**A written word is worth a thousand spoken words: The influence of spelling on spoken-word production**

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**Abstract**

The present study investigated the role of spelling in phonological variant processing. Participants learned the auditory forms of potential reduced variants of novel French words (e.g., /pluʀ/) and their associations with pictures of novel objects over four days. After the fourth day of training, the spelling of each novel word was presented once. Half the words were spelled with an orthographic representation of the schwa (i.e., “e”), half were not. In the subsequent naming tasks, participants produced more schwa variants for novel words whose spelling contained an “e”. In addition, reduced variants with an “e” in spelling and an onset cluster attested word-internally in non-schwa words were produced with longer latencies than the same items whose spelling did not contain an “e”. Finally, in a recognition task where participants had to decide whether a given spoken item was part of the experimental stimuli trained the previous days, participants were more likely to say yes to a schwa variant when the spelling for the given word corresponded to this variant. These results show that a single exposure to spelling following extensive phonological learning can change the way speakers and listeners store and process words with phonological variants both in production and recognition tasks.

**Key words:** Phonological variation, novel words, French schwa, lexical representations, spoken word production, spoken word recognition

**Introduction**

In connected speech, words are not always realized in their canonical forms. One source of variability comes from so-called phonological variation processes. Words affected by these processes are often described as having two pronunciation variants, a canonical form, and a non-canonical form[[2]](#footnote-2). The latter can differ from the former via deletion (e.g., schwa deletion in English, Dalby, 1986; French, Dell, 1985; Dutch, Booij, 1995), insertion (e.g., French liaison, Encrevé, 1988), or substitution of one phoneme (e.g., flapping in American English, Zue & Laferriere, 1979; voice assimilation in French, Snoeren, Hallé, & Segui, 2006).

One important issue regarding phonological variation processes concerns the representations and cognitive mechanisms underlying the production and recognition of their non-canonical variants. Resolving this issue is crucial for our understanding and modelling of how speakers process words in connected speech, i.e., everyday forms of speech.

Several researchers have suggested that the way we process or represent words affected by phonological variation processes could be influenced by these words’ spellings. For word production, Bürki, Alario, and Frauenfelder (2011) examined the lexical representation of French schwa words (e.g., *seringue* ‘syringe’), which have two variants, a schwa ([]) and a non-schwa or reduced variant ([]). In French, these variants differ in a categorical way (e.g., Côté & Morrison, 2007; Dell, 1985), with schwa being either fully present or fully absent (unlike, for instance, English schwa words such as *p****o****tato,* where the deletion of a schwa in pre-stress position is a gradient process; Davidson, 2006). Bürki et al. used pseudohomophones (sequences of letters that do not form real words but are pronounced like existing words) of these words that matched either the schwa variant (e.g., “ceraingue” for *seringue*) or the reduced variant (e.g., “srainge” for *s’ringue*). In a naming task, these items were compared with matched pseudowords (e.g., “sireaugue” and “sreaugue”). The authors found an RT advantage for pseudohomophones for both variant types. Similar pseudohomophone effects have been reported for non-variant words and are taken to reflect the activation of the matching stored phonological representation in the output lexicon (e.g., Borowsky, Owen, & Masson, 2002; Grainger, Spinelli, & Ferrand, 2000; McCann & Besner, 1987; Seidenberg, Petersen, Plaut, & MacDonald, 1996). Bürki et al.’s results suggest that representations of both the schwa and the reduced variants of French schwa words are stored in the mental lexicon (see Bürki & Gaskell, 2012, for a similar conclusion about English words with a post-stress schwa, e.g., *cam****e****ra*). The hypothesis that French schwa words have two corresponding representations was further assessed in a subsequent study. Bürki and Frauenfelder (2012) asked French participants to learn the associations between pictures of non-existing objects and novel schwa words (e.g., /ʃənyk/) presented auditorily. The novel words varied in their alternating status (i.e., whether these words were learned with one or two variants). A subsequent picture naming task revealed that production latencies were longer for the same items (schwa or reduced variants) learned as alternating words (i.e., with two variants) than as words with only one pronunciation variant. This finding suggests that a schwa and a non-schwa representation were generated for alternating novel schwa words, and that the two representations competed for production.

Crucially for our purposes, Bürki et al. (2011) also found that speakers appeared to represent variants they rarely or never uttered. For instance, Swiss French speakers, who mostly use the reduced variants of words with a schwa in the second syllable (e.g., *casserole* ‘pot’), nevertheless appeared to store representations of schwa variants. According to Bürki et al., a possible explanation for this finding is that the lexicon contains a phonological representation based on a word’s spelling even when that variant is never produced. However, other plausible explanations exist. It could be that French speakers have encountered or used the spoken forms of the non-used variants on a few occasions, and this limited exposure was sufficient to generate a lexical representation for these variants. A further alternative is that speakers may infer the existence of a variant on the basis of the phonotactic properties of the word. For instance, they might deduce that the word form [] from c*lavecin ‘harpsichord’* has a corresponding schwa variant given that the cluster [vs] does not exist in French non-schwa words.

Correspondence with a word’s spelling has also been regularly proposed as a post hoc explanation of findings in the recognition domain. Racine and Grosjean (2005) examined the recognition of French non-initial schwa words by Swiss participants and showed that the recognition of non-produced schwa variants was not delayed when compared with recognition of the corresponding reduced variants that were typically used in production. Racine and Grosjean suggested that the correspondence of the schwa variants with the spelling could explain why these variants were not recognized more slowly. Similarly, Ranbom and Connine (2007) found that nasal flapped variants in American English (e.g., *gentle* produced []) were recognized with longer response times than non-flapped variants ([]), even though they were much more frequent. In addition, they observed that the recognition speed of flapped variants was modulated by their frequency, whereas that of the non-flapped variants was not. Ranbom and Connine suggested that both variants could be lexically represented, with the representation of the rarely used variant possibly being derived from orthography (see also Connine, 2004). Importantly, however, whereas correspondence with the word’s spelling provides a neat explanation for several results in the field, it remains post hoc and has never been directly tested. Furthermore, traditional psycholinguistic paradigms based on existing words cannot be used to discriminate this account from the alternatives described above, as they do not allow control over speakers’ previous exposures to variants. Full control of this variable requires the use of artificial word learning paradigms.

The present research has two aims. Its first aim is to examine the hypothesis that exposure to a word’s spelling is sufficient to generate a corresponding phonological representation. This will answer the question of whether the finding that speakers represent variants they do not use (Bürki et al., 2011) can indeed be attributed to the influence of spelling, or is due to the speakers’ occasional exposure to these variants’ spoken forms. This issue is important because it provides information about how lexical representations of word pronunciation are created and maintained.

The second and more general aim of this research is to add to our understanding of the ways in which orthographic knowledge can influence spoken word production. Words affected by phonological variation processes provide us with a perfect test case to address this question, given that one of their variants corresponds to the spelling whereas the other does not.

Most studies of the role of spelling in spoken word processing have focused on recognition tasks. An influence of orthographic form has been found in numerous studies, using a wide range of experimental paradigms (e.g., rhyme detection and rhyme similarity judgements, Seidenberg & Tanenhaus, 1979; phoneme monitoring, Dijkstra, Roelofs, & Fieuws, 1995; unimodal priming paradigm with offset overlap, Chéreau, Gaskell, & Dumay, 2007; same/different task involving mispronunciations, Ranbom & Connine, 2011; masked priming with homophones, Grainger & Ferrand, 1994). Several studies also relied on the manipulation of orthographic consistency and found that RTs, in a variety of tasks, were faster for words whose spelling to sound correspondences are consistent than for words that could potentially be spelled in different ways (e.g., Montant, Schön, Anton, & Ziegler, 2011; Perre, Pattamadilok, Montant, & Ziegler, 2009; Petrova, Gaskell, & Ferrand, 2011; Ziegler & Ferrand, 1998; Ziegler, Petrova, & Ferrand, 2008). Additional evidence suggesting an influence of spelling on spoken word processing comes from studies comparing skilled and beginning readers. For instance, Ziegler and Muneaux (2007) compared the performance of advanced and beginning readers in an auditory lexical decision task, and showed that advanced readers were influenced by the number of orthographic neighbours, whereas beginning readers were not.

