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Automatic phonological activation during visual word recognition in bilingual children: A cross-language masked priming study in Grades 3 and 5.

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Abstract

Previous masked-priming research has shown automatic phonological activation during visual word recognition in monolingual skilled-adult readers. Activation also occurs across languages in bilingual adult readers, suggesting that the activation of phonological representations is not language-specific. Less is known about developing readers: first, it is unclear whether there is automatic phonological activation during visual word recognition among children in general; and second, no empirical data exists on whether the activation of phonological representations is language-specific or not in bilingual children. The present study investigates these issues in bilingual third and fifth graders using cross-language phonological masked priming in a lexical decision task. Targets were French words and primes were English pseudowords of three types: (1) phonological primes - share phonological information with the target beginning (e.g., dee-DIMANCHE [Sunday], pronounced /diː/-/dimɑ̃ʃ/) (2) orthographic-control primes - control for letter(s) shared by the phonological prime and target (i.e., *d*) and their position (e.g., doo-DIMANCHE, pronounced /duː/-/dimɑ̃ʃ/); and (3) unrelated primes - share no phonological or orthographic information with the target beginning (e.g., pow-DIMANCHE, pronounced /paʊ/-/dimɑ̃ʃ/). Significant phonological priming was observed suggesting that: (1) phonological representations are rapidly and automatically activated by print during visual word recognition from Grade 3 onwards; and (2) the activation of phonological representations is not language-specific in bilingual children.

Keywords: visual word recognition, children, phonology, bilingualism, masked priming

Introduction

While effects of both monolingual and bilingual phonological activation are well-established in adults, little is known about how early these effects appear in young readers. In particular, it is still unclear whether phonological representations are automatically activated during visual word recognition (i.e., when written words are known and no longer require phonological recoding). In addition, there is no evidence whether or not the activation of phonological representations is language-specific among bilingual children. These issues are important because they could show the obligatory involvement of phonological representations in visual word recognition and the importance of the setting up of strong links between orthography and phonology in both languages during learning to read. The present study aimed to address: (1) whether phonological representations are automatically activated during visual word recognition in bilingual children; (2) whether this phonological involvement increases with reading experience; and (3) whether or not this activation is language-specific. In order to answer this question, the present cross-sectional study was carried out at two points in the reading development of bilingual readers (third vs. fifth grade).

