unit /ɔk/ (*oque*, *ok*, *oc*). Conversely, for the word *table*, there is a one-to-one mapping between the individual sounds and their orthographic counterparts. One difficulty with this interpretation is that, in the control written picture naming study, a similar pattern of errors was observed despite the fact that the task was not timed and that the participants were told to check their responses. More importantly, when the error scores obtained in the control task were introduced as covariates in the error analyses of Experiments 1–3, the consistency effect vanished. These findings suggest that these errors were due to inaccurate orthographic knowledge. A similar observation that university students have incorrect orthographic specifications for some low-frequency words has recently been reported by Holmes and Carruthers (1998). Thus, the data gathered in the control task lead us to favor the hypothesis that the consistency effect found for errors in the speeded-writing tasks did not result from orthographic code competition during processing but instead from inaccurate orthographic specifications within the lexicon. This hypothesis is compatible with the observation that consistency did not affect writing latencies in Experiments 1 and 2 as well as for final-inconsistent items in Experiment 3. If errors were the result of on-line competition, we would have expected similar effects on latencies.[7]

The present study showed that spelling errors occur in adults even when they have enough time to check their own productions. This observation is in line with other data demonstrating reading and spelling difficulties in high school and university students who are not considered learning-disabled (e.g., Holmes & Car-

[7] In Experiment 3, the consistency effect was also observed for latencies when the inconsistent units corresponded to the initial unit of the word. Hence, for these items, we cannot exclude the possibility that errors were mainly the result of orthographic competition.

ruthers, 1998; Skankweiler, Lundquist, Dreyer, & Dickinson, 1996). In young children, spelling errors are often assumed to result from reliance on sound-to-print associations when orthographic word-specific representations are missing or underspecified. Hence, it has been observed that numerous incorrect spellings in children are phonologically plausible and that the proportion of these errors is higher in children with no learning disabilities than in children having difficulties in using analytical correspondences between print and sound (Lennox & Siegel, 1993). Although phonologically plausible spelling errors are expected on irregular/inconsistent words if spelling is derived by sound-to-print correspondences, errors can also result from incorrect word-specific orthographic representations in the mental lexicon. One argument in favor of such a hypothesis is the fact that adults have been shown to recognize words faster when presented with their own misspellings than when presented with the correct orthographic form (Holmes & Carruthers, 1998). How incorrect word spellings can stabilize in lexical memory is a question that has not yet been addressed in great detail, but it is now clearly established that adults' spelling performance decreases when the spellers have been presented with incorrect spellings, even 1 week before (Dixon & Kaminska, 1997; see also Brown, 1988; Jacoby & Hollingshead, 1990). According to Ehri (1997), some spellings are more difficult to learn than others, such as in the case of words including phonemes represented by exceptional and unfrequent graphemes and words in which silent letters occur (Ehri & Wilce, 1982). The influence of the regularity/consistency of the relations between print and sound can be viewed as a self-teaching mechanism such as proposed by Jorm and Share (1983; Share, 1995, 1999). It is assumed that the phonological recoding of print determines the acquisition of word-specific orthographic representations and that each successful phonological conversion of the printed word increases the probability of learning the correct word spelling. Hence, spellings corresponding to irregular/inconsistent words are more difficult to learn because they are harder to map to correct phonological codes. It might be that a similar self-teaching mechanism operates when writing words. If so, the spelling that is produced could be consolidated in lexical memory when it matches the phonological code of the word. Consequently, incorrect spellings might be reinforced when they are homophonic to the intended word. Such a possibility is higher for words involving sound-to-print inconsistencies since they permit various orthographic renderings for the same sounds. Therefore, during the course of spelling acquisition, inconsistent words should be more difficult to remember than consistent words because these former possess more orthographic options than the latter. In accordance with this interpretation is the experienced erosion in spelling knowledge reported by psycholinguists after conducting large number of experiments using pseudohomophones (Bosman & Van Orden, 1997).

Homophone substitutions (e.g., writing *hear* for *here*, *seen* for *scene*) and quasihomophone substitution errors (e.g., writing *oven* for *often*) have been frequently interpreted as denoting phonological involvement in written spelling. Several explanations have been put forward to account for these errors. One possibility is that they reflect phonological mediation either through sublexical conversion (Rapp et al., 1997) or through direct connections between phonological and orthographic lexemes (Morton, 1980). Another possibility is that they result from the establishment of erroneous associations between semantics and orthography during the course of learning (e.g., *hear* versus *here* as the appropriate orthographic form for the meaning *listen*).