Whereas some of these studies’ findings suggest that the influence of spelling occurs because the orthographic form is automatically activated on-line whenever listeners process a spoken word (e.g., Chéreau et al., 2007; Pattamadilok, Perre, Dufau, & Ziegler, 2009), others suggest that the phonological representations built during early word learning in children have been modified off-line when these children learnt to read and encoded the words’ spellings (e.g., Montant et al., 2011; Perre et al., 2009; Ranbom & Connine, 2011; see also Taft, 2006). The two mechanisms are, however, not mutually exclusive and likely take place in parallel.

In contrast to recognition research, the issue of whether orthographic knowledge influences spoken word production is controversial. Whereas some studies suggest that this is indeed the case, others claim that such effects are specific to the task or population examined and do not generalize to other tasks or populations. A first line of evidence suggesting that spelling may affect spoken word production is found in second language learning studies. These studies suggest that exposure to the spelling interacts with the phonological input, affecting second-language learners’ representations and, consequently, their pronunciations. For instance, even though German final obstruents are always devoiced, English learners of this language tend to produce them with voicing, because their orthography corresponds to voice obstruents (Young-Scholten, 2002). These results are however specific to second-language learning and cannot be generalized to word production in one’s native language without further empirical support. A major and crucial difference between the two populations concerns the respective roles of phonological and orthographic information in the course of the learning process. Whereas a first language is initially learnt on the sole basis of phonological information, second language learning usually involves access to the spelling from the very start.

A few studies have also reported evidence suggesting an influence of orthographic information in native speakers’ productions. For instance, Gaskell, Cox, Foley, Grieve, and O’Brien (2003) have found that the spelling of the following word influences which form speakers select for the indefinite (a/an) and definite (the/thee) English singular determiners. This finding suggests an influence of the following word’s spelling on the production of determiners, but does not show whether a word’s own spelling influences its production.

Damian and Bowers (2003) examined the influence of a word’s spelling on its production using a version of the word-form preparation paradigm. Within an experimental block, participants memorized three word pairs (e.g., *fruit-melon*) and were then asked to produce the second of the pair (target) upon seeing a visual representation of the first. Three conditions were compared. In the first, the three target words of the block overlapped in spelling and phonology. In the second, they shared neither the spelling nor the phonology. In the final condition the three target words shared phonology but not spelling. Results revealed that production latencies to target words were shorter in the first condition compared with the other two. The presence of phonological facilitation in condition 1 and its absence in condition 3 was taken to suggest an interaction between phonology and spelling. Several authors have argued, however, that the influence of spelling in such tasks has its locus in the memorisation component rather than in production *per se* (e.g., Alario, Perre, Castel, & Ziegler, 2007). In line with this explanation, subsequent studies failed to find evidence in favour of an influence of a word’s spelling in similar production tasks with no memory component. For instance, Alario et al. (2007) used the same methodology as Damian and Bowers but asked their participants to name the pictures rather than produce a word upon seeing a written prompt. They found that production latencies were facilitated in blocks where several words had the same onset phoneme, irrespective of the orthographic properties of these words. Similar results were obtained by Roelofs (2006) in Dutch and Bi, Wei, Janssen, and Han (2009) in Mandarin Chinese.

In order to avoid the methodological issues raised by these previous studies Rastle, McCormick, Bayliss, and Davis (2011) examined the influence of spelling on spoken word production with a word learning paradigm. They asked their participants to learn associations between spoken novel words and novel pictures. The following day, their participants learned the spellings of the novel words. Spelling-to-sound relationships were varied, with the spelling of the initial phoneme conforming to either regular English spelling-to-sound correspondences (e.g., the phoneme /k/ spelled *k*) or irregular ones (e.g., /k/ spelled *ch*). On the third day, participants had to name the pictures. Results showed that the novel words whose spellings were regular were named faster than those with irregular spellings, suggesting an influence of orthographic knowledge in spoken-word production. A possible explanation for the discrepancies between the results of these studies lies in the different nature of the spelling effect examined. The form preparation paradigm used in Alario et al. (2007), Bi et al. (2009), and Roelofs (2006) is meant to detect an on-line activation of orthographic information during the production process. By contrast, and as revealed by recent evidence in the word recognition domain, consistency effects such as the ones reported by Rastle and colleagues are likely driven by a restructuring of phonological representations (Montant et al., 2011; Perre et al., 2009). Possibly, and unlike for spoken word recognition, the orthographic code only influences spoken word production via an off-line restructuring of the phonological representations.

This review clearly shows that evidence is mixed relating to the influence of orthography on production in tasks where the spelling is *a priori* irrelevant. In addition, the locus of this influence (i.e., on-line versus off-line mechanism) has not yet been examined directly. In the present study, we will seek novel evidence that orthographic knowledge influences word production. More importantly, we will examine the hypothesis that this influence can be related to an off-line restructuring of the pre-existing phonological representations.

In order to examine the role of exposure to spelling in phonological variant processing, we used French novel potential non-schwa variants (i.e., with a possible schwa in their first syllable). The use of novel words was crucial for two reasons. First, it permitted us to vary exposure to spelling while keeping everything else constant. Second, it ensured that any influence of spelling we observed was due to spelling *per se*, rather than to occasionally encountering schwa variants in the language environment.

We taught our participants French novel words and their associations with pictures of non-existing objects by means of auditory presentation only, over the course of four days. Given their phonotactic properties, the novel words were potential reduced variants of schwa words (e.g., [], []). Importantly, however, participants never heard the schwa variants for these words, and were not told that these stimuli could be considered as schwa words. At the end of the learning process, once the phonological forms of the novel words had been robustly learned, participants encountered the spelling of each novel word once. For half the words, the spelling contained an orthographic representation of the schwa (the vowel “e”), for the other half, it did not. By using a single orthographic presentation following many auditory presentations we ensured that the primary and dominant lexical representation was phonological. Note that when exposed to the novel words’ spellings, participants were presented with the spoken forms of the novel words but not with the corresponding pictures. This ensured that there was no direct association between spellings and pictures. If spelling influenced picture naming it would have to be via modification of the phonological representation.

We then tested our participants with two picture naming tasks on both Day 4 and Day 5. As mentioned above, studies with existing schwa words have shown that these words are represented in the production lexicon with two representations. We thus examined whether naming performance in a situation where spelling is not available provided evidence that participants had nonetheless, for the words spelled with an extra vowel, restructured their phonological representation of the novel words by adding a schwa variant representation. The use of naming tasks on separate days examined whether such restructuring remained robust in long-term lexical memory (or even became stronger over time). After the two naming tasks on Day 5, participants performed a recognition task. With this task, we examined whether spelling also influenced variant processing in recognition.

Based on the hypothesis that exposure to spelling alone is sufficient to generate a corresponding phonological representation we predicted longer naming latencies for novel words with an orthographic representation of the schwa (e.g., “pelour”) than for those whose spelling does not contain an orthographic representation of the schwa (e.g., “plour”). The longer latencies for novel words with an orthographic representation of the schwa would be the consequence of a competition process between the phonological representation corresponding to the reduced variant established during previous encounters with the novel word’s spoken form, and the phonological representation for the schwa variant, generated upon the encounter with the novel word’s spelling. As discussed above, Bürki and Frauenfelder (2012) have shown that novel schwa words learnt with two variants are named with longer latencies than the same novel words learnt with a single pronunciation.

Note that the proposal that participants generate a schwa representation does not imply that they will produce that variant in the naming task. According to Bürki et al. (2011), Swiss French speakers have two representations for non-initial schwa words but rarely use the schwa variant in spoken word production tasks. The variant’s presence is instead normally observed only via heightened competition (delayed responses) in production of the non-schwa form. Nonetheless, assuming that our participants produced schwa variants in a small proportion of cases, we predicted that they would do so more often for novel words whose spelling contains an “e” than for novel words whose spelling does not contain an “e”.

In the recognition task, participants had to decide whether a given item was a novel word learned during the experiment or a completely new item. Predictions for this task differ according to whether we assume that listeners use one or two phonological representations for schwa words in recognition tasks. Unlike in word production research, the proposal to include two representations in the input lexicon for these words has not yet been tested directly. Participants should only respond yes to items with a corresponding phonological representation and will therefore not do so if they represent the novel words with a non-schwa representation only. By contrast, if participants also use two phonological representations in recognition tasks, and if exposure to the spelling is sufficient to generate a representation that has never been encountered before, they should accept schwa variants as items learned during the experiment more often if there was an orthographic representation of the schwa in the spelling.

**Method**

***Participants***

Twenty-three monolingual French students from the University Pierre Mendès in Grenoble (France) took part in the experiment. They were paid or given course credit for their participation.