Studies using the masked priming paradigm (Forster & Davis, 1984) provide a large body of evidence indicating that phonological representations are automatically activated in the early stages of visual word recognition by skilled adult readers (in French, Carreiras, Ferrand, Grainger, & Perea, 2005; Ferrand & Grainger, 1993; Grainger & Ferrand, 1994, 1996; Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000; in Hebrew, Frost, Ahissar, Gotesman, & Tayeb, 2003; in English, Lukatela, Eaton, Lee, & Turvey, 2001; Lukatela, Frost, & Turvey, 1998; Perfetti, Bell, & Delaney, 1988; for a review see Rastle & Brysbaert, 2006). These phonological effects are thought to reflect a rapid, automatic and non-strategic activation of phonological representations from orthographic information. In this paradigm, a letter string (the prime) is briefly presented followed by a target for which participants have to perform a lexical decision. The prime duration is very short (typically between 30 and 60 ms), ensuring that participants are unaware of its existence (Forster, Mohan, & Hector, 2003). The prime's influence is measured through the speed and/or accuracy of target recognition. Phonological priming is demonstrated when a target word, following a phonological prime (word or pseudoword sharing phonological information with the target, e.g., bloo-BLUE, in English), is recognized faster and/or more accurately than when preceded by an orthographic-control prime (word or pseudoword in which the only information in common with the target is the orthographic information that is already shared between the phonological prime and the target, e.g., blar-BLUE). The comparison between phonological and orthographic-control conditions enables measurement of the benefit in word recognition due to the phonological information shared only between the phonological prime and the target. The phonological effect indicates that the phonological prime (e.g., bloo) activates its phonological code (e.g., /blu:/), which in turn is used in the process of target word recognition (e.g., BLUE). Such masked phonological priming has been found with full phonological overlap between prime and target (e.g., klan-CLAN [clan] vs. slan-CLAN, pronounced /klɑ̃/-/klɑ̃/ vs /slɑ̃/-/klɑ̃/ respectively in French; Ferrand & Grainger, 1993) and with partial phonological overlap between prime and target (e.g., fomie-FAUCON [falcon] vs fémie-FAUCON, pronounced /fomi/-/fokɔ̃/ vs. /femi/-/fokɔ̃/ respectively in French; Carreiras et al., 2005). Masked phonological priming effects have been found in monolingual readers (e.g., Carreiras et al., 2005; Ferrand & Grainger, 1993; Grainger & Ferrand, 1994, 1996; Lukatela et al., 2001; Lukatela et al., 1998; Perfetti et al., 1988; Ziegler et al., 2000; for a review see Rastle & Brysbaert, 2006) and also in bilingual readers in both their first and second language (in Dutch-French bilinguals, Brysbaert, Van Dyck, & Van de Poel, 1999; Van Wijnendaele & Brysbaert, 2002). Some masked priming studies have gone even further by investigating phonological priming across languages in bilingual skilled readers. Findings indicate that visual word recognition in the second language benefits from first-language phonological prime presentation, and vice versa. For example, for the Dutch prime pseudoword-French target word pair soer-SOURD [deaf], the Dutch orthography of the pseudoword prime soer (pronounced /syʀ/ in Dutch but /soɛ/ in French) activates the phonological code /syʀ/ and the French phonological code /soɛ/, which in turn facilitates the activation of the French word SOURD (pronounced /syʀ/ in French). Moreover, the effect size was the same in both priming directions, namely from first to second language and from second to first language (Brysbaert et al., 1999; Van Wijnendaele & Brysbaert, 2002; for similar results Greek-Spanish bilinguals see also Dimitropoulou, Duñabeitia, & Carreiras, 2011). For example, phonological effects were found with pseudohomophone primes (e.g., Dutch-French prime-target pair, *soer-SOURD*) in Dutch-French and French-Dutch bilingual skilled-adult readers (Brysbaert et al., 1999; Van Wijnendaele & Brysbaert, 2002; see also Brysbaert, 2003; Brysbaert & Van Wijnendaele, 2003; Duyck, Diependaele, Drieghe, & Brysbaert, 2004). Similar results were found between alphabetic languages sharing the same script and also between alphabetic languages with different scripts. For example, using two alphabetic languages (i.e., the general principle of phonemic alphabetic languages is that, within a language, the graphemic (simple or complex) units correspond to phonemic units), Dimitropoulou and colleagues (2011) showed a cross-script masked phonological priming effect in Greek-Spanish bilinguals (for other cross-script studies see also Gollan, Forster, & Frost, 1997 (Hebrew-English); Kim & Davis, 2003 (Korean-English); Lukatela & Turvey, 1990 (Cyrillic-Roman); Nakayama, Sears, Hino, & Lupker, 2012 (Japanese-English); and Voga & Grainger, 2007 (Greek-French)). Moreover, similar results were found when the language pairs had very different writing systems as with Chinese (Chinese characters correspond to a whole-syllable) and English (Zhou, Chen, Yang, & Dunlap, 2010). All these findings provide evidence that phonological representations are co-activated across languages, even when orthographic representations are not (for ERP evidence in French-English bilinguals, see Carrasco-Ortiz, Midgley, & Frenck-Mestre, 2012). All these results suggest that the phonological representations of the two languages are automatically activated in a non-language-specific way during visual word recognition.

