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Children's Implicit Learning of Graphotactic and Morphological Regularities

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In French, the transcription of the same sound can be guided by both probabilistic graphotactic constraints (e.g., /ɛt/ is more often transcribed *ette* after *-v* than after *-f*) and morphological constraints (e.g., /ɛt/ is always transcribed *ette* when used as a diminutive suffix). Three experiments showed that pseudo-word spellings of 8-to 11-year-old children and adults were influenced by both types of constraints. The influence of graphotactic regularities persisted when reliance on morphological rules was possible, without any falling off as a function of age. This suggests that rules are not abstracted, even after massive amounts of exposure to a rule-based material. These results can be accounted for by a statistical model of implicit learning.

Implicit learning occurs when somebody acquires new information without intending to do so. It is conceived as a fundamental process involved in domains as diverse as knowledge about the physical world, acquisition of social skills, first- and second-language learning, and reading and writing. However, implicit learning has mainly been investigated in laboratory settings through a wide variety of experimental situations involving complex and arbitrary stimulus domains (e.g., artificial grammar learning, sequence learning, dynamic system control, acquisition of invariant characteristics; for reviews, see Berry & Dienes, 1993; Cleeremans, Destrebecqz, & Boyer, 1998; Reber, 1993). Only recently, a few researchers have addressed connections between implicit learning experiments in the laboratory and in real-life contexts, such as the acquisition of musical structures (e.g., Tillmann, Bharucha, & Bigand, 2000), first and second languages (e.g., Gomez & Gerken, 2000; Michas & Berry, 1994), and written language (e.g., Pacton, Perruchet, Fayol, & Cleeremans, 2001). For instance, Pacton et al. (2001) showed that adapting paradigms typically used in laboratory implicit learning experiments allows a better understanding of the nature of children's orthographic knowledge.

In this article, we take into account results issued from the implicit learning literature to plan experiments designed to assess whether children rely on untaught morphological rules. We begin by reviewing how the issue of rule abstraction has been dealt within laboratory studies on implicit learning. Then, we review the few studies on written language acquisition that address this issue. Finally, we discuss the characteristics of French orthography that are exploited in our experiments.

The Abstraction Issue in the Implicit Learning of Artificial Grammars

Most studies designed to address the issue of rule abstraction in implicit learning settings used Reber's (1967, 1993) artificial grammar learning (AGL) paradigm. In this paradigm, participants are asked to memorize strings (unknown to them) generated from a finite-state grammar that defines legal letters and permissible transitions between them. After training, participants are informed that this set of stimuli is rule governed. They are then asked to indicate whether a new set of strings obeys or violates the rules. Participants typically get about 65% to 75% of these classifications correct. They are generally unable to articulate rules used to generate the material.

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Reber (1967) has suggested that participants abstract the grammar rules during the study phase, when they are exposed to sample of letter strings generated from the grammar. During the test phase, participants are assumed to use the acquired rule-based knowledge to judge the grammaticality of new items. However, alternative explanations have been subsequently proposed. In particular, it has been suggested that participants could judge grammaticality by making use of the relative frequency of particular fragments that were presented in the study phase (e.g., Perruchet, 1994; Redington & Chater, 1996). Because this account relies heavily on the distributional and statistical aspects of the materials, we hereafter refer to the statistical account to refer to the alternative to rule-based account.

Another variant of the AGL studies does not seem easily open to the statistical account yet. In this variant, the surface form of the materials is changed between training and test. For example, the training string MXVVM and VXMTM might become HJKKH and KJHLH, respectively. The new strings follow the same underlying rules as the training string, but they are instantiated with a novel set of stimuli (e.g., other letters, sequences of tones). In these transfer situations, participants continue to perform at above-chance levels. However, level of performance with unfamiliar strings is lower than with familiar strings (the so-called transfer-decrement phenomenon; e.g., Altmann, Dienes, & Goode, 1995; Dienes & Altmann, 1997; Gomez, 1997; Redington & Chater, 2002; Shanks, Johnstone, & Staggs, 1997; Whittlesea & Wright, 1997).

The possibility of transfer to new materials has initially been seen as evidence for the claim that participants in AGL studies acquire rule-based knowledge during the training phase (Knowlton & Squire, 1996; Reber, 1993). According to these studies, transfer to new materials rules out the theories of AGL in which participants acquire knowledge of whole instances, or fragments of the training materials, because these approaches would represent the input in terms of its surface form.

However, even here, these results could be explained in terms of statistical learning. To do so, one has to reconsider the opposition between rule-based and statistical learning interpretations. In traditional conceptions, the notion of rule involves surface-independent features, and the notion of statistical mechanisms involves surface-dependent features. However, as claimed by Redington and Chater (2002), ''surface-independence and rule-based knowledge are orthogonal concepts'' (p. 124). In particular, statistical processes can apply to features that are abstracted away from their sensory content. Now, statistical principles acting on simple abstract or relational primitives, such as those that can be provided by low-level perceptual processes, can account for the available data evidencing transfer (Perruchet & Vinter, 2002a, 2002b). In favor of this account there is more empirical evidence that the presence of simple repetitions or alternations in the study strings is necessary to obtain transfer effects (e.g., Gomez, Gerken, & Schvaneveldt, 2000; Tunney & Altmann, 1999). Thus, transfer could occur because some perceptually salient features used for statistical analyses are sufficiently abstract to be directly relevant to new materials and not because an unconscious processor abstracts deep underlying rules from a set of items of which only the surface features would be initially encoded.

Although both rule-based and distributional approaches can account for transfer effects, the transfer-decrement phenomenon is problematic for rule-based approaches because the use of genuine rule-based knowledge is supposed to be similar for familiar and unfamiliar items (e.g., Anderson, 1993; Manza & Reber, 1997; Smith, Langston, & Nisbett, 1992; Whittlesea & Dorken, 1997). For instance, Manza and Reber (1997), two advocates of rule-based knowledge, acknowledge that ''a system that represented knowledge in [this] pure abstract form would result in transfer judgment accuracy being equal to control judgment accuracy which, of course, was not what we typically found'' (p. 102). According to Manza and Reber, the transfer decrement would correspond to a point in training at which the rule-abstraction process is not yet fully completed. This interpretation works well in lab studies in which training is necessarily restricted.

However, the results reported by Pacton et al. (2001) suggest that the transfer-decrement in lab studies cannot be explained by insufficient practice preventing the full development of abstract rule-based knowledge. They explored whether and to what extent transfer to novel forms occurs in the context of an out-of-the-lab learning situation that extended over years. They investigated whether children learn an untaught rule specifying that in French, consonants can only be doubled in medial position. Children were presented with pairs of pseudo-words such that one pseudo-word in each pair included a double consonant in legal position whereas the other included a double consonant in illegal position. Children were asked to select the invented word in each pair that looked most like a French word. As early as first grade, children judged *nullor* (a pseudo-word with a doublet in a legitimate,

word-medial position) as more word-like than *nnulor* (with a doublet in a prohibited word-initial position). This effect further transferred to consonants that do not allow doubling in French. For example, although *k* and *x* are never doubled in the language, children found that pseudo-words such as *koxxir* were more word-like than pseudo-words such as *kkoxir*. However, the effect for these letters remained substantially lower than for frequently doubled letters, and the magnitude of this transfer-decrement remained unchanged from Grades 1 to 6. Such a pattern of results, also observed with a completion task, indicated that even after as long as 5 years of exposure to print, children's orthographic knowledge did not correspond to a general rule such as ''consonants can only be doubled in medial position in French.'' The question is now whether this conclusion generalizes to morphological rules, which involve semantic features.

Do Children Use Morphology in Their Spellings?

Morphemes designate linguistic units that have a meaning or a syntactic function and that cannot be subdivided in this way. For example, the word *undesirable* comprises three morphemes: the stem *to desire*, the prefix *un*, and the suffix *able*. In many written languages, knowledge of the relationships between morphemes and script often helps in choosing a particular spelling pattern when there are two or more plausible spelling forms for the same sound. For example, the English two-morpheme word *helped* is formed by the stem *help* followed by the inflectional morpheme *-ed*. Knowing that the final [t] of *helped* is a morpheme marking the past tense leads to spell [t] *-ed* rather than *-t*. In a longitudinal study, Nunes, Bryant, and Bindman (1997a) showed that children initially spelled past regular verbs phonetically (e.g., *stept* for *stepped*; see also Beers & Beers, 1992; Treiman, 1993), then used the written form *-ed* even for grammatically inappropriate words (e.g., *sofed* for *soft*), then used *-ed* for all verbs (e.g., *keped* for *kept*), and, finally, used *-ed* only for regular verbs (see Totereau, Barrouillet, & Fayol, 1998, for a similar sequence concerning the acquisition of the nominal and verbal plurals in written French).