***Material***

Our materials were based on 20 different two-consonant clusters. All the chosen clusters occur at the onset of reduced variants of French words with a schwa as second phoneme (e.g., /p/ and /l/ in *peluche* ‘cuddly toy’). We first selected the 9 clusters of this type that also exist in French non-schwa words at this position (e.g., [pl] in *plage* ‘beach’) as attested by the existence of at least two words starting with this sequence in the Lexique database (New, Pallier, Ferrand, & Matos, 2001). We will refer to these clusters as *initially attested* clusters. The remaining 11 selected clusters occur word-internally (e.g., [rv] as in *merveille* ‘wonder’) but not at the onset of non-schwa words. We will refer to these clusters as *internally attested* clusters. We decided to use the latter clusters rather than reuse the 9 initially attested clusters for more than one novel word in order to limit the confusability among items. In addition, the use of both types of clusters tests a wider range of circumstances, allowing us to identify more clearly the conditions in which spelling has an effect.

We then created ten monosyllabic (e.g., [] ‘plour’) and ten disyllabic ([] ‘mnateur’) novel words, each starting with one of the 20 clusters. There were five mono- and four disyllabic words with an initially attested cluster, and five mono- and six disyllabic words with an internally attested cluster (see ). In order for the novel words to sound like possible French words, we ensured that the last part of each novel word (that is the sequence of phonemes located after the onset cluster for monosyllabic words (e.g., [] in *plour*) and the second syllable for disyllabic items (e.g., [] in *mnateur*) corresponded to an existing word end in French (i.e., some French words end with the same sequence of phonemes or syllable, e.g., *f****our*** ‘oven’, *ordina****teur*** ‘computer’). We then associated each novel word with a picture of an unfamiliar object. The pictures were drawings of nonexistent objects and photos of unusual or antique objects. Some were taken from previous experiments involving novel words (Leach & Samuel, 2007), others were found in packages designed for other experiments (Images courtesy of Michael J. Tarr, Brown Universityhttp://www.tarrlab.org/) or on the internet. shows three pictures and their associated novel words. The entire set of pictures and stimuli can be found in .

Figure 1. Example of pictures used in the experiment and their corresponding novel words.

For the old-new categorization task, the stimuli consisted of the 20 reduced variants, the 20 corresponding schwa variants, 20 pseudoword foils matched to the reduced variants (e.g., [] ‘ploune’), and 20 pseudoword foils matched to the schwa variants (e.g., [] ‘peloude’). Each pseudoword foil differed from its matched variant on the last phoneme only.

All spoken materials were recorded preceded by the masculine indefinite determiner *un (*‘a’) by a female native speaker of French on a TASCAM DR-100 portable digital recorder in a quiet room. Note that given the frequency of reduced non-schwa variants in French, all the onset clusters used in the experiment are frequently produced by native French speakers and can thus be realized easily and fluently without an inserted schwa. The reduced variants were recorded twice. The first recordings were used in the presentation and learning phases of the experiment and the second were used in the old-new categorization task.

***Design and Procedure***

Participants undertook five experimental sessions on consecutive days. They were tested individually using DMDX software (Forster & Forster, 2003) to control stimulus presentation and data collection for all tasks. On the first day, participants were told that they would have to learn fictitious novel words along with their associations with pictures of novel objects. They were instructed to consider the novel words as possible words of French. They were informed that they would be tested on their knowledge of these words and their associations with the pictures in naming tasks on Days 4 and 5, and that the participant with the highest score of correct responses in the naming tasks would receive an additional 25 Euros.

The overall design of the experiment is summarized in Figure 2. During the first four sessions (Days 1-4), participants performed the learning task, during which they were familiarized with the phonological forms of the reduced variants and their associations with the pictures. The repetition of the learning phase over several days ensured a sufficient and enduring level of memorisation of the associations between the phonological forms of the novel words and the pictures, so that participants would be able to name the pictures accurately in the subsequent phases of the experiment. On Day 4, the learning phase was followed by the presentation of the novel words’ spelling for the first and only time. Participants then performed a filler task, whose aim was to distract their attention from the novel words. Participants were then tested in a cued picture naming task (i.e., with the cue being the first phoneme of the novel word) followed by a standard picture naming task. Both naming tasks were used to examine participants’ responses and latencies. In addition, the cued naming task was included to offer participants an opportunity to practise and consolidate the associations between pictures and words in an active way, and in a task that would favour correct responses. Recall that so far participants merely associated the novel words with their corresponding pictures and never had the chance to practise retrieval of the novel words themselves.

On Day 5, participants started the session with the same naming tasks as on Day 4, followed by an old-new categorization task. The rationale to test participants again after a night of sleep and without additional training was twofold. Firstly, we were interested in long-term effects of spelling, i.e., the possibility that spelling induced a durable change in phonological representation. We thus wanted to be sure that any effects of spelling we found on Day 4 were still present the next day. This would show that spelling effects were not merely short-term “priming” effects due to the recent presentation of the orthographic form. In addition, we wanted to examine whether the effect of spelling would be stronger the following day. Several studies of word learning have shown that the integration of novel spoken forms in the mental lexicon only occurred, or was stronger, after a night of sleep (e.g., Dumay & Gaskell, 2007; Lindsay & Gaskell, 2009). We wanted to examine whether the integration of new information, driven by orthography, to previously established phonological representations corresponding to the same words, also required a consolidation period. At the end of this last experimental session, participants were presented with the recording of each novel word and had to write down its spelling as they recalled it from the previous day. This last task was introduced to provide a way to measure how well participants remembered which novel words had an “e” in the spelling and which did not.

Figure 2. Schematic illustration of the organization of the different phases of the experiment.

During the *Presentation phase* participants were presented once with each of the 20 novel word–picture combinations. The picture appeared in the centre of the screen and at the same time, the spoken form of the corresponding novel word (which was always a reduced variant), was played via headphones, preceded by the determiner. Participants were instructed to memorise the associations between words and pictures. They were allowed to listen to the spoken word form as many times as they felt they needed by clicking on a question mark below the picture. The space bar was used to move to the following trial.

In the *Learning phase*, the spoken form of a novel word (again, always the reduced variant) preceded by the determiner *un* was played via headphones followed by the visual presentation of 1-6 pictures. One picture corresponded to the associated novel word (target picture) and the filler(s), if present, corresponded to other novel words from the learning set. Participants had to click on the target picture. The pictures stayed on the screen for 10 seconds or until a response was given. Incorrect responses and no responses were followed by the sentence “*Mauvaise réponse*, *réessayez (*‘Wrong response, try again’) and the repetition of the same trial. There was a 500 ms blank screen interval between trials. Except on Day 1, where they started with two pictures, participants started with one picture to choose from (the target picture). When all novel words had been practised with one picture, the overall correct response score was computed. If this was 90% or higher, an additional filler picture was added to the response set and the 20 novel words were practised with the new number of pictures. If the response score was below 90%, the 20 novel words were again practised with the same number of pictures. This was repeated until participants successfully completed the task with four pictures to choose from on Day 1, five on Day 2 and six on Days 3 and 4. Note that the filler pictures and the positions of the filler and target pictures were varied for a given word within a given learning phase and across days.

In the *Presentation of spelling* phase, participants heard the spoken form of each novel word preceded by the determiner twice via headphones, followed by a visual presentation of the spelling in the centre of the computer screen, written in Arial 16 point font. They were asked to memorise this spelling and to write it down on a piece of paper. They had as much time as they felt they needed and were instructed to press the space bar when ready to move to the following item. There was a 500 ms blank screen interval between trials. For each participant, half the words had a spelling with an orthographic representation of the schwa (an “e”) between the first two consonants (e.g., “pelour”), and half did not (e.g., “plour)”. We created two lists, as balanced as possible with regard to the distribution of initially attested and internally attested cluster novel words with and without “e” (see ). In the first list, among the novel words without an “e” there were five initially attested and five internally attested cluster novel words. Among the novel words with an “e”, four had an initially attested cluster and six had an internally attested cluster. In the second list, the novel words without an “e” from the first list were spelt with an “e” and vice versa.[[3]](#footnote-3)

During the *Filler task*, which lasted for about four minutes, a sequence of 2-5 digits appeared in the centre of the computer screen and stayed there for 2000 ms. This was followed by a coloured question mark in a coloured square. Participants had to name the colour of the square and then the sequence of digits as quickly as possible. The picture stayed on the screen for 3000 ms or until a response was given. There was a 2000 ms blank screen interval between trials. The task comprised four parts, with six trials in each. The first part involved sequences of two digits; a digit was then added in each subsequent part.