The above results from bilingual adults can be interpreted in the Bilingual Interactive Activation + model (BIA+; Dijkstra & Van Heuven, 1998; Dijkstra & Van Heuven, 2002), which shares the basic architecture of the monolingual bi-modal interactive-activation model (Grainger & Holcomb, 2007, see also McClelland & Rumelhart, 1981). According to these models, letters from the written word are processed in parallel to activate letter (or graphemic) representations in the first instance. These sublexical orthographic representations are mapped onto their corresponding phonological representations. At this point, activation spreads to phonological lexical representations. Note that in the BIMOLA model (Léwy & Grosjean, 2008) only phonemic features are shared across languages while phonemes are language-specific. Thus, the written word stimulus rapidly activates a set of sublexical phonological representations that can influence the course of visual word recognition via their interaction with sublexical orthographic representations or else via the activation of whole-word phonological representations. BIA+ assumes that orthographic, phonological and semantic representations are automatically activated during visual word recognition and that this activation is not language-specific. This means that the lexicon is bilingual and addressable in a non-language-specific way from sublexical orthography. Moreover, BIA+ predicts that as soon as grapheme-phoneme correspondences are mastered in each language, activation of sublexical phonological representations can be achieved from graphemes of each or both languages. Note that, as a model of skilled reading, BIA+ cannot make direct predictions about reading development.

However, up until now the language non-selective access view has scarcely been studied in bilingual children (Brenders, van Hell, & Dijkstra, 2011, in Dutch children learning English). To the best of our knowledge, rapid and automatic phonological activation during visual word recognition across languages among bilingual children has not been studied at all. A few findings have been reported from studies of monolingual children but these are conflicting. Davis, Castles, and Iakovidis (1998) did not find masked phonological priming in a lexical decision task among English fourth graders (e.g., rait-RATE vs. raut-RATE, pronounced /reɪt/-/reɪt/ vs. /rɔːt/-/reɪt/, respectively). In contrast, Booth, Perfetti, and MacWhinney (1999) succeeded in demonstrating a masked phonological priming effect (i.e., the phonological priming condition was compared to the orthographic-control priming condition) using the brief presentation paradigm with children reading English. In this paradigm, the phonological (e.g., TUME) or the orthographic-control (e.g., TAMS) pseudoword prime is presented first, followed by the target word (e.g., tomb). Each is shown for a very short period of time (e.g., 60 ms), followed by a pattern mask consisting of a row of Xs for a duration of 500 ms. The participants' task is to write down the target word after each trial. Participants are encouraged to guess the identity of the target if they are not sure. Note that this task necessitates the retrieval of orthographic and phonological lexical representations. Overall, it was found that fifth graders were more accurate than third graders (48% vs. 24%, respectively, in their Experiment 1), indicating that the reading system is faster and more efficient in older than younger readers. Moreover, the phonological priming effect was stronger for Grade 5 than for Grade 3 children (15% vs. 2%), suggesting that phonological representations are activated faster and more effectively by more advanced than less advanced readers. Another important result was that in both grades, the phonological priming effect was stronger when the orthographic similarity between the phonological prime and target was low (e.g., FAIZE-phase vs. BACLE-phase, pronounced /feɪz/-/feɪz/ vs. /bækl/-

/feɪz/, respectively) than when it was high (e.g., KOLD-cold vs. DOLD-cold, pronounced /kəʊld/-/kəʊld/ vs. /dəʊld/-/kəʊld/, respectively). Moreover, the orthographic priming effect (i.e., the difference between the orthographic control and unrelated priming conditions) was weaker when orthographic similarity between the prime and target was low (e.g., BACLE-phase vs. WILOR-phase) than when it was high (e.g., DOLD-cold vs. HESS-cold). These results suggest that a greater orthographic priming effect masks the phonological priming effect, while less orthographic overlap leaves "more room" for the emergence of the phonological priming effect (for similar results in skilled readers see Dimitropoulou et al., 2011; Zeguers, Snellings, Huizenga, & van der Molen, 2014). In a recent study conducted in French, Ziegler, Bertrand, Lété, and Grainger (2014) examined this issue using a sandwich priming paradigm (Lupker & Davis, 2009) in which the order of the stimuli was target (27 ms) - prime (70 ms) - target (until lexical decision; e.g., neige-naije-NEIGE [snow] vs neige-noide-NEIGE, pronounced /nɛʒ/-/nɛʒ/-/nɛʒ/ vs /nɛʒ/-/nwad/-/nɛʒ/ respectively). Results showed a phonological priming effect, which was present from the end of first grade to fifth grade and which remained constant across grades.