However, it is difficult to determine whether the evolution from spellings that are massively alphabetic (e.g., *stept*) to spellings that take morphology into account (e.g., *stepped*) reflects children's growing morphological knowledge or, simply, rote learning of specific word spelling over time. To disentangle between these alternatives, Bryant, Nunes, and Snaith (2000; see also Nunes, Bryant, & Bindman, 1997b) assessed children's use of morphology with pseudo-word spelling tasks. They investigated whether 8- to 11-year-old children learned an untaught rule of spelling according to which English verbs whose stems sound the same in the present and past forms are given the *-ed* spelling (e.g., *cleared*, *peeled*) whereas verbs whose stems sound different in the present and past have phonetically spelled endings (e.g., *heard*, *slept*). Children were asked to spell regular past pseudo-verbs, whose stems sound the same in the present and past (e.g., /krɛl/ – /krɛld/), and irregular past pseudo-verbs, whose stems sound different in the present and past (e.g., [/prɛl/ – /prold/]) that were embedded in sentences such as ''My friend always *prells* at bedtime. We usually *prell* in the morning, but last week we /prold/ in the afternoon.'' In the two studies, children spelled regular past pseudo-verbs with an *-ed* ending more often than they did the irregular verbs and, conversely, spelled the endings of the irregular past pseudo-verbs phonetically more often than they did the regular verbs. Nunes et al. (1997b) further assessed whether children came to master the use of morphological spelling patterns through reliance on a rule or through analogies to real words by using irregular pseudo-verbs whose present and past tense were either analogous or nonanalogous to those of any real irregular verbs. The pattern held for nonanalogous pseudo-verbs but the performances were lower than with analogous pseudo-verbs—a result similar to Pacton et al. (2001) with regard to children's knowledge about double letters and to the transfer-decrement observed in AGL studies.

Even more recently, Kemp and Bryant (2003) explored whether children and adults rely on the morphological spelling rule that regular plural endings in English must be spelled as *-s* whether they are pronounced with a final /s/ (e.g., *cats*) or a final /z/ (e.g., *dogs*), even though nonplural /z/ endings can be spelled *-z*, *-zz*, *-ze*, or *-se*. Because the plural form of nouns ending in a consonant is always spelled with *-s*, words such as *pads* could be correctly spelled because children have learned that *bs* and *ds* are legal endings in English whereas *bz* and *dz* are not (Cassar & Treiman, 1997; Pacton et al., 2001) rather than because they use the plural morphological rule. However, reliance on graphotactic regularities, rather than on the plural morphological rule, does not work when the sound /z/ is preceded by a long vowel because in this case /z/ can be spelled with *-s* (plurals) or *-ze* or *-se* (nonplurals). Thus, reliance on the plural morphological rule allows people to spell all plural nouns correctly, but reliance on graphotactic regularities leads to correct spellings for

nouns whose final /z/ is preceded by a consonant but not for nouns whose final /z/ is preceded by a long vowel. Kemp and Bryant reported that children in Grades 1 to 3 were far more likely to use the correct-*s* for a plural word when the /z/ ending was immediately preceded by a consonant (e.g., *fibs*) than when it was preceded by a long vowel (e.g., *fleas*). Similar results were obtained with a task involving pseudo-words with children and adults, indicating that the pattern observed with words could not be attributed to differences in the rote learning of spellings. Kemp and Bryant concluded that children "rely on their sensitivity to the frequency with which certain letters co-occur, rather than on their knowledge of a morphology-based rule, when spelling plural and non-plural words and pseudowords" (p. 72).

The Present Study

French is a good candidate to sort out rule-based and statistical interpretations of implicit learning. The transcription of the same sound can be constrained by both graphotactic regularities (i.e., the probability of succession of the graphemes; Jaffré & Fayol, 1997) that are probabilistic and morphological regularities that can be described with an (untaught) abstract rule. This allowed us to explore the combined influence of two types of regularities that are usually independently explored. Investigating whether the graphotactic regularities continue to influence spellers' performances when reliance on a morphological rule is possible constitutes a privileged way to explore whether rules are abstracted after massive amounts of exposure to rule-based material.

In French, the phoneme /o/ can be spelled as *o* (e.g., *piano*), *au* (e.g., *tuyau*, *hose*), *eau* (e.g., *manteau*, *coat*), *ot* (e.g., *escargot*, *snail*), *aut* (e.g., *défaut*, *default*), among other spellings. Similarly, the sound /ɛt/ can be spelled *ète* (e.g., *planète*, *planet*), *aite* (e.g., *défaite*, *defeat*), *ette* (e.g., *assiette*, *plate*), or *ête* (e.g., *conquête*, *conquest*). The distribution of the transcriptions of /o/ and /ɛt/ varies as a function of the preceding consonants (Brulex: Content, Mousty, & Radeau, 1990). For example, /ɛt/ is rarely spelled *ette* after *-b* and *-t* but is frequently after *-l*. Those graphotactic regularities are probabilistic and idiosyncratic insofar as there is no single high-level rule that could provide a concise definition for which letters can precede a given transcription of /ɛt/ or /o/. On the other hand, /o/ is always transcribed *eau* and /ɛt/ is always transcribed *ette* when they correspond to diminutive suffixes (Catach, 1986).[1] For instance, *éléphanteau* (*baby elephant*) and *renardeau* (*fox cub*) are two-morpheme words based on the stems *éléphant* (*elephant*) and *renard* (*fox*) followed by the masculine diminutive suffix *-eau*. Likewise, *vachette* (*young cow*) and *fillette* (*little girl*) are two-morpheme words based on the stems *vache* (*cow*) and *fille* (*girl*) followed by the feminine diminutive suffix *-ette*. These simple and productive rules, which are relevant to a large sample of words, are untaught.

To investigate the influence of the graphotactic and morphological regularities, we compared the spelling of the same pseudo-words in two conditions: one involving only graphotactic constraints (G condition) and the other involving morphological and graphotactic constraints (GM condition). In the G condition, children were asked to spell pseudo-words such as /sorivɛt/ and /soritɛt/, which only differed by the consonants that preceded /ɛt/. We hypothesized that if children were sensitive to graphotactic regularities, they should use *ette* more often for /sorivɛt/ than for /soritɛt/ because *ette* is frequent after /v/ but rare after /t/. In the GM condition, children were asked to spell the same pseudo-words embedded within sentences such as "a little /soriv/ is a /sorivɛt/" or "a little /sorit/ is a /soritɛt/." Our hypothesis was that if the derivational morphology does influence children's spellings, *ette* should be used more often in the GM condition than in the G condition.

A rule-based model of implicit learning appears especially relevant to account for the acquisition of the morphological rules. Such a model predicts that rule-abstraction processes are elicited when people are faced with rule-governed material. However, this model does not exclude the possibility that people learn statistical regularities when these regularities cannot be described by a rule (e.g., Manza & Reber, 1997). On the other hand, a statistical model of implicit learning is especially relevant to account for an increasing sensitivity to graphotactic regularities. However, such a model is able to account for a sensitivity to morphological regularities because statistical analyses do not only operate on low-level, surface features (e.g., Perruchet & Vinter, 2002a, 2002b; Redington & Chater, 2002). Thus, when words such as a "*fillette*" (*a little girl*) or a "*maisonnette*" (*a little house*) are encountered, the feature of diminutiveness may become associated with the feature "ends in *ette*," and this association can be strengthened through repetitions as with any other association.

Although children's increasing sensitivity to graphotactic and morphological regularities can be explained within a rule-based and within a statistical

model of implicit learning, the two models lead to diverging predictions in our experimental situation. The crucial point concerns the impact of the graphotactic constraints in the GM condition. According to a rule-based account, people are initially sensitive to the idiosyncratic properties of the material, and then rule knowledge evolves from this sensitivity (Manza & Reber, 1997). Because of a gradual abstraction of the morphological rules, the impact of the graphotactic constraints in the GM condition should progressively decrease. On the other hand, according to a statistical account, children would become increasingly sensitive to both graphotactic and morphological regularities. However, children are not assumed to abstract the rules implicitly even in the morphological domain in which such extraction is possible. Therefore, morphological constraints should not evolve as the all-or-none effect that is typical of rule-directed phenomena.

To sum, a rule-based account predicts an impact of the graphotactic constraints in the G condition but not in the GM condition after an extensive exposure to written language. A statistical account predicts an impact of the graphotactic constraints in both the G and the GM conditions even after prolonged exposure to print.

Study 1

Method

Participants. Participants included 40 (18 females, 22 males) second-grade children (*M* age = 8 years 3 months, *SD* = 3.4 months), 40 (20 females, 20 males) third-grade children (*M* age = 9 years 3 months, *SD* = 4.6 months), and 40 (23 females, 17 males) fifth-grade children (*M* age = 11 years 1 month, *SD* = 4.4 months). Children were recruited from two French primary schools located in an area of average socioeconomic status in Dijon. The 120 children met the following criteria: (a) parental permission, (b) French as native language, and (c) no language problems according to their teachers. In this study and all other experiments reported here, the majority of the participants were white.