In the *Cued* and *Free naming tasks,* pictures of the novel words appeared one by one on the screen, and participants had to provide the name of the corresponding novel word as quickly as possible. Trials in the cued picture naming task were as follows: a fixation cross was first presented on the screen and stayed there for 500 ms. While the fixation cross was still on the screen, a sound file started playing, with the determiner *un* followed by the first phoneme of the novel word corresponding to the picture to be named in the trial. At the onset of the phoneme, the fixation cross was replaced by the picture. The picture remained on the screen for 6000 ms and was followed by a 500 ms blank screen interval. Participants had to provide their response without a determiner (since the determiner was already in the cue). The list of the 20 novel words was presented twice, the novel words being randomised in each presentation of the list. Trials in the free picture naming phases were identical to those in the cued naming phase except that no auditory clue (i.e., determiner+first phoneme) was presented and that the picture disappeared if a response was given within the 6000 ms of picture presentation. Participants saw the list of 20 novel words four times. During the first two they were instructed to produce the novel words preceded by the indefinite determiner *un* and during the third and fourth presentations they produced the words in isolation (the order of these two conditions being counterbalanced across participants). Again, the novel words were randomised in each presentation of the list. On both days of testing all participants performed the cued naming task first.

Finally, in the *old-new categorization task*, participants were presented with 80 stimuli, consisting of 20 each of the following categories: reduced variants (e.g., [] ‘plour’), schwa variants (e.g., [] ‘pelour’), foils matched to the reduced variants (e.g., [] ‘ploune’), and foils matched to the schwa variants (e.g., [] ‘peloude’). In each trial a fixation cross was first presented in the centre of the screen for 300 ms, followed by one stimulus presented auditorily via headphones. Participants were instructed to press the button labelled “old” if the sequence they heard was part of the novel words learned in the experiment, and the button labelled “new “ if it was not. Each trial terminated after 3000 ms or as soon as a response was given. There was a 1000 ms blank screen interval between trials. In order to maximise the time between the four stimuli corresponding to a given novel word, the stimuli were separated into four lists, with an equal number of each stimulus type in each list, and with the four stimuli corresponding to one novel word in different lists. There were four versions of this test, with each list presented once in positions 1 to 4. The stimuli were randomised within each list.

In the *Recall spelling* task participants heard each novel word (i.e., reduced variant) twice and were asked to write down the spelling they had encountered the previous day for this item on a piece of paper. The task was self-paced and participants pressed the ‘p’ key to start a new trial.

**Analyses**

We analyzed participants’ responses and response times in the picture naming and recognition tasks by means of mixed effects regression models (e.g., Baayen, Davidson, & Bates, 2008; Goldstein, 1987) using the statistical software R (R Development Core Team, 2007) and the package lme4 (Bates & Sarkar, 2007). Participant and item were entered as random terms. In all the statistical models, only the predictors showing an effect or involved in a significant interaction were retained. Bonferroni corrections were applied when examining pairwise comparisons between levels of a given predictor. Additional analyses were conducted in order to provide further support for our main findings. For continuous dependent variables we report F1/F2 analyses, whereas for proportional data we ran secondary analyses including random slopes that allowed for participants to vary in their sensitivity to the predictors.

**Results**

***Learning phases***

Before conducting the analyses related to our research questions, we examined whether there was adequate encoding of the spoken forms and their associations with the pictures in the learning phase. In order to do so, we compared participants’ performance over the four days, on trials where they had to select the target picture among two to four pictures. summarises performance on each day.

Table 1. Error rate, number of trials necessary to reach the end of the 4 picture learning phase, and mean response times to correct responses, as a function of day of training

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Day 1** | **Day 2** | **Day 3** | **Day 4** |
| **Error rate** | 9% | 3% | 0.3% | 0.6% |
| **Number of trials** | 2625 | 1559 | 1404 | 1409 |
| **Response times in ms (95% Confidence Intervals)** | 1632 (±40) | 1540 (±52) | 1258 (±43) | 1098 (±38) |

Statistical analyses showed an effect of day of learning on the probability of making an error (F[[4]](#footnote-4)(3, 6993) = 53.8, p < 0.0001), number of trials to reach the end of the 4-picture part of the learning phase (F(3, 6993) = 4271.9, p < 0.0001) and reaction times (F(3, 6489) = 265.9, p < 0.0001). The proportion of errors decreased from Day 1 to Days 2 to 4, and from Day 2 to Days 3 and 4. There was no further change from Day 3 to Day 4. In addition, the number of trials to reach the end of the 4-picture part of the learning phase decreased from Day 1 to Days 2 to 4, and from Day 2 to Days 3 and 4, but was similar on Days 3 and 4. Response times to correct responses decreased from Day 1 to Day 4, the difference being significant between each day to the next day. Statistical details including comparisons between each day are given in Appendix D.

Participants varied in the number of trials needed to reach the end of the learning phase on a given day. In addition, the number of exposures varied among items for a given participant. On average, participants heard a given item 26 times across all learning phases prior to their encounter with the orthographic form.

We also examined whether participants differed in their performance on initially attested versus internally attested cluster novel words. We first examined participants’ responses as a function of cluster type at the end of the learning process. Here the trials considered were not restricted to those with 2 to 4 pictures to choose from as we did not compare participants’ performance across days. On Day 4, the error rate in the learning phase was extremely low (1.3%). In addition, the probability of making an error did not vary as a function of cluster type (1.3% for initially attested clusters versus 1.4% for internally attested clusters, p = 0.8). This shows that at the end of the learning phase, the result of the memorisation process was equally good for all cluster types. Secondly, we examined whether differences were present at earlier stages of the learning phase. We looked at participants’ responses on all days and found no effect of onset cluster type on the probability to make an error (p = 0.7), and no interaction between cluster type and day (p = 0.7).

Taken together, these analyses show that participants took about three days and 26 exposures to reach ceiling level in terms of error rate, suggesting that the associations between the novel words and the corresponding pictures were robustly learned by the end of the learning phase and prior to the presentation of the novel words’ spellings. Furthermore, novel words with an internally attested cluster were not harder to learn than novel words with an initially attested cluster and were remembered equally well at the end of the learning phase on day 4.

***Recall spelling task and post-test***

In this analysis, we examined the responses in the recall spelling task to determine whether exposure to spelling was sufficient to allow for the correct spelling to be memorised. In order to study the impact of spelling on subsequent processing, we indeed had to be sure that participants had stored the correct orthographic form with regard to the presence of the “e”, at least for a majority of words.

Participants correctly reported the presence or absence of “e” in the spelling in 299 out of 460 cases (mean: 65%, 95% conf. interval: 61-100 %). This proportion is above chance level (χ2(1) = 41.4, p < 0.0001). Table 2 summarizes performance as a function of cluster type and presence of “e” in spelling. Participants’ performance in this task was influenced by graphotactic probabilities (i.e., whether thespelling sequences are common representations of the phonemes and phoneme sequences or not). Their error rate was much lower for items whose spelling to sound correspondences are frequent in French (that is for items with an internally attested cluster and an “e” in spelling, e.g., *relassier*, and for items with an initially attested cluster without an “e” in spelling, e.g., *plour*) than for items whose spelling to sound correspondences are less frequent or non-existent (items with an internally attested cluster without “e” in spelling, e.g., *rlassier*, and with an initially attested cluster and an “e” in spelling, e.g., *pelour*). This influence is reflected in the interaction between cluster type and presence of “e” in spelling on spelling accuracy (β = -3.21, z = -6.87, p < 0.0001). This result is line with previous studies showing that when learning novel visual words, children and adults tend to use letter sequences that are more frequent in their own language orthography (Kemp & Bryant, 2003; Pacton, Fayol & Perruchet, 2005, see also Cassar & Treiman, 1997).