To date, there is no developmental model of silent reading for bilingual children. The developmental multiple-route model of silent reading (Grainger, Lété, Bertand, Dufau, & Ziegler, 2012; see also Diependaele, Ziegler, & Grainger, 2010; Ferrand & Grainger, 1993; Holcomb & Grainger, 2007) aims to explain the development of phonological and orthographic processes during reading acquisition in monolingual children. According to the developmental multiple-route model of silent reading, in alphabetic systems (like French and English) phonological recoding is the essential first step in reading acquisition, enabling word reading by sequential application of grapheme-to-phoneme conversion rules (Ehri, 1992, Ehri, Nunes, Stahl, & Willows, 2001; Perfetti, 1992). Similar to the predictions of the Self-teaching hypothesis (Share, 1995, 1999), each successful phonological recoding of a word provides an opportunity for setting-up orthographic representations in the lexicon (see also Bowey & Muller, 2005). According to Grainger et al. (2012), during reading acquisition, slow and effortful phonological recoding is gradually replaced by a mechanism of word recognition in which a fast and automatic activation of orthographic lexical representations occurs (Booth et al., 1999; Perfetti, 1992). At this point, the letters in words are no longer processed sequentially as is the case in phonological recoding but are processed in parallel (i.e., all letters in the word at the same time). Graphemic representations are activated and then two types of process occur: a purely orthographic process, involving sublexical and lexical levels of processing, and a phonological process, in which graphemic representations activate corresponding phonemic representations after which the activation spreads to lexical representations. These two processes improve with reading experience. One clear prediction of the developmental multiple-route model is that automatic phonological influences on silent word reading, such as those revealed by masked phonological priming for example, should not be visible in the earliest phases of reading acquisition. This is because such automatic phonological influences depend on the setting-up of parallel letter processing together with mechanisms that enable the fast and automatic activation of phonemic representations from graphemic representations (Alario, De Cara, & Ziegler, 2007). In other words a prerequisite condition for obtaining automatic activation of phonological representations is that letter processing is accomplished in parallel, something that occurs after the earliest phases of reading acquisition. However, this condition is not sufficient. The other condition is that the activation of phonemic representations from graphemic representations is rapid and automatic. The model predicts that this type of automatic phonological activation develops gradually in young readers.

The aim of the present study is to investigate two critical issues. First, whether phonological representations can be rapidly and automatically activated in reading by developing readers, and in addition, whether or not the phonological contribution changes as a function of reading experience (as found previously in monolingual children by Booth et al., 1999 and Ziegler et al., 2014, respectively). Second, whether or not the activation of phonological representations is language-specific (English and French) in bilingual children. To this purpose, we conducted an experiment using a cross-language masked phonological priming paradigm, which is relevant for studying automatic processes. Masked priming is a paradigm that allows precise measurements of very subtle effects in processing. One problem with this method is that results are easily obscured by variability. To show automatic activation of phonological representations using masked priming, reading processes need to be automatic and the reading level of children needs to be sufficiently homogeneous. The reading performance (in terms of both speed and accuracy) of beginning readers is very heterogeneous and the underlying reading strategies used by the children can differ (e.g., slow and serial phonological recoding vs. more automatic whole-word recognition). This intra-group variability makes it tricky to reveal masked phonological priming effects among beginning readers. It is therefore unsurprising that there are very few phonological masked priming studies that have been conducted with children prior to the third grade[1].