Stimuli. To construct the pseudo-words, we calculated the distributions of the written forms *eau* and *ette* in the final position of words as a function of the preceding consonant using a French computerized database Brulex (Content et al., 1990). Table 1 shows the stimuli used in Study 1.

Six pairs of pseudo-words were elaborated to test the impact of graphotactic and morphological constraints on the transcription of /o/. The two pseudo-words of each pair differed only with regard to their final consonants. One pseudo-word ended with one of the three consonants /r/, /t/, and /v/ after which /o/ is frequently transcribed *eau* in French (e.g., /klar/ or /vitar/). The other pseudo-word ended with one of the three consonants /k/, /f/, and /g/ after which /o/ is never transcribed *eau* in French (e.g., /klaf/ or /vitaf/). A diminutive corresponding to each of these 12 pseudo-words was elaborated by adding /o/ after the final consonant of those pseudo-words. For example, the diminutive of /vitaro/ was composed of the stem /vitar/ followed by the diminutive suffix /o/. Each of the six final endings /ko/, /fo/, /go/, /ro/, /to/, and /vo/ occurred at the end of one bisyllabic consonant-consonant-vowel-consonant-vowel (CCVCV) pseudo-word (e.g., /klaro/ or/ klafo/) and at the end of one trisyllabic CVCVC pseudo-word (e.g., /vitaro/ or /vitafo/).

Table 1
Stimuli Used in Experiments 1, 2, and 3

EAU frequent	EAU never	ETTE frequent	ETTE rare
/brev/ – /brevo/ /pilav/ – /pilavo/ (940)	/brek/ – /breko/ /pilak/ – /pilako/ (0)	/kryl/ – /krylɛt/ /kalal/ – /kalalɛt/ (140)	/kryf/ – /kryfɛt/ /kalaf/ – /kalafɛt/ (1)
/plit/ – /plito/ /pymit/ – /pymito/ (286)	/plig/ – /pligo/ /pymig/ – /pymigo/ (0)	/gla ∫ / – /gla ∫ ɛt/ /turi ∫ / – /turi ∫ ɛt/ (36)	/glab/ – /glabɛt/ /tyrib/ – /tyribɛt/ (1)
/klar/ – /klaro/ /vitar/ – /vitaro/ (209)	/klaf/ – /klafo/ /vitaf/ – /vitafo/ (0)	/trav/ – /travɛt/ /soriv/ – /sorivɛt/ (16)	/trat/ – /tratɛt/ /sorit/ – /soritɛt/ (1)

Note. Presented here are pseudo-words composed of a stem without diminutive suffix (e.g., /brev/) and their related pseudo-words composed of a stem followed by a diminutive suffix (e.g., /brevo/). The cumulated frequencies (per million) of words in which the sounds /o/ and /ɛt/ of the /consonant +o/ and /consonant +ɛt/ endings are transcribed respectively *eau* and *ette* are indicated in parentheses.

Hereafter, pseudo-words in which /o/ followed a consonant after which /o/ is frequently transcribed *eau* in French are labeled *EAU frequent*. Those in which /o/ followed a consonant after which /o/ is never transcribed *eau* in French are labeled *EAU never*.

Six pairs of pseudo-words were elaborated to test the impact of graphotactic and morphological constraints on the transcription of /ɛt/. The two pseudo-words of each pair differed only with regard to their final consonants. One pseudo-word ended with one of the three consonants /ʃ/, /l/, and /v/ after which *ette* is frequent in French (e.g., /travˇ/ or /soriv/). The other pseudo-word ended with one of the three consonants /b/, /f/, and /t/ after which *ette* is infrequent in French (e.g., /trat/ or/ sorit/). A diminutive corresponding to each of these 12 pseudo-words was elaborated by adding /ɛt/ after the final consonant of those pseudo-words. For example, the diminutive /sorivɛt/ was composed from the stem /soriv/ followed by the suffix /ɛt/. Each of the six final endings /bɛt/, /fɛt/, /ʃɛt/, /lɛt/, /tɛt/, and /vɛt/ occurred at the end of one bisyllabic CCVCVC pseudo-word (e.g., /travɛt/ or /tratɛt/) and at the end of one trisyllabic CVCVCV pseudo-word (e.g., /sorivɛt/ or /soritɛt/). Hereafter, pseudo-words in which /ɛt/ followed a consonant after which /ɛt/ is frequently transcribed *ette* in French are labeled *ETTE frequent*. Those in which /ɛt/ followed a consonant after which /ɛt/ is rarely transcribed *ette* in French are labeled *ETTE rare*.

Two lists were made. The first list included the 12 pseudo-words ending with /o/ preceded by the masculine indefinite article *un* (e.g., un /vitaro/) and the 12 pseudo-words ending with /ɛt/ preceded by the feminine indefinite article *une* (e.g., une /sorivɛt/) put in a random order. In the second list, each of the 24 pseudo-words of the first list was embedded within a sentence such as "un petit /vitar/ est un /vitaro/" ("a little /vitar/ is a /vitaro/") or "une petite /soriv/ est une /sorivɛt/" ("a little /soriv/ is a /sorivɛt/"), which provided information about the morphological structure of the pseudo-word (i.e., a stem followed by the diminutive suffix /o/ or /ɛt/). The 24 items of both lists were audiotaped using a tape recorder.

Procedure. The experiment included two sessions separated by a 1-week interval. Children were told that the experimenter had made up new words that no one had ever seen or heard and that their task consisted in writing these "new words." In the two conditions (G condition and GM condition), children had to spell the pseudo-word preceded by the indefinite article *un* or *une*, but although the first list was called out in the G condition, the second list was provided in the GM condition. For example, participants were asked to write "a /vitaro/" in the two conditions but heard "a /vitaro/" in the G condition and "a little /vitar/ is a /vitaro/" in the GM condition. For each grade level, half of the participants undertook the G condition in the first session and the GM condition in the second session (G–GM groups). The other half performed the experiment in the reverse order, that is, the GM condition in the first session and the G condition in the second session (GM–G groups).

Note that the GM condition after the G condition seems more appropriate than the G condition after the GM condition to assess the influence of morphological information on children's spelling. Indeed, the question concerns the potential impact of providing participants with morphological information (which is the case for the G–GM group) rather than depriving them of this information (which is the case in the GM–G group). However, a potential problem with the G then GM order is that children's spelling could be influenced by graphotactic constraints in the GM condition because they could try to spell the pseudo-words as they had written them in the previous G condition, whereas this effect would not be observed if the GM condition has been conducted first. Although asking some children to perform the sole GM condition would have been enough, the children of the GM–G group performed the G condition after the GM condition so that the order of the G and GM conditions was completely counterbalanced in Study 1.

Results

Because the material has been elaborated to assess the impact of the graphotactic and morphological constraints on the use of *eau* (to transcribe /o/) and *ette* (to transcribe /ɛt/), we focused on children's use of those spellings. However, it is interesting to note that as early as second grade, /o/ and /ɛt/ were transcribed with a wide range of written forms. For example, 35 second-grade children transcribed /o/ in at least three different ways and 5 second-grade children used only two different ways. Phonologically incorrect transcriptions of [consonant+/o/] and [consonant+/ɛt/] endings (e.g., *vitavo* or *vitaveau* for /vitafo/) as well as phonologically plausible spellings of /fo/ and /fɛt/ endings in which /f/ was spelled *ph* instead of *f* were left out. This excludes 3.0% of the spelling of pseudo-words ending in /o/ and 4.1% of the spelling of pseudo-words ending in /ɛt/.

We first report the results for the pseudo-words ending in /o/, then those for the pseudo-words ending in /ɛt/. For each type of pseudo-words, analyses of variance (ANOVAs) were conducted to determine when and how the graphotactic and morphological constraints influenced children's spelling, and how the integration of these two constraints evolves across grades. The proportion of /o/ transcribed *eau* and the proportion of /ɛt/ transcribed *ette* were separately submitted to a 3 (grade: second, third, and fifth) × 2 (order: G–GM vs. GM–G) × 2 (morphological constraints: G condition vs. GM condition) × 2 (graphotactic constraints: EAU never vs. EAU frequent; ETTE rare vs. ETTE frequent) ANOVA with repeated measures on the last two variables for analyses taking participants as a random variable (i.e., *F*1). For analyses on items (i.e., *F*2), the proportion of *eau* and the proportion of *ette* were separately submitted to a 2 (graphotactic constraints) × 2 (morphological constraints) × 3 (grade) × 2 (order) ANOVA with repeated measures on the last two variables. Table 2 gives the proportion of /o/ transcribed *eau* and the proportion of /ɛt/ transcribed *ette* as a function of graphotactic constraints, morphological constraints, and grades for the G–GM group and GM–G group.