Table . Error rate in the spelling recall task as a function of cluster type and presence of “e” in spelling

|  |  |  |
| --- | --- | --- |
|  |  | **Cluster type** |
|  |  | Initially attested clusters | Internally attested clusters |
| **Presence of “e”** **in spelling** | Present | 42% | 16% |
| Absent | 17% | 53% |

It is possible that this effect of graphotactic probabilities on participants’ performance was due to the automatic generation of an orthographic representation prior to the encounter with the visual stimuli during the encoding of the novel spoken forms (cf. Johnston, McKague & Pratt, 2004). If so, these representations likely respected the French graphotactic system and were thus more likely to contain an “e” for internally attested cluster novel words. These automatically generated orthographic representations would then have been strengthened or modified by the subsequent encounter with the spelling, depending on whether this spelling was congruent or incongruent with these representations. We examined this possibility in a post-test. Ten participants who had not participated in the original study were asked to memorize the associations between the spoken novel words of the original study and their corresponding pictures. Each spoken form and corresponding picture was presented twice. In a subsequent spelling test, participants heard each novel word and were asked to write them down. Except for two participants who spelt one item (*rlassier*) with an “e” all the novel words were spelt without the “e”, suggesting that upon hearing a novel word with an onset cluster that can be found in French non-schwa variants but not at the onset of non-schwa words, French speakers do not automatically generate a spelling that contains an “e” for these novel words. Given this post-test, we can be confident that if the spelling is found to have an effect in subsequent naming and recognition tasks, this effect cannot be explained in terms of a mere reinforcement of pre-existing orthographic representations[[5]](#footnote-5).

To summarize, the analysis of our participants’ responses in the spelling recall task reveals that their performance was significantly influenced by the spelling encountered. In the following analyses, we will examine whether this influence was sufficient to affect participants’ behaviour in subsequent spoken word production and recognition tasks. In addition, results in the post-test show that upon being presented with a spoken novel word starting with a cluster found exclusively in non-schwa variants at this position, French participants do not automatically generate an orthographic representation that contains an “e”. We can thus be confident that any spelling effect we observe in the subsequent naming and recognition tasks are due to the memorisation of the spelling encountered.

***Naming responses***

Each vocal response was checked for accuracy. Productions of non-target words, no responses, and mispronunciations were considered as errors and removed from the dataset. Each correct response was classified as being a schwa or a reduced variant on the basis of perceptual information by a trained phonetician. Importantly, this judge was blind to whether the spelling of each novel word, for any given participant, did or did not contain an orthographic representation of the schwa. Whenever an occurrence could not be classified as clearly a schwa or a reduced variant, the occurrence was marked as unclear and removed from the analyses. There were 1139 errors (21%) and 26 unclear occurrences (0.5%) across the two days and tasks.

On the 4355 remaining correct responses 91 (2.1%) had a schwa clearly present. Given the presence of these schwa variants in the dataset, we examined whether the probability of producing a schwa variant was influenced by the spelling and/or the type of cluster. shows the proportion of schwa variants produced as a function of the presence of “e” in the spelling on Day 4 and Day 5 broken down by cluster type.

% of schwa variants

Figure 3. Proportion of novel words produced with a schwa collapsed across the cued and free naming tasks as a function of the presence of “e” in spelling on Day 4 and Day 5, broken down by cluster type. The error bars represent the standard errors.

We ran a generalized mixed-effects model with the variant produced as the response, and cluster type, presence of “e” in the spelling, day, and task as fixed predictors. Results revealed that the probability of producing a schwa variant was significantly higher (a) on Day 5 (2.5%) as compared to Day 4 (1.6 %, β = -0.56, z = -2.24, p < 0.05), (b) if the cluster was not attested at word onset (3. 5%) than if it was attested at this position (0.5%, β = 2.74, z = 3.12, p < 0.01), (c) in the cued picture naming (3.4%) than in the free naming task (1.4%, β = 1.14, z = 4.63, p < 0.0001) and (d) if the spelling contained an “e” (3.0% versus 1.1%, β = -1.19, z = -4.14, p < 0.0001)[[6]](#footnote-6). The interactions between day of testing and presence of “e” in spelling (p = 0.08), between cluster type and presence of “e” in spelling (p = 0.13), and between day and cluster type (p = 0.6) were not significant[[7]](#footnote-7).

A detailed analysis of participants’ consistency in the variants produced was also conducted. We found that whenever a schwa variant was produced for a given item and participant, it was not the case that the given item was produced by that participant exclusively using the schwa variant on each of the six repetitions of this item (i.e., two in the cued naming task and four in the free naming task). Except for one item, the novel words with at least one occurrence of a schwa variant were produced with both variants. This suggests that these items were considered as words with two variants rather than as words with a schwa pronunciation only.

These analyses show that whether participants produced a schwa or non-schwa variant was influenced by the novel word’s spellings. This finding lends support to the hypothesis that exposure to a word’s spelling is sufficient for speakers to modify their pre-established phonological representations, at least for some words. These analyses further show that exposure to spelling is influential even where there is a phonotactic cue to the presence of schwa that might be expected to be dominant.

***Naming latencies***

Here we examined whether production latencies to reduced variants whose spelling contained an orthographic representation of the schwa were longer than production latencies to the same novel words with no representation of schwa in the spelling.

Only correct responses that had been clearly labelled as reduced variants were considered (n = 4264). Latencies were corrected where necessary using the software CheckVocal (Protopapas, 2007). We eliminated 243 responses that contained dysfluencies (6%). A visual inspection of the latency distribution led to the further removal of 5 outliers below 450 ms and 44 outliers above 3000 ms. Following the Box-Cox test (Box & Cox, 1964) we used the inverse of the latencies rather than the raw measures. shows the mean latencies as a function of the presence of “e” in the spelling for each day of testing.

The linear mixed effects model was run on the 3972 remaining responses. Following Baayen (2008), residuals larger than 2.5 times the standard deviation were considered outliers and removed. Results showed that reduced variants with an “e” in spelling took longer to be named (986 ms, 95% confidence interval = ±17) than the same novel words whose spelling did not contain an “e” (940 ms, 95% confidence interval = ±15, β = 4.9 10-5, t = 4.58, p < 0.0001)[[8]](#footnote-8). In addition, production latencies decreased with order of presentation (β = -1.7 10-6, t = -9.05, p < 0.0001), were shorter on Day 5 than on Day 4 (β = -1.2 10-4, t = -15.60, p < 0.0001), and in free picture naming than in cued picture naming tasks (β = -1.7 10-4, t = -19.13, p < 0.0001). There was no main effect of cluster type (p = 0.3) but an interaction between cluster type and presence of “e” in spelling (β = -4.0 10-5, t = -2.63, p < 0.01) suggesting that the effect of spelling was only present for novel words whose onset cluster was not attested word-initially. There was no interaction between spelling and day of testing (p = 0.1).

Naming latencies (ms)

Figure 4. Naming latencies for reduced variants collapsed across the cued and free picture naming tasks as a function of the presence of “e” in spelling and day, for each cluster type. The error bars represent the standard error of the mean.

The longer latencies observed for novel words with an internally attested cluster and an “e” in the spelling suggest that participants had stored these novel words with a schwa and a non-schwa representation when their spellings contained an orthographic representation of the schwa, and that these two representations compete during lexeme selection.

The lack of spelling influence on novel words with an initially attested cluster could suggest that the schwa variant is only a potent competitor when both spelling and phonotactics point to its presence. In cases where the clusters were attested word-initially, there were indeed very few schwa variants produced, suggesting that schwa variants are very weak competitors in these circumstances. According to this explanation, the lack of a spelling influence on response times for novel words with an initially attested cluster is not due to these novel words being stored with a single representation but to the relative strength of the two representations. Whenever one of the representations is much stronger than the other, the production of the strong variant is not affected by the presence in the lexicon of the weak competitor.

***Recognition responses***

We analysed participants’ responses in the old-new categorization task to determine whether participants tended to (erroneously) accept the schwa variants as items learned during the experiment, and whether the probability of making such errors was influenced by spelling. Results for the generalized mixed effects model on all responses (excluding no responses, n = 1813) showed that participants made many more errors on schwa variants (42%) than on all other types of stimulus (i.e., the reduced variants, plus the pseudoword foils matched to both types of variant), which by contrast elicited an error rate of less than 2 % (F(3, 1809) = 39.01, p < 0.0001, reduced variants: β = -4.54, z = 10.49, p < 0.0001; pseudoword foils matched to schwa variants: β = -5.41, z = -8.50, p < 0.0001; pseudoword foils matched to reduced variants: β = -4.40, z = -10.77, p < 0.0001). Given the small proportion of errors for non-schwa variants (1.5%), and given that this proportion does not differ from the proportion of errors on corresponding pseudoword foils (1.7%) we restricted more detailed analyses to just the schwa variants (see Figure 5).

% of “ yes” responses to schwa variants of novel words

Figure 5. Proportion of yes responses to schwa variants in the old-new categorization task as a function of spelling, broken down by cluster type. Error bars represent the standard errors.