In the present study, we used the masked priming paradigm typical in studies of skilled adult readers to investigate the development of the automatic involvement of phonological representations during the visual word recognition process (and not at the transition between serial decoding and parallel processing). We used a lexical decision task in order to examine whether phonological involvement is automatic and obligatory even when the task relies as little as possible on phonological processing (the naming task (Ziegler et al., 2000) necessarily involves phonological processing and the writing down target task (Booth et al., 1999) relies

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[1] Only one study (Ziegler et al., 2014) has examined beginning readers (from the end of first grade). However, the long response times and the high error rates in first and second grades (1800 ms and 1300 ms, and 18% and 16%, respectively) show that words are not yet well known and that, at this age, children mostly use phonological recoding as their reading process. In the present study, we focused on phonological priming in the parallel letter processing phase and did not examine serial decoding.

more on phonological processing than the lexical decision task). We used English primes and French targets. This choice was based on the fact that English letter strings are illegal in French more often than the reverse scenario. So, all primes were English with a typically English orthography. To maximize the role of the phonological process (Booth et al., 1999; Dimitropoulou et al., 2011; Zeguers et al., 2014) and to limit the action of the purely orthographic process (and hence, to limit orthographic priming in order to permit the emergence of the phonological priming effect), the phonological primes were all pseudowords for which the number of letters shared with the target was minimized. This design allowed testing of the predictions of the developmental model of silent reading (Grainger et al., 2012), namely, the gradual emergence of the parallel processing of words, and more specifically, the development of the automatic activation of phonemic representations from graphemic representations during this developmental process.

Our hypothesis was the following: if phonological representations are automatically activated in visual word recognition (Booth et al., 1999) and if the activation of phonological representations is not language-specific in children, just like in adults (Brysbaert et al., 1999; see also Dijkstra & Van Heuven, 1998), we expect to obtain a phonological priming effect across languages. In addition, if access to phonological representations becomes more efficient with reading experience (Booth et al., 1999), we expect to observe an increase in phonological priming between the younger and older readers.

Method

Participants

Participants were 45 third graders (mean age = 8 years 11 months, SD = 5 months) and 33 fifth graders (mean age = 10 years 10 months, SD = 4 months). All participants came from two French schools in London where approximately 70% of the teaching took place in French and 30% in English. French and English reading instruction was similar, and mostly based on phonics, in both schools. All participants were early bilinguals, as they were all exposed to both languages from a young age. The third graders were exposed to French roughly from birth (mean age = 1 month; SD = 5 months; range = birth to 36 months), and to English from 6 months on average (SD = 13 months; range = birth to 36 months). On average, the fifth graders were exposed to French from 8 months (SD = 19 months; range = birth to 72 months), and to English from 1 year and 3 months (SD = 25 months; range = birth to72 months). Each participant learned to read in French and English from at least 6 years of age. The native language of these participants was French (32%), English (6%) or both (63%). The participants' reading level in French and English was evaluated using standardized tests (*L'Alouette* for French, Lefavrais, 1967 and the *British Ability Scales Word Reading Test* for English, Elliott, Smith, & McCulloch, 1997). For the third graders, the mean French reading age was 9 years, 11 months (SD = 17 months) and the mean English reading age was 10 years, 3 months (SD = 12 months). For the fifth graders, the mean French reading age was 11 years, 8 months (SD = 21 months) and the mean English reading age was 11 years, 6 months (SD = 17 months). All participants had normal or corrected-to-normal vision. According to their teachers, none of the children had a language impairment or learning difficulties. Informed parental consent was obtained for all participants. The protocol followed the general ethics rules defined by the Helsinki guidelines for human experimental work and was approved by the local institutional ethics committee.