In Experiment 1, a substantial proportion of errors on homophonic labels were homophone substitutions. However, the finding that, in Experiment 1, homophonic labels did not result in longer written latencies than nonhomophonic ones seems to rule out a phonological mediation account of homophone substitution errors. Indeed, it is hard to understand how the inappropriate orthographic code of a homophone target could be activated while, at the same time, producing no additional processing cost on written latencies when the correct form is produced. The observation of similar percentages of homophone substitution errors in Experiment 1 (6%) and in the control written picture naming task (5%) suggests that homophone substitution errors mostly reflect competence errors and not, as previously claimed (Ellis, 1984), performance errors. As a result, we think that a more plausible explanation of homophone substitution errors is that inappropriate associations still exist in adulthood between semantic and orthographic specifications so that, on some occasions, the wrong orthographic form is matched to the intended meaning of the homophone. In some of the participants, the correct orthographic forms of homophones might even be lacking. Holmes and Carruthers (1998) have shown, for example, that university students are sometimes more confident about their own misspellings than of the correct spellings of low-frequency words.

In conclusion, the finding that onset latencies in written picture naming are affected by initial sound-to-print inconsistencies represents, to our knowledge, the first empirical evidence suggesting a phonological influence on written production from pictures by normals. Proponents of the orthographic autonomy hypothesis assume that orthographic codes can be directly accessed from semantic specifications. Hence, brain damage affecting either semantic-to-phonological links or phonological word forms (or both) may not hinder written production insofar as the connections between orthographic and semantic codes are preserved. In this theoretical framework, our data would suggest, at the very least, that in the normal functioning of writing, the influence of phonology on orthographic code specification is unavoidable. Finally, as we have discussed, the observation that final inconsistencies did not influence onset written naming latencies might result from a sequential component in sound-to-print mapping. The present study, therefore, provides strong empirical constraints for the modeling of the writing process. We acknowledge that the functional details of the modeling need to be identified in detail in future research.

APPENDIX 1

Stimuli for Experiment 1

Homophonic names	Nonhomophonic names
Aile (wing) [elle] (she)	Aigle (eagle)
Ancre (anchor) [encre] (ink)	Bol (bowl)
Cor (horn) [corps] (body)	Bombe (bomb)
Cygne (swan) [signe] (sign)	Chat (cat)
Dent (tooth) [dans] (in)	Clou (nail)
Houx (holly) [ou] (or)	Flûte (flute)
Malle (trunk) [mal] (bad)	Fouet (whip)
Mètre (meter) [mettre] (to put)	Gant (glove)
Paon (peacock) [pan] (tail)	Gland (acorn)
Poing (fist) [point] (point)	Hache (axe)
Pois (pea) [poids] (weight)	Jeep (jeep)
Porc (pig) [port] (harbour)	Lampe (lamp)
Pot (pot) [peau] (skin)	Lance (lance)
Poêle (fryer) [poil] (hair)	Loup (wolf)
Puits (well) [puis] (then)	Oie (goose)
Renne (reindeer) [reine] (queen)	Pelle (shovel)
Seau (pail) [sot] (silly)	Pile (battery)
Selle (saddle) [sel] (salt)	Raie (ray)
Tente (tent) [tante] (aunt)	Rat (rat)
Toit (roof) [toi] (you)	Sac (bag)
Ver (worm) [vers] (towards)	Tank (tank)
Vis (screw) [vice] (vice)	Tronc (stem)

Note. Homophonic mates are presented in square brackets. The approximate English translation is given in parentheses.

APPENDIX 2

Stimuli for Experiment 2

High-frequency names		Low-frequency names	
Consistent	Inconsistent	Consistent	Inconsistent
Arbre (tree)	Aile (wing)	Arche (arch)	Aigle (eagle)
Bouche (mouth)	Bras (arm)	Bague (ring)	Ancre (anchor)
Cloche (bell)	Chaise (chair)	Biche (doe)	Brosse (brush)
Corde (rope)	Chèvre (goat)	Crabe (crab)	Cintre (coat-hanger)
Jupe (skirt)	Cœur (heart)	Cruche (jug)	Cygne (swan)
Lion (lion)	Croix (cross)	Douche (shower)	Gland (acorn)
Livre (book)	Dent (tooth)	Gomme (rubber)	Harpe (harp)
Lune (moon)	Doigt (finger)	Lime (nail file)	Hyène (hyena)
Masque (mask)	Gant (glove)	Louche (soup ladle)	Morse (walrus)
Mouche (fly)	Lampe (lamp)	Loupe (magnifying glass)	Noix (walnut)
Nuage (cloud)	Lettre (letter)	Luge (sledge)	Paon (peacock)
Ongle (nail)	Pied (foot)	Niche (kennel)	Peigne (comb)
Plume (feather)	Poing (fist)	Ours (bear)	Pelle (shovel)
Poche (pocket)	Pouce (thumb)	Palme (flipper)	Phare (beacon)
Porte (door)	Règle (ruler)	Poulpe (octopus)	Pince (pliers)
Prise (plug)	Singe (monkey)	Ruche (beehive)	Scie (saw)
Robe (dress)	Tasse (cup)	Tarte (pie)	Seau (pail)
Table (table)	Timbre (stamp)	Tigre (tiger)	Serpe (bill-hook)
Vache (cow)	Train (train)	Tube (tube)	Tank (tank)
Vase (vase)	Verre (glass)	Urne (urn)	Trèfle (trefoil)

Note. The approximate English translation is given in parentheses.