The model restricted to the schwa variants (n = 440) revealed that the probability of accepting a schwa variant as an “old” item was higher when the novel word had an “e” in its spelling (47% versus 38% for novel words without “e” in spelling, β = 0.67, z = 2.55, p < 0.05)[[9]](#footnote-9). Moreover, the probability of accepting a schwa variant as an “old” item was higher for items with an internally attested cluster (48 %) than for items with an initially attested cluster (35%, β = -0.94, z = -2.32, p < 0.05). The interaction between cluster type and spelling was not significant (p = 0.9). These results first show that exposure to the spelling significantly influenced the recognition of the novel spoken words. In addition, they suggest that participants also relied on the phonotactic properties of the items and tended to consider a given novel word as a reduced variant of a schwa word more often when the cluster was not attested word-initially.

**General Discussion**

The present research had two aims. Its first aim was to examine the hypothesis that the way speakers and listeners process and represent spoken words affected by phonological variation processes is influenced by these words’ spellings. More specifically, we tested the proposal that speakers generate a phonological representation for variants they have never encountered whenever these variants are consistent with the word’s spelling (Bürki et al., 2011). The second aim of this study was to add to our general understanding of the role of orthography in spoken word production and show that orthographic knowledge influences the production process via the off-line restructuring of pre-existing phonological representations.

In order to address these issues, we exposed participants to reduced variants of novel French words. Once phonological representations for these variants had been generated and strengthened over several days of repeated auditory exposure, participants encountered the spelling of each novel word once. Half of the words were spelled with an orthographic representation of the schwa (i.e., “e”), half were not. We examined whether this encounter with an orthographic representation of the schwa was sufficient to affect subsequent processing in naming and recognition tasks. Several results converge to suggest that this was indeed the case. Moreover, our data suggest that the processing of novel non-schwa variants is also influenced by these variants’ phonotactic properties and that to some extent; these properties can modulate the effect of spelling. Crucially, however, an influence of spelling was found in recognition and production tasks, even when phonotactic cues to the presence of schwa might have been expected to be dominant.

Firstly, participants produced a small percentage of schwa variants in the naming task, and the probability of producing a schwa variant was significantly higher for items with an orthographic representation compatible with the schwa variant. Note that in this task, participants were simply asked to name a picture that had never been directly associated with an orthographic form. This result suggests that the participants’ phonological representations of the novel words were modified by the exposure to the novel words’ spelling. The very low proportion of schwa variants produced (only 2.1% of the productions were schwa variants) was expected and is in line with the speaking behaviour of French speakers with existing schwa words. As mentioned in the Introduction, even though Swiss speakers have both schwa and non-schwa representations of schwa words such as *casserole* they almost never produce the schwa variant for these words (Bürki et al., 2011). The presence of a phonological representation in the production lexicon thus does not necessarily mean that the speaker will use the pronunciation corresponding to this representation regularly in his or her everyday speech.

The probability of producing a schwa variant in the naming task was also influenced by the phonotactic composition of the novel words, with novel words with an internally attested cluster produced more often with a schwa than novel words with an initially attested cluster. Again, this behaviour mirrors that of French speakers with existing schwa words (e.g., Léon, 1971). This suggests that our participants also sometimes relied on the phonotactic properties of the novel words to generate a schwa representation for variants they had never encountered.

Secondly, we found that novel words with an internally attested but not an initially attested cluster were named with longer latencies when their spelling contained an “e” than when it did not. We interpret this result as showing that novel words with an internally attested cluster with an “e” in spelling were stored with two phonological representations –one corresponding to the variant heard (i.e., reduced variant) and one corresponding to the spelling (i.e., schwa variant) – and that these two lexemes competed for production (see Baayen, 2007 for a review of competition effects in word production). This result mirrors the finding by Bürki and Frauenfelder (2012) with the same type of stimuli. They found that novel words experienced in two variants (i.e., a schwa and a reduced variant) were named with longer latencies than the same items learned in one pronunciation only (either the schwa or the reduced variant). The question arises of whether this result contradicts the conclusion that our participants also relied on the phonotactic properties of the novel words to generate and store a schwa variant representation. It is important to note here that the shorter latencies for novel words with an internally attested cluster without “e” in spelling do not necessary imply that these words were all stored with a single representation. If a schwa variant representation had been generated for some of them on the basis of their phonotactic properties, this representation was likely maintained in memory after exposure to the spelling. The schwa representation was however probably much weaker than the non-schwa representation, and, consequently, did not act as a serious competitor in the time course of production.

Similarly, the lack of spelling influence on production latencies for novel words with an initially attested cluster does not necessarily imply that exposure to the spelling with “e” for these words did not lead to the generation of a schwa variant representation. As argued above and in the light of the influence of spelling on production responses, a more parsimonious explanation assumes that a schwa variant representation was indeed generated for novel words with an initially attested cluster with an “e” in spelling, but that this representation was not strong enough to compete with the non-schwa representation. According to this explanation, if a single encounter with the spelling is sufficient to generate a phonological representation, this representation does not equal, in terms of strength, representations generated and reinforced through frequent encounters with the spoken form. Interestingly, however, it seems that when both the spelling and the phonotactic properties of the spoken form point to the presence of a schwa, the schwa representation becomes strong enough to compete with the non-schwa representation.

An influence of spelling on the processing of recently learned schwa words was also found in a recognition task. When deciding whether a given spoken item was part of the experimental stimuli learned on the preceding days, participants were more likely to incorrectly say yes to a schwa variant when the spelling for the given word corresponded to this variant. This result is again as would be expected if spelling affects phonological variant processing. It suggests that participants had stored a schwa variant representation in their input lexicon for most novel words whose spelling contained an orthographic representation of the schwa. The phonotactic composition of the novel words also affected recognition responses, with more schwa variants considered as novel words learnt during the experiment for novel spoken words with an internally attested cluster. This result again suggests that the phonotactic properties of the novel words may also be used to indicate the representation of a variant that has never been encountered. This result parallels a study by Ernestus (2009) in the recognition domain, revealing that Dutch listeners may rely on the regularities of their language to infer and store a non-reduced variant they have never heard or produced (but see Spinelli & Gros-Balthazard, 2007). Importantly, the spelling effect we found is independent of the phonotactic composition of the novel words.

Taken together, these three results suggest that exposure to the novel words’ spelling was sufficient to affect these novel words’ phonological representations, and led to the generation of a representation for variants that had never been heard. In addition, they suggest that the phonotactic properties of the novel words were also used to generate representations of variants that had never been encountered. It seems however that it is only when both phonotactic and spelling information point to the existence of a schwa variant that this variant’s representation becomes strong enough to compete with the representation of the frequently heard form.

*The influence of spelling in phonological variant processing*

These findings lend direct empirical support to the hypothesis that phonological variation processing is influenced by orthographic knowledge, both in production and recognition. There is a tendency in phonology to treat form alternations in an encapsulated way, but our results show very clearly that other aspects of lexical knowledge such as spelling cannot be disregarded. Furthermore, this influence of orthographic information is found on the processing of spoken forms that were well established in the phonological lexicon and whose associations with the pictures were fully memorized, as shown by the ceiling effects reached at the end of the learning phase. As a consequence, the effects of spelling we observe are likely not triggered by a strategic use of orthographic information to enhance the memorisation of the spoken forms.

This conclusion sheds further light on findings from previous studies with existing schwa words. Firstly, it suggests that the observation by Bürki et al. (2011), that non-used variants of non-initial schwa words corresponding to the word’s spelling are represented in French speakers’ production lexicon, is indeed driven by the spelling for most items. This is because the majority of words used in this study have non-schwa variants whose clusters formed by the schwa’s surrounding consonants are attested in French at this position. For the few words whose clusters are not attested at this position (e.g., *clavecin* ‘harpsichord’, céleri ‘*celery*) the lexical representation of schwa variants may have emerged both prior to or upon the learning of these words’ spellings.

In recognition, our results confirm the frequent but never directly tested proposal that spelling affects the recognition of phonological variants (e.g., Racine & Grosjean, 2005; Ranbom & Connine, 2007). Given that both an on-line and an off-line influence of spelling during spoken word recognition tasks are attested in the literature, and given the off-line restructuring we observe in the production data, it is likely that the spelling effect we observe in the recognition task is at least partly driven by a similar off-line restructuring mechanism. Unfortunately, however, our data do not allow us to provide strong empirical arguments in favour of this claim.