Material

The stimuli consisted of 53 French target words and 53 French target pseudowords. The mean number of letters was 7 (SD = 1.41) and the mean number of syllables was 1.75 (SD = 0.52). The mean frequency of the words was 98 occurrences per million (SD = 150) according to the Manulex database (Lété, Sprenger-Charolles, & Colé, 2004). All primes were English pseudoword fragments selected from the beginning of English words. For example, the unrelated prime gloa is the beginning of gloat (/gləʊt/). Only 14 primes out of 159 (53 x 3 prime conditions) in total were derived from English words with a low frequency of 1.04 (SD = 2.18; Children's Printed Word Database, Masterson, Dixon, & Stuart, 2002). Three different primes were assigned to each of the targets: phonological, orthographic-control and unrelated. All primes were fragments with typically English orthographic patterns, which were either illegal in French or for which print-to-sound conversion was different in English[2] than in French. For example, the English phonological prime *dee*, pronounced /di:/ in English (but /də/ in French) shared phonological information[3] with the beginning of the French target DIMANCHE ([Sunday]), pronounced /dimɑ̃ʃ/. On average, 53% of the phonemes and 24% of the letters in phonological primes overlapped with the target words[4]. The English orthographic-control prime *doo*, pronounced /du:/ in English (but /do/ in French) shared the same letters as the phonological primes with the target (e.g., <u>d</u>ee-<u>D</u>IMANCHE). The orthographic-control prime was intended to verify whether the small amount of orthographic overlap with the target (in the example the letter *d)* played a role in priming. The English unrelated prime *pow*, pronounced /paʊ/ in English, did not share any phoneme or letter with the beginning of the target (see Appendix A). The Levenshtein distance was computed to assess the orthographic similarity between the prime and the beginning of the target word in

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[2] Note that print-to-sound conversion is inconsistent in English. For example, the grapheme *ea* is most frequently pronounced /i:/ in English but can also be pronounced /eɪ/ or /e/ (and even /əa/ in French). In the present study, we do not address the issue of inconsistency. Grapheme-phoneme matching was done on the basis of the most frequent grapheme-phoneme conversion in English.

[3] In 81% of our phonological primes, we selected typically English graphemes that correspond to a phoneme shared by both languages. For example, the phoneme /i/ has the same articulatory execution in French and English (see the English and French vowel quadrilaterals in Capliez, 2011). The symbol ":" added to /i/ in English provides suprasegmental information about phoneme duration. In 19% of our phonological primes, we selected typically English graphemes that correspond to a phonologically-close "French" phoneme. For example, the phonemes /ɔ/ and /o/ are phonologically close because there is only one difference in the pronunciation of these phonemes, namely the aperture. For /ɔ/, the aperture is a little more open than for /o/ (Capliez, 2011).

[4] We calculated the phonological overlap between the phonological primes and targets on the basis of the number of phonemes (common to both languages or phonologically close) shared between the primes and the targets. For instance, the French word DIMANCHE (pronounced /dimɑ̃ʃ/) has 5 phonemes. The phonological prime *dee* (pronounced /di:/) has 2 phonemes. In this example, the phonological overlap is of 40%. Letter overlap was calculated in a similar way.

each priming condition (Levenshtein, 1966). The mean Levenshtein distance was 1.90 (SD = 0.53) and 1.94 (SD = 0.57) for the phonological condition [e.g., dee-DI(MANCHE)] and orthographic control condition [e.g., doo-DI(MANCHE)] respectively, and did not differ significantly ($t < 1$). The mean Levenshtein distance was 3.52 (SD = 0.54) for the unrelated condition [e.g., pow-DI(MANCHE)]. To avoid repetition effects for target words (as each was linked with three different primes), three versions of the experiment were created. We constructed the prime-target pseudoword pairs in a similar way to the prime-target word pairs. The three types of prime were the same as for the target words. All primes were English-like and target pseudowords were French-like (e.g., the target pseudoword GROUSSE-/gʀus/, created on the base of the word *gousse* [pod], was primed by the phonological prime *groo*-/gruː/). Given that the number of English-like primes is limited, we opted to constrain the number of prime-pseudoword target pairs to avoid too many repetitions of the same English-like primes. To achieve this, we constructed only one list of pseudoword targets which was added to each list of word targets (e.g., Nakayama et al., 2012). In the list of pseudowords, one third of the list was primed by a phonological prime, one third by an orthographic-control prime and one third by an unrelated prime (as for the target words). Every participant was randomly assigned to one of the three versions. In each version, each target word appeared only once, but with a different prime. The number of primes in each condition was approximately the same (17 or 18) in each of the three versions of the experiment. Within each version, the presentation order of the items was randomized.