Pseudo-words ending in /o/. The main effect of grade was marginally significant by participants, $F1(2, 114) = 2.8$, $p = .057$, and was significant by items, $F2(2, 20) = 16.6$, $p < .001$. Planned comparisons indicated that *eau* was more often used in fifth grade than in second and third grades, $F1(1, 114) = 5.8$, $p = 0.2$; $F2(1, 10) = 19.9$, $p = .001$. There was a main effect of the graphotactic constraints, with EAU frequent pseudo-words more often spelled with *eau* than EAU never pseudo-words (32.8% vs. 15.4%), $F1(1, 114) = 89.0$, $p < .001$; $F2(1, 10) = 36.1$, $p < .001$. The main effect of morphological constraints was also significant, revealing a greater use of *eau* in the GM condition than in the G condition, $F1(1, 114) = 17.6$, $p < .001$; $F2(1, 10) = 67.9$, $p < .001$.

The morphological constraints by grade interaction, $F1(2, 114) = 8.4$, $p < .001$; $F2(2, 20) = 44$, $p < .001$, reflected that more use of *eau* in the GM condition than in the G condition increased with grades (averaged on the order: 0.6% in second grade, 3.8% in third grade, and 16.3% in fifth grade). The second interaction resulted from the fact that *eau* was more frequently used in the GM condition than in the G condition in the two groups, but the difference between the G and GM conditions was more pronounced for the G–GM group (29.7% vs. 19.5%), $F1(1, 57) = 14.3$, $p < .001$; $F2(1, 10) = 58.4$, $p < .001$, than for the GM–G group (25.5% vs. 21.9%), $F1(1, 57) = 3.6$, $p = .06$; $F2(1, 10) = 7.1$, $p = .02$. We examined the morphological constraints effect at each grade level separately for the G–GM and GM–G groups. Indeed, although the order of the G and GM conditions was counterbalanced in this study, the main interest with regard to the use of morphological information concerned the performance of the G–GM group. For the G–GM group, significant effects of the derivational morphology were observed in third grade (+5.8%), $F1(1, 19) = 5.6$, $p = .03$; $F2(1, 10) = 7.8$, $p = .01$, and in fifth grade (+23.3%), $F1(1, 19) = 14.9$, $p = .001$; $F2(1, 10) = 83.5$, $p < .001$. For the GM–G group, *eau* was used significantly more often in the GM than in the G condition only in fifth

Table 2

Mean Percentages of /o/ Transcribed eau *(Top Panel) and of /ɛt/ Transcribed* ette *(Bottom Panel) as a Function of Morphological Constraints (G Condition vs. GM Condition), Graphotactic Constraints (EAU Never vs. EAU Frequent; ETTE Rare vs. ETTE Frequent), Grade Level, and Order (G–GM Group vs. GM–G Group): Study 1*

		G condition		GM condition	
Order	Grade	EAU never	EAU frequent	EAU never	EAU frequent
G–GM	2	13.3	27.5	11.7	31.7
		(14.9)	(27.7)	(15.4)	(29.1)
	3	7.5	22.5	12.5	29.2
		(15.7)	(31.7)	(22.9)	(31.5)
	5	13.3	32.5	34.3	58.7
		(19.2)	(35.7)	(26.6)	(39.0)
GM–G	2	16.7	26.7	16.7	31.7
		(14.3)	(17.4)	(15.3)	(20.2)
	3	10.8	31.7	15.0	30.8
		(15.6)	(35.0)	(24.7)	(30.2)
	5	12.9	32.6	20.3	43.4
		(24.4)	(36.8)	(26.7)	(42.0)
		ETTE rare	ETTE frequent	ETTE rare	ETTE frequent
G–GM	2	37.5	74.2	45.8	81.7
		(30.0)	(28.9)	(31.0)	(23.5)
	3	35.2	55.8	39.3	67.5
		(32.5)	(42.0)	(34.2)	(39.2)
	5	55.5	87.5	65.3	95.7
		(36.3)	(20.1)	(36.8)	(7.7)
GM–G	2	40.0	65.0	55.8	70.8
		(20.5)	(29.6)	(28.8)	(27.0)
	3	34.2	70.8	49.2	75.0
		(28.3)	(23.5)	(29.4)	(18.3)
	5	58.0	88.2	72.7	97.2
		(34.7)	(23.7)	(31.4)	(7.0)

Note. Standard deviations are in parentheses. G = only graphotactic constraints; GM = graphotactic and morpological constraints.

grade (+8.8%), $F1(1, 19) = 4.2$, $p = .05$; $F2(1, 10) = 16.9$, $p = .002$.

We now address the question of the integration of the graphotactic and morphological constraints, which is central to our study because it is on this aspect that ruled-based and statistical accounts of implicit learning lead to diverging predictions. Neither the Graphotactic Constraints × Morphological Constraints interaction nor the Graphotactic Constraints × Morphological Constraints × Grade interaction were significant, Fs < 1. This means that the impact of the graphotactic constraints did not differ significantly according to whether pseudo-words were spelled in the G condition or in the GM condition and that this effect was stable across grades. ANOVAs conducted for the sole GM condition confirmed that the use of *eau* varied according to graphotactic regularities in this condition for the G–GM group, $F1(1, 57) = 37.2$, $p < .001$; $F2(1, 10) = 15.5$, $p = .003$, and for the GM–G group, $F1(1, 57) = 45.7$, $p < .001$; $F2(1, 10) = 32.8$, $p < .001$, in a stable way across grades (no Grade × Graphotactic Constraints interaction for the two groups, Fs < 1).

Pseudo-words ending in /ɛt/. There was a main effect of grade, $F1(2, 114) = 11.8$, $p < .001$; $F2(2, 20) = 52.3$, $p < .001$, with more *ette* in fifth grade than in second and third grades, $F1(1, 114) = 22.5$, $p < .001$; $F2(1, 10) = 87.3$, $p < .001$, Fs < 1. There was a main effect of the graphotactic constraints, with ETTE frequent pseudo-words more often spelled with *ette* than were ETTE rare pseudo-words (77.4% vs. 49.1%), $F1(1, 114) = 145.2$, $p < .001$; $F2(1, 10) = 39.1$, $p < .001$. Children's spellings were also influenced by morphological constraints, with /ɛt/ more often spelled *ette* in the GM condition than in the G condition (68.0% vs. 58.5%), $F1(1, 114) = 32.3$, $p < .001$; $F2(1, 10) = 30.3$, $p < .001$. This effect was significant in the three grades (7.9% in second grade, 8.0% in third grade, and 9.0% in fifth grade, all Fs > 5.5, ps < .04).

The Order × Graphotactic Constraints × Morphological Constraints interaction was significant by participants only, $F1(1, 114) = 4.8$, $p = .03$; $F2(1, 10) = 3.3$, $p = .1$. This interaction reflected the fact that the magnitude of the graphotactic constraints effect in the GM condition was higher for the G–GM group (31.4%) than for the GM–G group (21.7%), whereas the magnitude of the graphotactic constraints effect in the G condition did not differ between the G–GM group (29.8%) and the GM–G group (30.6%). Beyond this difference, the important result was the existence of a significant graphotactic constraints effect in the GM condition for the G–GM group, $F1(1, 57) = 37.2$, $p < .001$; $F2(1, 10) = 15.5$, $p = .003$, and for the GM–G group, $F1(1, 57) = 66.8$, $p < .001$; $F2(1, 10) = 50$, $p < .001$. Furthermore, this effect was stable across grades in the two groups (no Grade × Graphotactic Constraints interactions in the GM condition for the two groups, Fs < 1).

Discussion

From the third grade onward, *eau* was used more often in the GM condition than in the G condition, at least for the G–GM group. As early as second grade, in the G–GM and GM–G groups, *ette* was used more often in the GM condition than in the G condition. We reasoned that greater use of *eau* and *ette* in the GM condition than in the G condition would reveal the impact of morphology on children's spelling, and this is the result we obtained. However, as the crucial comparison was between the writing of the same pseudo-words in isolation and within a sentence, one may argue that the difference observed between the G and GM conditions reflects some influence of the sentence independent of the specific information provided by the diminutive suffix. For instance, the sentence emphasizes the possibility of decomposing the pseudo-words into parts. This may prompt children to isolate the suffix and to deal with it as an individual chunk. This could modify its spelling irrespective of whether the morphological information about diminutiveness has been influential. This hypothesis was explored in Study 2. Study 2 showed that this alternative failed to account for the higher use of *eau* and *ette* in the GM condition than in the G condition in Study 1.