Importantly, an off-line restructuring of the phonological representations would not imply that the orthographic code is not activated on-line during the recognition of variants. An on-line activation of the orthographic code would in fact be necessary to explain the advantage for schwa variants over non-schwa variants in experiments with words (e.g., Racine & Grosjean, 2005). This activation could take the form of a two-way interaction between the phonological and orthographic codes during speech processing, as assumed for instance in some visual word recognition models. In the Bimodal interactive activation model (e.g., Grainger & Ferrand, 1994) upon hearing a spoken word, corresponding spellings are automatically activated and can in turn influence the processing of the spoken form. The advantage for schwa variants upon non-schwa variants could be explained by the better match with the underlying orthographic representations. Accordingly, the more the spoken input matches the corresponding orthographic representation, the more the sublexical phonological information sends activation to the corresponding orthographic information, and the more this orthographic information can in turn send activation to the phonological form and speed up its recognition. Given that schwa variants are consistent with the words’ spellings, the amount of facilitation generated by the phonology-orthography connections is greater for these variants than for the non-schwa variants.

*The influence of spelling on word production*

The present study’s findings shed new light on the highly debated question of whether orthographic knowledge plays a role in spoken word production. As discussed in the Introduction, this issue is controversial, and studies have reported mixed outcomes. We suggested that these discrepancies could readily be explained by constraining the type of mechanism underlying the spelling influence. Accordingly, the influence of spelling in word production only arises via an off-line restructuring mechanism and does not, as in spoken word recognition tasks, also occur via an on-line activation of the orthographic representations. This proposal accounts for the consistency effect reported by Rastle and colleagues (2011) as well as for the absence of orthographic facilitation in the word form preparation paradigm (e.g., Alario et al., 2007; Roelofs, 2006). It also accounts for the present finding that, upon seeing the spelling with an “e”, participants have changed the content of their mental lexicon to include (or strengthen) a representation with the schwa. This off-line restructuring in turn has consequences for the on-line production of the novel words, as the two variants compete during the production process. Note that the longer latencies for novel words with an “e” in the spelling could also be explained by an automatic on-line activation of the orthographic code during the production process. According to this alternative account, our participants stored all novel words with a single schwa representation, on the basis of the spoken input. The shorter latencies for novel words with an internally attested cluster and no “e” in spelling could be explained by a mechanism of feedback between phonological (output) and orthographic units similar to the one described above in the Bimodal interactive activation or similar models. A greater overlap between the phonological and orthographic units (as is the case for non-schwa variants with no “e” in spelling) would lead to greater facilitation and shorter response times.

Such an on-line account can however hardly explain the participants’ response pattern in the naming task. If participants only had a representation for the non-schwa variants, they should not have produced schwa variants at all. In French, as in many alphabetic languages, it is not uncommon for some words to have a spelling that does not respect the grapheme to phoneme transcription rules of the language. For instance, the French word *seconde ‘*second’is spelt with a “c” but pronounced with a [g] ([]). French speakers do not produce words such as *seconde* with a pronunciation that matches the spelling, even occasionally. We thus conclude that the spelling effects we observe in the production task reflect an off-line restructuring of the pre-existing phonological representations. This conclusion in turn suggests that word production is not immune to influences of orthographic knowledge and that this influence arises via an off-line restructuring of previously created phonological representations.

Our finding that exposure to the spelling generates a change in how novel schwa words are represented in the mental lexicon does not, as such, represent a challenge for traditional psycholinguistic spoken word recognition or production models (e.g., Caramazza, 1997; Levelt, Roelofs, & Meyer, 1999; McClelland & Elman, 1986; Norris, McQueen, & Cutler, 2000). These models do not make specific assumptions about how the phonological representations contained in the input or output lexicon have been generated, and will be equally efficient with “restructured” representations. On the other hand, our finding that French speakers and listeners represent some newly learnt words with two phonological representations, together with previous findings with existing schwa words in French (e.g., Bürki et al., 2011) or English (Bürki & Gaskell, 2012) represent an important challenge for these models’ assumption that each word is stored in memory with a single phonological representation. Allowing for some words to be represented with more than one representation is not a trivial change and has important consequences for instance, for the processing of other words. It is known that the recognition process is highly influenced by similar sounding words (i.e., phonological neighbours, e.g., McQueen, Norris, & Cutler, 1994; Norris, McQueen, & Cutler, 1995; see also Broersma & Cutler, 2011). Several studies suggest that the production of a given word is also influenced by phonological neighbours (e.g., Baayen, 2007). If non-schwa forms are stored in the lexicon, their influence on neighbouring words must be taken into account (e.g., the recognition/production of the word *plume* ‘feather’ is now influenced by the presence of /plyR/, non-schwa variant of the word *pelure* ‘peel’, in the lexicon). The inclusion of non-schwa variants in the mental lexicon also calls into question our current conception of phonotactic legality. Syllables and parts of syllables such as complex onsets that are considered inexistent and thus illegal in French, such as /mi/, become completely legal in a model with two representations for schwa words.

Our findings that exposure to spelling changes the mental lexicon’s content and may lead to the occasional use of variants that have never been encountered before also highlight the potential impact of literacy on language change. Several authors suggest that language change is slowed down by literacy (see for instance Gelb, 1952 or Zengel, 1962). Our findings suggest that changes in speaking habits may also be caused by literacy (see Frawley, 1994, for a similar view).

A notable aspect of this study is the emergence of a spelling effect after only a single exposure to the orthographic form. Previous studies on the learning of novel orthographies had already shown that substantial novel word learning in the visual modality can occur after limited exposure. For instance, Share (1999) asked second graders to read aloud texts in Hebrew that contained novel words. Each novel word was repeated four or six times. In the test phase three days later, the author found that the correct spellings were selected more often and named faster than incorrect homophonic foils. Salasoo, Shiffrin, and Feustel (1985) examined visual word learning in adults, who either saw brief presentations of whole letter strings followed by a mask or successive brief presentations of parts of the letter string, with these parts becoming longer with each presentation. In both cases, participants were asked to identify the letter string. At first, identification was better for words but after six repetitions, existing words lost their advantage over non-words. This result also suggests that the memorisation of novel orthographic forms in adults is rapid (but see Qiao, Forster, & Witzel, 2009 for a discussion on the lexicalization of these forms). The present study shows that even if the memorisation of novel orthographic forms after a single exposure is far from perfect, this single exposure has a pervasive impact on subsequent production and recognition tasks. To our knowledge, this is the first demonstration of spelling effects after such minimal exposure. An interesting question for further studies is whether the spelling influence we observe would be similar with a different type of exposure. In the present study, we asked our participants to spell the words. Some studies have indeed shown that having to spell the words helps to memorize them better (Rosenthal & Ehri, 2008, see also Ricketts, Bishop, Pimperton, & Nation, 2011). Possibly, a better encoding of the spellings would have been obtained with an exposure of a different nature. For instance findings by Share (1999) suggest that reading aloud also improves memory for novel spellings, at least for children (see also Rosenthal & Ehri, 2011, but see Ricketts, Bishop, & Nation, 2009).

*Nature and time course of spelling effect*

An additional interesting result concerns the nature and time course of the spelling effect in production. Our data revealed that the impact of the novel word’s spelling was immediate, and remained stable over time. Firstly, the persistence of the spelling effect one day after exposure shows that this effect was not merely short-term, due to the recent presentation of the orthographic form. Rather, the encounter with the spelling likely induced a durable change in the existing phonological representations.

Moreover, the finding that the spelling effect occurred right after exposure rather than after a delay informs us on the time course of the integration of orthographic knowledge in the phonological lexicon. Previous studies in novel word learning, either in the phonological or visual domain have suggested that the lexicalisation of a novel word is a two stage process. Listeners can memorise the phonological information or orthographic form of novel words quickly, and use it efficiently immediately after exposure (“phonological learning” in spoken word recognition research, Gaskell & Dumay, 2003; see Salasoo et al. (1985) for data in visual word recognition). However, it is only after a period of consolidation, preferably during which sleep has occurred, that the new representations become fully engaged with the lexicon such that they interact with existing representations (Bowers, Davis, & Hanley, 2005; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003). Our result that the word’s spelling influenced responses directly after exposure suggests that the lexical restructuring of previously established phonological representations on the basis of orthographic information does not require a period of consolidation. Note, however that there was a trend in our data in favour of a more frequent production of schwa variants on Day 5 than Day 4 (p = 0.08). If confirmed by subsequent studies, this result would suggest that the tendency to infer and produce variants that have never been encountered increases over time. An additional interesting goal for further studies would be to examine if, and how a brief exposure to the word’s spelling also affects the processing of other words in the lexicon, and whether this influence also evolves with sleep and/or time.