APPENDIX 3

Stimuli for Experiments 3 and 5

Initial words		Final words	
Inconsistent	Control	Inconsistent	Control
Aigle (eagle)	Arche (arch)	Clown (clown)	Cloche (bell)
*Aile (wing) [herbe (grass)]	Avion (plane)	Bombe (bomb)	Bouche (mouth)
*Ceinture (belt)	*Cravate (neck-tie)	*Doigt (finger)	*Disque (record)
*Cerf (stag) [cierge (candle)]	Cube (cube)	Dièse (sharp)	Douche (shower)
Cible (target)	Crabe (crab)	Fraise (strawberry)	Film (film)
Cintre (coat-hanger)	Cheval (horse)	Gland (acorn)	Gourde (water bottle)
*Cygne (swan) [cirque (circus)]	Carte (ring)	Dauphin (dolphin)	Urne (urn)
Enclume (anvil)	Licorne (unicorn)	*Luth (lute) [lynx (lynx)]	Louche (soup ladle)
Gilet (vest)	Gomme (rubber)	*Paon (peacock)	*Poulpe (octopus)
*Girafe (giraffe)	*Grenade (grenade)	Noeud (knot)	Niche (kennel)
Hache (axe)	Bague (ring)	Lampe (lamp)	*Palme (flipper)
Hamac (hammock)	Biche (doe)	Plante (plant)	Poule (hen)
Harpe (harp)	Lime (nail-file)	*Poing (fist) [plat (dish)]	Prune (plum)
Hibou (owl)	Borne (road sign)	Tronc (trunk)	Tarte (pie)
Klaxon (horn)	Banane (banana)	Tank (tank)	Torche (torch)
Oeil (eye)	Ongle (nail)	Raie (ray)	Ruche (beehive)
Oeuf (egg)	Ours (bear)	Tasse (cup)	Tigre (tiger)

APPENDIX 3—*continued*

Oignon (onion)	Orgue (organ)	Noix (walnut)	Moto (motor bike)
*Phare (beacon) [cercle (circle)]	Pipe (pipe)	Loup (wolf)	Lune (moon)
Phoque (seal)	Panier (basket)	*Poêle (fryer)	Loupe (magnifying glass)
Quille (skittle)	Dragon (dragon)	*Mètre (meter) [membre (member)]	Mouche (fly)
Scie (saw)	Luge (sledge)	Peigne (comb)	Poche (pocket)
*Wagon (wagon)	*Violon (violin)	*Puits (well) [pull (pullover)]	Plume (feather)

Note. The approximate English translation is given in parentheses. Items marked with an "*" were not included in Experiment 5. Items in square brackets correspond to nonhomophonic words used in Experiment 5.

APPENDIX 4

Stimuli for Experiment 4

High-frequency words		Low-frequency words	
Consistent	Inconsistent	Consistent	Inconsistent
Poche (pocket)	Train (train)	Fugue (running away from home)	Bêche (spade)
Lune (moon)	Type (type)	Bave (dribble)	Zèle (zeal)
Larme (tear)	Froid (cold)	Prune (plum)	Crêpe (pancake)
Monde (world)	Frère (brother)	Bribe (scrap)	Dièse (sharp)
Crise (crisis)	Pièce (room)	Crabe (crab)	Flair (scent)
Riche (rich)	Cœur (hear)	Louve (she-wolf)	Flash (flash)
Double (double)	Oeuvre (work)	Charte (charter)	Gendre (son-in-law)
Proche (near)	Grosse (big)	Torche (torch)	Glaire (glair)
Ligne (line)	Femme (women)	Digue (dam)	Gland (acorn)
Libre (free)	Règle (ruler)	Bulbe (bulb)	Kyste (cyst)
Pointe (wire nail)	Membre (member)	Pioche (pick)	Moelle (marrow)
Juge (judge)	Fils (son)	Luge (sledge)	Môme (kid)
Bouche (mouth)	Prêtre (priest)	Poutre (beam)	Phoque (seal)
Bonne (maid)	Neige (snow)	Biche (doe)	Plomb (lead)
Page (page)	Rêve (dream)	Ours (bear)	Pull (pullover)
Nuage (cloud)	Style (style)	Niche (kennel)	Score (score)
Rouge (red)	Plein (full)	Arche (arch)	Snack (snack)
Mouche (fly)	Plaire (to please)	Fougue (heat)	Suaire (shroud)
Mode (fashion)	Rôle (role)	Tube (tube)	Tank (tank)
Arme (weapon)	Sens (direction)	Tige (trunk)	Zinc (zinc)

Note. The approximate English translation is given in parentheses.

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