Children's transcriptions of /o/ and /ɛt/ further varied according to their preceding consonants in both the G and the GM conditions. This result extends previous studies in which the impact of the graphotactic regularities was explored as a separate issue (e.g., Cassar & Treiman, 1997; Nation, 1997; Pacton, Fayol, & Perruchet, 1999; Treiman, 1993) by showing that sensitivity to orthographic frequency patterns still influences children's spelling when they can rely on a simple, morphology-based rule. The size of the graphotactic constraints effect in the GM condition was stable across grades in the two groups. Thus, the existence of a graphotactic constraints effect in the GM condition for the G–GM group could not be explained by children's tendency to spell the pseudo-words as they did in the former G condition. Because a rule-governed behavior should no longer be influenced by whether the material is more or less familiar (e.g., Anderson, 1993; Manza & Reber, 1997; Whittlesea & Dorken, 1997), the impact of the graphotactic constraints in the GM

condition indicates that children did not rely on morphological rules such as "if /ɛt/ corresponds to a diminutive suffix, then /ɛt/ is spelled *ette*" even after 5 years of exposure to print. It could nevertheless be argued that the oldest group in Study 1 consisted of fifth graders, and that 5 years of exposure to print could be insufficient to pick up a general rule. The aim of Study 3 was to assess whether the spelling of pseudo-words by French adults was influenced by graphotactic regularities when the context provided them with clear cues for relying on morphological rules specifying how to spell the diminutive suffixes /o/ and /ɛt/.

Study 2

In Study 1, *eau* and *ette*, the correct transcriptions of /o/ and /ɛt/ when they correspond to diminutive suffixes, were more often used in the GM condition than in the G condition. Because pseudo-words were dictated in isolation in the G condition and embedded within a sentence triggering the individualization of the suffix in the GM condition, the departure between the two conditions could result from this difference rather than from the information provided about diminutiveness by the suffix. Study 2 explores whether such an alternative explanation can account for the results that we interpreted as evidence for the impact of morphology on children's spelling in Study 1. After a G condition similar to the one used in Study 1, in which participants heard "a /vitaro/" or "a /sorivɛt/," participants heard sentences such as "a tall /vitar/ is a /vitaro/" or "a tall /soriv/ is a /sorivɛt/." Thus, in this situation, the stem was also presented in isolation (/vitar /, /soriv/) and within a pseudo-word (/vitaro/, /sorivɛt/) and the information provided by the sentence also concerned the height. If the higher use of *eau* and *ette* in the GM condition than in the G condition in Study 1 only resulted from embedding pseudo-words within a sentence triggering the individualization of /o/ and /ɛt/, the use of *eau* and *ette* should also increase from the isolation condition to the sentence condition in Study 2. By contrast, if the higher use of *eau* and *ette* in the GM condition than in the G condition in Study 1 reflects the impact of the morphological information about diminutiveness on children's spelling, *eau* and *ette* should not be used differently in the isolation and sentence conditions in Study 2.

Method

Participants. We tested 20 (13 females, 7 males) third-grade children (*M* age = 9 years 1 month, *SD* = 3.9 months) and 20 (10 females, 10 males) fifth-grade children (*M* age = 10 years 9 months, *SD* = 4.2 months). Children were recruited from a French primary school located in an area of average socioeconomic status in Dijon. The 40 children met the following criteria: (a) parental permission, (b) French as native language, and (c) no language problems according to their teachers.

Stimuli. The pseudo-words used in Study 1 were used again in Study 2. The first list was identical to the one used in Study 1, with the 12 pseudo-words ending with /o/ preceded by the masculine indefinite article *un* (e.g., un /vitaro/) and the 12 pseudo-words ending with /ɛt/ preceded by the feminine indefinite article *une* (e.g., une /kalalɛt/) put in a random order. In the second list, each of the 24 pseudo-words was embedded within a sentence such as "un grand /vitar/ est un /vitaro/" ("a tall /vitar/ is a /vitaro/") or "une grande /soriv/ est une /sorivɛt/" ("a tall /kalal/ is a /sorivɛt/"). The 24 items of both lists were audiotaped using a tape recorder.

Procedure. The experiment included two sessions separated by a 1-week interval. Children were told that the experimenter had made up new words that no one had ever seen or heard before and that their task consisted in writing these "new words." Children had to spell the same pseudo-words preceded by the indefinite article *un* or *une* in the two conditions but, whereas the first list was called out in the first isolation condition, the second list was provided in the sentence condition.

Results

Leaving out phonologically incorrect transcriptions of [consonant+/o/] and [consonant+/ɛt/] endings (e.g., vitavo /vitafo/) excludes 0.5% of the spelling of pseudo-words ending in /o/ and 2.1% of the spelling of pseudo-words ending in /ɛt/. The proportion of /o/ transcribed *eau* and the proportion of /ɛt/ transcribed *ette* were separately submitted to a 2 (grade: third vs. fifth) × 2 (graphotactic constraints: EAU never vs. EAU frequent; ETTE rare vs. ETTE frequent) × 2 (condition: isolation vs. sentence) ANOVA with repeated measures on the last two variables for analyses taking participants as a random factor (i.e., *F*1). For analyses on items (i.e., *F*2), the proportion of /o/ transcribed *eau* and the proportion of /ɛt/ transcribed *ette* were separately submitted to a 2 (graphotactic constraints) × 2 (condition) × 2 (grade) ANOVA with repeated measures on the last two variables. Table 3 gives the proportion of /o/ transcribed *eau* and the proportion of /ɛt/ transcribed *ette* according to graphotactic constraints in the isolation and sentence conditions.

Table 3
Mean Percentages of /o/ Transcribed eau *(Top Panel) and of /ɛt/ Transcribed* ette *(Bottom Panel) as a Function of Conditions (Isolation vs. Sentence), Graphotactic Constraints (EAU Never vs. EAU Frequent; ETTE Frequent vs.ETTE Rare), and Grade Level: Study 2*

	Isolation condition		Sentence condition	
Grade	EAU never	EAU frequent	EAU never	EAU frequent
3	11.7	30.8	9.2	35.0
	(12.2)	(21.8)	(10.1)	(22.9)
5	12.0	33.0	15.0	36.0
	(17.4)	(27.9)	(15.7)	(24.1)
	ETTE rare	ETTE frequent	ETTE rare	ETTE frequent
3	41.7	65.8	36.7	67.5
	(34.0)	(35.2)	(32.7)	(28.9)
5	59.5	91.0	61.0	88.0
	(35.3)	(18.3)	(36.4)	(24.8)

Note. Standard deviations are in parentheses.

With regard to pseudo-words ending in /o/, as in Study 1, /o/ was more often spelled *eau* for EAU frequent pseudo-words (33.7%) than for EAU never pseudo-words (12.0%), $F1(1, 38) = 55.4$, $p < .001$; $F2(1, 10) = 45.7$, $p < .001$. However, contrary to Study 1, the proportion of *eau* did not differ significantly according to whether pseudo-words were written in isolation (21.8%) or embedded within sentences (23.8%), Fs < 1. Neither the grade level effect nor the four interactions were significant, Fs < 1.

With regard to pseudo-words ending in /ɛt/, fifth-grade children used *ette* more often than did third-grade children (78.1% vs. 49.7%), $F1(1, 38) = 6.6$, $p = .014$; $F2(1, 10) = 31.6$, $p < .001$. As in Study 1, /ɛt/ was more often spelled *ette* for ETTE frequent pseudo-words (78.1%) than for ETTE rare pseudo-words (49.7%), $F1(1, 19) = 52.0$, $p < .001$; $F2(1, 10) = 49.5$, $p < .001$. However, contrary to Study 1, the proportion of *ette* did not differ significantly according to whether pseudo-words were written in isolation (64.5%) or embedded within sentences (63.3%), Fs < 1. The four interactions were not significant, Fs < 1.

Discussion

Study 2 confirmed the influence of graphotactic regularities on children's transcription of /o/ and /ɛt/ found in Study 1. The major result of Study 2, however, was that *eau* and *ette* were not used differently according to whether pseudo-words were dictated in isolation or within sentences. This lack of difference between the isolation and sentence conditions in Study 2 shows that the increasing use of *eau* and *ette* from the G condition to the GM condition in Study 1 could not be attributed to a by-product of embedding pseudo-words within sentences but, on the contrary, did reflect the influence of derivational morphology on children's spelling.

Study 3

In Study 1, children's spellings were influenced by morphological information and by graphotactic regularities when no morphological rule could be applied (G condition) but also in conditions triggering the application of the morphological rule (GM condition). The impact of the graphotactic constraints in the GM condition, which remained stable across grades, indicated that children did not systematically rely on morphological rules such as "if /ɛt/ corresponds to a diminutive suffix, then /ɛt/ is spelled *ette*" after 5 years of exposure to print. Because 5 years of exposure to print may not be enough to pick up the morphological rules exploited in the present study, Study 3 explored whether graphotactic constraints still influenced adults' spellings in the GM condition.

Method

Participants. Participants were 60 (52 females, 8 males) students from a 1st-year psychology course (M age = 19 years 1 month, range = 17 years 11 months to 23 years 6 months). All participants were French native speakers.