Our finding that the spelling effect does not need a period of consolidation in order to surface parallels findings by Snoeren, Gaskell, and Di Betta (2009) on the recognition of place assimilation in English novel words. In their study, participants were exposed to the canonical forms of novel words presented in isolation (e.g., *decibot*). On the same or following day, they performed a phoneme detection task on the assimilated forms of these novel words as well as on pseudowords (i.e., novel words they had not been exposed to). They had to monitor the underlying phoneme of the last consonant (e.g., /t/ in *decibop*). The items were presented in sentential contexts that either permitted or did not permit the assimilation of the last phoneme. Results revealed more responses corresponding to the canonical form in contexts where assimilation was permitted. Importantly, this effect was absent for the pseudowords but present for both the novel words learned on the previous day and the novel words learned on the same day. This finding suggests that compensation for assimilation, like the lexical restructuring of previously established phonological representations we observe in the present study, is part of the immediate phonological learning process.

*Conclusion*

To conclude, the present study lends direct empirical support to the proposal that spelling changes the way speakers and listeners store and process words with phonological variants. We demonstrate that orthography can be strikingly powerful in this respect: a single exposure to spelling following extensive phonological learning is sufficient to induce such a change in previously established phonological representations. In addition it suggests that speakers use their phonotactic knowledge to represent variants they have never encountered previously. More broadly, our findings show that orthographic knowledge affects spoken word production via an off-line restructuring mechanism, and highlight the influence of exposure to the spelling in learning tasks with new words.

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Appendix A: Clusters and corresponding novel schwa words used in Experiment

|  |  |  |  |
| --- | --- | --- | --- |
| **Cluster** | **Novel word** | **Cluster type** | **Nb of syllables** |
|  |  | Attested at word onset | 1 |
|  |  | Attested at word onset | 2 |
|  |  | Attested at word onset | 2 |
|  |  | Attested at word onset | 2 |
|  |  | Attested at word onset | 1 |
|  |  | Attested at word onset | 1 |
|  |  | Attested at word onset | 2 |
|  |  | Attested at word onset | 1 |
|  |  | Attested at word onset | 1 |
|  |  | Attested word-internally | 2 |
|  |  | Attested word-internally | 1 |
|  |  | Attested word-internally | 2 |
|  |  | Attested word-internally | 1 |
|  |  | Attested word-internally | 1 |
|  |  | Attested word-internally | 2 |
|  |  | Attested word-internally | 2 |
|  |  | Attested word-internally | 1 |
|  |  | Attested word-internally | 2 |
|  |  | Attested word-internally | 1 |
|  |  | Attested word-internally | 2 |

Appendix B: Pictures of novel objects used in Experiment and their corresponding novel words

|  |
| --- |
| **Novel schwa words** |
| plour3.JPG | mnateur3.JPG | smabeau3.JPG |
|  |  |  |
| skantole3.JPG | schnire3.JPG | ptile3.JPG |
|  |  |  |
| sruleme3.JPG | sluge3.JPG | fral3.JPG |
|  |  |  |
| vnossien3.JPG | tnaume3.JPG | rpitege3.JPG |
|  |  |  |
| rsar3.JPG | rvinche3.JPG | rtanule3.JPG |
|  |  |  |
| rlassier3.JPG | lsime3.JPG | lvanon3.JPG |
|  |  |  |
| dvau3.JPG | dmurier3.JPG |  |
|  |  |  |

Appendix C: Distribution of spellings with and without “e” in the two lists used for the presentation of spelling

|  |  |  |
| --- | --- | --- |
| **Cluster type** | **List 1** | **List 2** |
| Attested at word onset | plour | pelour |
| Attested at word onset | smabeau | semabeau |
| Attested at word onset | schnire | chenire |
| Attested at word onset | srulème | serulème |
| Attested at word onset | fral | feral |
| Attested word-internally | tnaume | tenaume |
| Attested word-internally | rsar | ressar |
| Attested word-internally | rtanule | retanule |
| Attested word-internally | lsime | lecime |
| Attested word-internally | dvau | devau |
| Attested at word onset | menateur | mnateur |
| Attested at word onset | secantole | skantole |
| Attested at word onset | petile | ptile |
| Attested at word onset | celuge | sluge |
| Attested word-internally | venossien | vnossien |
| Attested word-internally | repitège | rpitège |
| Attested word-internally | revinche | rvinche |
| Attested word-internally | relassier | rlassier |
| Attested word-internally | levanon | lvanon |
| Attested word-internally | demurier | dmurier |

Appendix D: Comparisons between days during the learning phases, in terms of probability of making an error, number of trials necessary to reach the end of the 4-picture phase, and response times

**Probability of error**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Day 2** | **Day 3** | **Day 4** |
| **Day 1** | β = -1.28, z = -7.20, p < .0001  | β = -3.44, z = -6.70, p < .0001 | β = -2.74, z = -7.49, p < .0001 |
| **Day 2** | - | β = -2.15, z = -4.03, p < .0001 | β = -1.44, z = -3.67, p < .001 |
| **Day 3** | - | -  | β = 0.69 , z = 1.11, p = 0.3 |

**Number of trials**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Day 2** | **Day 3** | **Day 4** |
| **Day 1** | β = -54.64, t = -81.64, p < .0001 | β = -60.99, t = -87.98, p < .0001 | β = -60.78, t = -87.78, p < .0001 |
| **Day 2** | - | β = -6.35, t = -8.29, p < .0001 | β = -6.14, t = -8.02, p < .0001 |
| **Day 3** | - | -  | β = 0.21, t = 0.27, p = 0.79 |

**Response times**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Day 2** | **Day 3** | **Day 4** |
| **Day 1** | β = **-**0.087, t = -5.41, p < .0001 | β = -0.28, t = -17.12 p < .0001 | β = -0.43, t = -26.07, p < .0001 |
| **Day 2** | - | β = **-**0.19, t = -10.82, p <.0001 | β = -0.35, t = -19.09, p <.0001 |
| **Day 3** | - | -  | β = -0.13, t = -6.50, p < .0001 |

1. Corresponding author’s present address: Équipe Neuropsycholinguistique, FAPSE, University of Geneva, 42, Bd du Pont d’Arve, 1205 Geneva, Switzerland, 0041 22 379 83 21 [↑](#footnote-ref-1)
2. While there is usually little discussion in the linguistic literature as to which variant has to be considered canonical for a given variation process, the criteria underlying this categorization are not homogeneous among processes. The canonical form can correspond to the word’s spelling or to the more frequent variant. [↑](#footnote-ref-2)
3. For all the analyses we present, we examined in addition whether the factor list (list 1 versus list 2) interacted with the factor “presence of “e” in spelling”. We found that this was not the case. [↑](#footnote-ref-3)
4. For all the analyses we present, we ensured that whenever the coefficient of a given predictor or interaction was significantly different from zero (as indicated by a p value below 0.05), the addition of this predictor (or interaction) was justified given the predictors already included in the model by means of *F-*tests (Baayen, 2008, p. 167). Statistical values associated with these additional analyses are however only reported for predictors with more than two levels. [↑](#footnote-ref-4)
5. Note also that this post-test further shows that the participants did not perceive a schwa in the novel words with an internally attested cluster. [↑](#footnote-ref-5)
6. The influence of spelling survives the inclusion of random slope terms allowing for the participants to vary in their sensitivity to this variable although only when the dependent variable is the spelling recalled by the participant rather than the spelling to which they were exposed. This may suggest that whereas participants differ with regard to their ability to memorise the correct spelling after one exposure, they are all similarly affected by the orthographic representation they have stored for the novel words, a representation which is largely but not exclusively influenced by the spelling encountered. [↑](#footnote-ref-6)
7. Note that all the analyses we present show a similar outcome when the item *rlassier*, for which two participants inserted an « e » in the post-test is removed from the dataset. [↑](#footnote-ref-7)
8. The effect of spelling is further supported by F1/F2 analyses of variance (ANOVAs) F1(1, 22) = 4.0, p = 0.058, F2(1, 19) = 5.52, p < 0.05. [↑](#footnote-ref-8)
9. The influence of spelling survives the inclusion of random slope terms allowing for the participants to vary in their sensitivity to this variable, although again only when the dependent variable is the spelling recalled by the participant rather than the spelling to which they were exposed. This again suggests that whereas participants differ with regard to their ability to retain the correct spelling after a single exposure, they are all similarly affected by their stored orthographic representation. [↑](#footnote-ref-9)