Stimuli. The stimuli used in Study 3 were exactly the same as those used in Study 1.

Procedure. The same procedure was used in Studies 1 and 3, except that although the same participants practiced the G and GM conditions in Study 1, participants were assigned either to the G condition (30 participants) or to the GM condition (30 participants) in Study 3. In Study 1, a within-subject design was used to ensure that the difference between the G and GM conditions reflected the influence of morphology on children's spellings rather than participant groups. A between-subject design was used in Study 3, which was primarily aimed at assessing whether there was still an impact of graphotactic regularities in conditions triggering the application of the morphological rule (GM condition) in an adult population.

Results and Discussion

Table 4 shows the mean percentages of /o/ transcribed *eau* and of /ɛt/ transcribed *ette* as a function

Table 4
Mean Percentages of /o/ Transcribed eau *and of /ɛt/ Transcribed* ette *as a Function of Morphological Constraints (G Condition vs. GM Condition), Graphotactic Constraints (EAU Never vs. EAU Frequent and ETTE Rare vs. ETTE Frequent): Study 3*

	/o/ pseudo-words		/ɛt/ pseudo-words	
Condition	EAU never	EAU frequent	ETTE rare	ETTE frequent
G	16.7	50.6	51,7	75.6
	(18.6)	(16.7)	(32.0)	(22.6)
GM	31.1	62.8	69.4	88.9
	(22.2)	(34.7)	(29.1)	(17.1)

Note. Standard deviations are in parentheses. G = only graphotactic constraints; GM = graphotactic and morpological constraints.

of graphotactic constraints, morphological constraints, and condition. There were main effects of the morphological constraints, with greater use of *eau* in the GM condition (47%) than in the G condition (33.7%), $F1(1, 58) = 6.1$, $p = .016$; $F2(1, 10) = 17.0$, $p = .002$, and likewise more use of *ette* in the GM condition (79.1%) than in the G condition (63.7%), $F1(1, 58) = 6.9$, $p = .01$; $F2(1, 10) = 20.1$, $p = .001$. There were also main effects of the graphotactic regularities for pseudo-words ending with /o/ (56.7% vs. 23.9%), $F1(1, 58) = 114.4$, $p < .001$; $F2(1, 10) = 35.5$, $p < .001$, and for pseudo-words ending with /ɛt/ (82.2% vs. 60.5%), $F1(1, 58) = 114.4$, $p < .001$; $F2(1, 10) = 35.5$, $p < .001$. As for elementary school children, there was no interaction between the morphological and graphotactic constraints for pseudo-words ending in /o/, $F1(1, 58) = 0.1$, $p = .7$; $F2(1, 10) = 0.1$, $p = .7$, and for pseudo-words ending in /ɛt/, $F1(1, 58) = 0.5$, $p = .5$; $F2(1, 10) = 3.0$, $p = .11$. Analyses for the sole GM condition confirmed the existence of significant graphotactic constraint effects in this condition, for pseudo-words ending in /o/, $F1(1, 29) = 39.9$, $p < .001$; $F2(1, 10) = 21.3$, $p < .001$, as well as for pseudo-words ending in /ɛt/, $F1(1, 29) = 21.9$, $p < .001$; $F2(1, 10) = 5.7$, $p = .04$.

Thus, adults' spellings were influenced by graphotactic constraints even in conditions triggering the application of the morphological rule, as were the spellings of the elementary school children in Study 1.

General Discussion

In the present study, a pseudo-word spelling task was used to explore children's (implicit) learning of graphotactic regularities and derivational morphology. An interesting characteristic of the French written language is that graphotactic constraints (that are probabilistic) and morphological constraints (that are describable by an abstract, general rule) can be used to guide the transcription of the same sound. This allowed us (a) to explore the joint influence on children's spelling of two types of information (morphology and graphotactic regularities) that are usually explored independently and (b) to assess whether spelling was driven by rules or statistical processes. If rules are actually involved, graphotactic regularities should lose their influence on spelling when this latter can be determined by morphological rules.

Sensitivity to Graphotactic Regularities

As early as second grade, children used many different written forms to transcribe /o/ and /ɛt/. We focused on the fact that children's use of *eau* and *ette* varied as a function of their preceding consonants. However, their use of spellings other than *eau* and *ette* also varied as a function of the preceding consonants. For example, in the G condition in Study 1, the fifth graders of the G–GM group spelled /o/ as *aut* more often after *-f* than after *-r* (7 vs. 2) and spelled /ɛt/ as *ête* more often after *-t* than after *-ch* (18 vs. 1), which corresponds to the distribution in Brulex (Tokens: 7,112 for *faut* vs. 153 for *raut*; 65,245 for *tête* vs. 0 for *chête*; Content et al., 1990). Thus, from an early age, children did not rely on phonemes and graphemes independently of the context (Pacton et al., 1999). One possibility is that the size of the sound-to-spelling correspondences on which children base their spellings is larger than the phoneme-grapheme unit (e.g., Nation, 1997; Nation & Hulme, 1996). Another possibility is that children rely on phonemes and graphemes but that the associations are sensitive to context. Children could be sensitive to graphotactic regularities, that is, to regularities relative to the order of letters. For instance, *eau* is frequently attached to *-v* but not to *-f*, independent of any regularity at a phonological level. In favor of this account, there is empirical evidence of statistical learning of the order of visual shapes (e.g., Fiser & Aslin, 2002). However, children could also be sensitive to the association between *eau* and certain sounds (e.g., *eau* is more often associated with /v/ than with /f/). If this were the case, it would be more appropriate to say that children are sensitive to phonographotactic regularities. The choice between these two accounts calls for further specifically devised studies.

Children's increasing sensitivity to the frequency or position of different patterns of the written language to which they are exposed is a further example of sensitivity to the distributional features of input, which has been reported in humans of all ages. For instance, after exposure to a synthesized speech stream composed of multisyllabic nonsense words, 8-month-old infants distinguished word from nonword syllable sequences when the only cues to word boundaries were in the distributional or statistical properties of the input (Saffran, Newport, & Aslin, 1996; see Saffran, Johnson, Aslin, & Newport, 1999 for similar results with streams of tones). In AGL studies, adult participants learned the frequency of chunks of information, such as two- or three-letter groupings (Perruchet & Pacteau, 1990) and their position (Reber & Allen, 1978). Sensitivity to statistical regularities in the written language domain further strengthens the idea that the development of such sensitivity is subtended by general learning mechanisms (Bates & Elman, 1996; Christiansen & Curtin, 1999; Perruchet & Vinter, 1998; Redington & Chater, 1998).

Sensitivity to Morphological Regularities

To assess the impact of derivational morphology on children's spelling, we compared children's use of *eau* and *ette* (the conventional transcriptions of the diminutive suffixes /o/ and /ɛt/) according to whether the same pseudo-words were spelled in isolation (e.g., "a /sorivɛt/," G condition) or embedded within sentences, indicating that pseudo-words were composed of a stem followed by a diminutive suffix (e.g., "a little /soriv/ is a /sorivɛt/," GM condition). In Study 1, *ette* was used more often in the GM condition than in the G condition as early as second grade. The same effect was observed from third grade onward for *eau*. Embedding the same pseudo-words within sentences in which /o/ and /ɛt/ were not diminutive suffixes anymore did not increase children's use of *eau* and *ette* (Study 2), indicating that the higher use of *eau* and *ette* in the GM condition than in the G condition in Study 1 was linked to the morphological information provided by the "a little" context.

The derivational morphology effect occurred earlier for pseudo-words ending in /ɛt/ (second grade) than for pseudo-words ending in /o/ (third grade) probably because a larger proportion of words ending in *ette* are diminutives than are words ending in *eau*. This is true in French in general but more specifically in children's books. Children may be particularly sensitive to the morphological structure of words ending with the diminutive morpheme *ette* because words such as *fille* (girl) and *fillette* (little girl) are frequent in their books. Beyond this difference and its potential roots, this study adds to the growing body of evidence (e.g., Bryant et al., 2000; Pacton, 2001; Treiman et al., 1994; Treiman & Cassar, 1996) that children use morphological information much earlier than is postulated by traditional stage models of spelling acquisition (e.g., Frith, 1985; Henderson, 1985).

Integrating Graphotactic and Morphological Constraints and the Abstraction Issue

The crucial comparison was between children's spellings of pseudo-words that can be spelled through reliance on the same morphological rule (e.g., "/ɛt/ is transcribed *ette* when it corresponds to a diminutive suffix") but that differ in terms of graphotactic regularities (e.g., /ɛt/ preceded by a consonant after which /ɛt/ is frequently or rarely spelled *ette*). Our reasoning was that if spellers have (implicitly) abstracted rules specifying how to transcribe /o/ and /ɛt/ when they correspond to diminutive morphemes, the graphotactic constraints effect, expected and observed in the G condition, should no longer be observed in the GM condition. Although participants took into account the morphological information, as testified by the higher use of *eau* and *ette* in the GM condition than in the G condition, their use of *eau* and *ette* varied as a function of the graphotactic constraints in the GM condition. This happened regardless of whether the GM condition followed (G–GM groups) or preceded (GM–G groups) the G condition. Furthermore, there was no trend toward a reduction in the magnitude of the graphotactic regularities impact in the *GM* condition from the second to the fifth grades in Study 1, and the impact of the graphotactic regularities was still observed among adult participants in Study 3. This echoes Kemp and Bryant's (2003) study in which children and adults correctly used *-s* for plural pseudo-words more often when the final /z/ was preceded by a consonant than when it was preceded by a long vowel, despite the possibility of relying on a rule specifying that plural nouns are spelled with *-s*.

These results are problematic for rule-based proponents of implicit learning (e.g., Manza & Reber, 1997). Indeed, according to them, performances on implicit learning tasks vary according to the familiarity of the material used to assess participants' learning because the test takes place at a point in training when the rule-abstraction process is not yet

fully completed. This account works well in lab studies in which training is necessarily restricted. However, it no longer applies in natural situations involving a massive amount of practice.

The pervasive impact of the graphotactic constraints in the GM condition, even after massive exposure to print, can be accounted for by a statistical perspective in which learning processes can apply to features that are abstracted away from their sensory content (Perruchet & Vinter, 2002a, 2002b; Redington & Chater, 2002). According to this perspective, abstract features such as diminutiveness can become associated with features such as "ends in *ette*." Children's learning of this association would lead them to use *ette* more often when pseudo-words such as /vitarɛt/ are embedded within sentences such as "a little /vitar/ is a /vitarɛt/." Associations between other features would also be established. In particular, as words with the final *ette* preceded by the letter *-v* (or the sound /v/) are far more frequent than words with the final *ette* preceded by the letter *-f* (or the sound /f/), the association between *-v* and *ette* (or between /v/ and *ette*) would be stronger than the association between *-f* and *ette* (or between /f/ and *ette*). Therefore, *ette* would be less often used for pseudo-words such as /vitafɛt/ than for pseudo-words such as /vitavɛt/ in the G and GM conditions. Thus, the graphotactic constraints effect persisted in the GM condition because even though children encountered more words ending with *eau* and *ette* in which the final /o/ and /ɛt/ stood for diminutive suffixes, words in which *ette* followed the letter *-v* (or the sound /v/) always outnumber words in which *ette* followed the letter *-f* (or the sound /f/).

A second account of the results that does not rely on abstract rule-based knowledge comes from the consideration that pseudo-words are spelled by analogy to real words. In this account, the effect of graphotactic regularities is due to the fact that the consonantal context is certainly a dimension relevant for drawing an analogy. For instance, a pseudo-word ending in /rɛt/ will preferentially evoke a word ending in /rɛt/; likewise, a pseudo-word ending in /fɛt/ will preferentially evoke a word ending in /fɛt/. Because a word ending in /rɛt/ has more chance of being spelled *ette* than a word ending in /fɛt/, the same outcome will be observed for a pseudo-word similar on this dimension. However, an analogy could also rely on more abstract features, such as the notion of diminutiveness, in the same way as statistical analysis can take both surface and abstract features as primitives. Because a diminutive word is spelled *ette*, the same outcome will be observed for a pseudo-word sharing this feature. Therefore, this interpretation also accounts for children's sensitivity to morphological rules. Moreover, the fact that the graphotactic constraint effect persists in the GM condition finds a natural explanation. Indeed, there is no a priori reason to assume that the notion of diminutiveness systematically provides a better cue for drawing an analogy than the phonological dimension. Thus, our findings may result from the fact that analogies could be based on one or the other of multiple dimensions, as a function of various factors. The choice between this latter account and an interpretation based on the extraction of statistical regularities calls for further specially devised studies. This kind of alternative is common to many domains. Without prejudging a conclusion for the specific issue dealt with in this article, it is worth noting that studies conducted in other domains have generally concluded that the analogy to specific words cannot account for the whole pattern of results (e.g., Bailey & Hahn, 2001; Perruchet, 1994).

A third interpretation of the persistence of the graphotactic constraints effect in the diminutive condition is that even though the morphological units are /o/ and /ɛt/, the association between /o/ and *eau*, on the one hand, and between /ɛt/ and *ette*, on the other hand, could be established at level other than that of the morpheme. For example, when words such as *éléphanteau* (baby elephant) are encountered in a context in which it is associated with the feature of diminutiveness, an association could be established between the diminutiveness and /to/ or *teau* rather than between the diminutiveness and /o/ or *eau*. According to this account, participants would use *eau* when they are told that a little /klat/ is a /klato/, but they would be less inclined to use *eau* when they are told that a /klafo/ is a little /klaf/ because /fo/ does not sound like a diminutive (see Kemp & Bryant, 2003, for a similar interpretation). Note also one could argue that participants learn rules that are specific and idiosyncratic rather than general (e.g., /to/ is spelled *teau* when it is a diminutive suffix). Such an interpretation in terms of rules that have limited scope, which would apply or not as a function of the context or the familiarity with the situation, would account for the graphotactic effect observed in the GM condition. However, in so doing, it loses what makes rules attractive, namely, their propensity to apply in a large number of situations irrespective of the participant's familiarity with these situations. If rules apply only in situations where simpler accounts work well, respect of the Occam's razor principle leads us to suggest that an abstractionist, rule-based position should be discarded.

Conclusion

In the present study, children's spellings were influenced by graphotactic regularities even in conditions triggering the application of a morphological rule. Indeed, children's and adults' correct transcription of /o/ and /ɛt/ varied as a function of graphotactic regularities despite the possibility of relying on simple rules such as "/ɛt/ is transcribed *ette* when it corresponds to a diminutive." Furthermore, the magnitude of this effect persisted over grade levels without any trend toward fading, as well as with adults. When coupled with other studies in which children or adults did not rely on morphological rules to spell pseudo-words (Kemp & Bryant, 2003; Nunes et al., 1997b) and words (Kemp & Bryant, 2003; Pacton & Fayol, 2003), it appears difficult to reconcile these data with the idea that participants rely on increasingly abstract, rule-based knowledge about the regularities contained in the material over training. The interesting picture that emerges from studies exploring whether children acquire implicitly orthographic and morphological rules is that similar trends are observed for aspects of the written language that are semantically grounded, such as inflectional morphology (Kemp & Bryant, 2003; Nunes et al., 1997b) and derivational morphology (the present study) and for aspects of the written language that are not semantically or morphologically grounded (e.g., the legal position of double letters; Pacton et al., 2001). The generality of this finding needs to be confirmed using other aspects of the written language. Nevertheless, these results are interesting because one could have hypothesized that spellers' orthographic behavior would be more likely to be rule directed for semantically grounded aspects of the language.

These results have significance for spelling acquisition. Many authors (e.g., Lennox & Siegel, 1994; Snowling, 1994; Treiman & Cassar, 1997) have emphasized the need to develop theories of spelling that do not follow a stage-like framework but that, conversely, take into account the relationships between the different sources of information (phonological, morphological, and lexical) that influence spelling. For this reason, it is crucial to study simultaneously the impact of different sources of information and their potential interactions. From this perspective, an important result of the present study is that sensitivity to graphotactic regularities, which has already been well documented when explored for itself (e.g., Cassar & Treiman, 1997; Pacton et al., 2001), still influences the performances of spellers even when they can rely on a simple, morphology-based rule.

References

Altmann, G. T. M., Dienes, Z., & Goode, A. (1995). On the modality-independence of implicitly learned grammatical knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 899–912.

Anderson, J. R. (1993). *Rules of mind*. Hillsdale, NJ: Erlbaum.

Bailey, T., & Hahn, U. (2001). Determinants of wordlikeness: Phonotactics or lexical neighborhoods? *Journal of Memory and Language*, *44*, 568–591.

Bates, E., & Elman, J. (1996). Learning rediscovered. *Science*, *274*, 1849.

Beers, C. S., & Beers, J. W. (1992). Children's spelling of English inflectional morphology. In S. Templeton & D. R. Bear (Eds.), *Development of orthographic knowledge and the foundations of literacy* (pp. 231–251). Hillsdale, NJ: Erlbaum.

Berry, D. C., & Dienes, Z. (1993). *Implicit learning: Theoretical and empirical issues*. Hillsdale, NJ: Erlbaum.

Bryant, P., Nunes, T., & Snaith, R. (2000). Children learn an untaught rule of spelling. *Nature*, *13*, 157–158.

Cassar, M., & Treiman, R. (1997). The beginnings of orthographic knowledge: Children's knowledge of double letters in words. *Journal of Educational Psychology*, *89*, 631–644.

Catach, N. (1986). *L'orthographe française*. Paris: Nathan.

Christiansen, M. H., & Curtin, S. L. (1999). Transfer of learning: Rule acquisition or statistical learning? *Trends in Cognitive Sciences*, *3*, 289–290.

Cleeremans, A., Destrebecqz, A., & Boyer, M. (1998). Implicit learning: News from the front. *Trends in Cognitive Sciences*, *2*, 406–416.

Content, A., Mousty, P., & Radeau, M. (1990). Brulex. Une base de données lexicales informatisée pour le Français écrit et parlé. *Année Psychologique*, *90*, 551–566.

Dienes, Z., & Altmann, G. T. M. (1997). Transfer of implicit knowledge across domains: How implicit and how abstract? In D. C. Berry (Ed.), *How implicit is implicit learning?* (pp. 107–123). Oxford, England: Oxford University Press.

Fiser, J., & Aslin, R. N. (2002). Statistical learning of higher-order temporal structure from visual shape-sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*, 458–467.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: Neuropsychological and cognitive studies of phonological reading* (pp. 301–330). London: Routledge & Kegan Paul.

Gomez, R. L. (1997). Transfer and complexity in artificial grammar learning. *Cognitive Psychology*, *33*, 154–207.

Gomez, R. L., & Gerken, L. A. (2000). Infant artificial language learning and language acquisition. *Trends in Cognitive Sciences*, *4*, 178–184.

Gomez, R. L., Gerken, L., & Schvaneveldt, R. W. (2000). The basis of transfer in artificial grammar learning. *Memory & Cognition*, *28*, 253–263.

Henderson, L. (1985). *Teaching spelling*. Boston: Houghton Mifflin.

Jaffré, J. P., & Fayol, M. (1997). *Orthographe: Des systèmes aux usages*. Paris: Flammarion.

Kemp, N., & Bryant, P. (2003). Do beez buzz? Rule-based and frequency-based knowledge in learning to spell plural *-s*. *Child Development*, *74*, 63–74.

Knowlton, B. J., & Squire, L. R. (1996). Artificial grammar learning depends on implicit acquisition of abstract and exemplar-specific information. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *22*, 169–181.

Lennox, C., & Siegel, L. S. (1994). The role of phonological and orthographic processes in learning to spell. In G. D. A. Brown & N. Ellis (Eds.), *Handbook of spelling: Theory, process and intervention* (pp. 93–109). Chichester, England: Wiley.

Manza, L., & Reber., A. S. (1997). Representing artificial grammar: Transfer across stimulus forms and modalities. In D. C. Berry (Ed.), *How implicit is implicit learning?* (pp. 73–106). Oxford, England: Oxford University Press.

Michas, I., & Berry, D. C. (1994). Implicit and explicit processes in a second language learning task. *European Journal of Cognitive Psychology*, *6*, 357–381.

Nation, K. (1997). Children's sensitivity to rime unit frequency when spelling words and nonwords. *Reading and Writing*, *9*, 321–338.

Nation, K., & Hulme, C. (1996). The automatic activation of sound-letter knowledge: An alternative interpretation of analogy and priming effects in early spelling development. *Journal of Experimental Child Psychology*, *63*, 416–435.

Nunes, T., Bryant, P., & Bindman, M. (1997a). Morphological spelling strategies: Developmental stages and processes. *Developmental Psychology*, *33*, 637–649.

Nunes, T., Bryant, P., & Bindman, M. (1997b). Learning to spell regular and irregular verbs. *Reading and Writing*, *9*, 427–449.

Pacton, S. (2001). *Children's linguistic awareness and spelling: The case of derivational morphology*. Congress of the European Society for Cognitive Psychology, Edinburg, Scotland.

Pacton, S., & Fayol, M. (2003). How do French children use morphosyntactic information when they spell adverbs and present participles? *Scientific Studies of Reading*, *7*, 273–287.

Pacton, S., Fayol, M., & Perruchet, P. (1999). L'apprentissage de l'orthographe lexicale: le cas des régularités. *Langue Française*, *124*, 23–39.

Pacton, S., Perruchet, P., Fayol, M., & Cleeremans, A. (2001). Implicit learning out of the lab: The case of orthographic regularities. *Journal of Experimental Psychology: General*, *130*, 401–426.

Perruchet, P. (1994). Defining the knowledge units of a synthetic language: Comment on Vokey and Brooks (1992). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*, 223–228.

Perruchet, P., & Pacteau, C. (1990). Synthetic grammar learning: Implicit rule abstraction or explicit fragmentary knowledge? *Journal of Experimental Psychology: General*, *119*, 264–275.

Perruchet, P., & Vinter, A. (1998). PARSER: A model for word segmentation. *Journal of Memory and Language*, *39*, 246–263.

Perruchet, P., & Vinter, A. (2002a). The self-organizing consciousness (target paper). *Behavioral and Brain Sciences*, *25*, 297–330.

Perruchet, P., & Vinter, A. (2002b). The self-organizing consciousness: A framework for implicit learning. In R. M. French & A. Cleeremans (Eds.), *Implicit learning and consciousness: An empirical, philosophical, and computational consensus in the making* (pp. 41–67). London: Psychology Press.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, *6*, 855–863.

Reber, A. S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconsciousness*. New York: Oxford University Press.

Reber, A. S., & Allen, R. (1978). Analogic and abstraction strategies in synthetic grammar learning. *Cognition*, *6*, 189–221.

Redington, M., & Chater, N. (1996). Transfer in artificial grammar learning: A re-evaluation. *Journal of Experimental Psychology: General*, *125*, 123–138.

Redington, M., & Chater, N. (1998). Connectionist and statistical approaches to language acquisition: A distributional perspective. *Language and Cognitive Processes*, *13*, 129–191.

Redington, M., & Chater, N. (2002). Knowledge representation and transfer in artificial grammar learning (AGL). In R. M. French & A. Cleeremans (Eds.), *Implicit learning and consciousness: An empirical, philosophical, and computational consensus in the making* (pp. 121–143). London: Psychology Press.

Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*, 27–52.

Saffran, J. R., Newport, E. L., & Aslin, R. N. (1996). Word segmentation: The role of distributional cues. *Journal of Memory and Language*, *35*, 606–621.

Shanks, D. R., Johnstone, T., & Staggs, L. (1997). Abstraction processes in artificial grammar learning. *Quarterly Journal of Experimental Psychology*, *50A*, 216–252.

Smith, E. E., Langston, C., & Nisbett, R. E. (1992). The case for rules in reasoning. *Cognitive Science*, *16*, 1–40.

Snowling, M. (1994). Towards a model of spelling acquisition: The development of some component skills. In G. D. A. Brown & N. Ellis (Eds.), *Handbook of spelling: Theory, process and intervention* (pp. 111–128). Chichester, England: Wiley.

Tillmann, B., Bharucha, J., & Bigand, E. (2000). Implicit learning of tonality: A self-organizing approach. *Psychological Review*, *107*, 885–913.

Totereau, C., Barrouillet, P., & Fayol, M. (1998). Overgeneralizations of number inflections in the learning of

written French: The case of noun and verb. *British Journal of Developmental Psychology, 16*, 447–464.

Treiman, R. (1993). *Beginning to spell: A study of first-grade children*. New York: Oxford University Press.

Treiman, R., & Cassar, M. (1996). Effects of morphology on children's spelling of final consonant clusters. *Journal of Experimental Child Psychology, 63*, 141–170.

Treiman, R., & Cassar, M. (1997). Spelling acquisition in English. In C. A. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell: Research, theory, and practice across languages* (pp. 61–80). Mahwah, NJ: Erlbaum.

Treiman, R., Cassar, M., & Zukowski, A. (1994). What types of lingustic information do children use in spelling? The Case of flaps. *Child Development*, *65*, 1310–1329.

Tunney, R. J., & Altmann, G. T. M. (1999). The transfer effect in artificial grammar learning: Re-appraising the evidence on the transfer of sequential dependencies. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *25*, 1322–1333.

Whittlesea, B. W. A., & Dorken, M. D. (1997). Implicit learning: Indirect, not unconscious. *Psychonomic Bulletin and Review, 4*, 63–67.

Whittlesea, B. W. A., & Wright, R. L. (1997). Implicit (and explicit) learning: Acting adaptively without knowing the consequences. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *23*, 181–200.

Endnote

[1]The written forms *eau* and *ette* do not always correspond to diminutives in French. For instance, the words *rateau* (rake) and *crevette* (shrimp) end, respectively, by *eau* and *ette* but are monomorphemic words. There is one exception to the rule of formation of the diminutive /o/: in the word *chiot* (pup); the diminutive suffix /o/ is not transcribed *eau* but *ot*. However, the word *chiot* does not end like the other words, that is, with a consonant sound followed by /o/ but by a vowel sound followed by /o/.