Procedure

Children were assessed individually at their school in a quiet room. They were tested in a single session lasting about twenty minutes. They were seated in front of a DELL computer using E-prime software. The lexical decision task involved 12 practice trials followed by a series of 106 (53 words, 53 pseudowords) experimental trials. Each trial began with the display of a fixation cross (800 ms) then a hash mark mask (800 ms), followed by a briefly presented fragment prime. The duration of the prime was 60 ms, which is typical in masked priming (Forster, Mohan, & Hector, 2003), and is an optimal duration to obtain phonological priming effects, as has been shown among skilled adult readers (Ferrand & Grainger, 1993; Ziegler et al., 2000). The prime was immediately followed by the target. Primes were presented in lowercase and targets in uppercase in order to ensure that the prime letters were entirely covered by the larger letters of the target and that their luminescence did not persist on screen. This also allows a physical distinction to be made between the letters shared by the prime and the target (e.g., r/R). A short pause was introduced after each series of 20 items. Participants were instructed (in French) to perform a lexical decision by deciding whether the letter sequence presented in uppercase was a word or not, responding as quickly and as accurately as possible. They indicated their responses by pressing one of two response buttons on the E-prime SRbox. Latency was measured from the target onset until the participant's response.

Results

Latencies and accuracy for the target words were analyzed. Two items were excluded because their error rates were larger than 30% (see Appendix A). Outliers (i.e., data beyond 3 SD, by participants) were not included in the analyses (0.96% of the data). The cleaned data ranged from 326 to 2870 ms. The overall error rate was 12.81% for the third graders and 7.49% for the fifth graders (see Table for means and SDs).

Table

Means and SDs for response times (RT, in ms) and error rates (err, in %) as a function of Grade and Priming condition.

	Grade 3		Grade 5	
Priming condition	RT (SD)	err (SD)	RT (SD)	err (SD)
Phonological	1000 (201)	11.17 (9.57)	851 (129)	5.38 (4.68)
Orthographic control	1050 (230)	14.06 (10.06)	873 (145)	9.37 (9.11)
Unrelated	1053 (221)	13.47 (10.47)	892 (144)	7.93 (10.01)

Repeated Measures Analyses of Variance (RM-ANOVAs) were performed by participants (F1) and by items (F2). Ziegler et al. (2014) advocate the use of inverse response times (i.e., each response time (RT) transformed as 1/RT) in developmental studies in order to normalize the latency distributions (Ratcliff, 1993). An additional benefit of this transformation is that it allows the testing of absolute (as opposed to proportional) differences between children from the two different grades. For instance, as can be seen in the Table, the Grade 3 children were slower than the Grade 5 children. As a result, potentially significant interactions between the between-participants variable (Grade) and the different priming effects could merely be artefacts of differences in overall speed between the Grade 3 and 5 children. By analyzing reading speed (items per second) instead of how long it takes to read a particular item, we can be reasonably sure that any significant interaction is an absolute effect and not a proportional effect (Marinus, Nation, & de Jong, 2015; Faust, Balota, Spieler, & Ferraro, 1999). We conducted analyses based on a 3 (prime-target relatedness: phonological, orthographic-control, unrelated) × 2 (grade: third, fifth) design. The RM-ANOVA on the inverse response times revealed that fifth graders responded faster than third graders children, $F_1(1,76) = 15.79$, $p < .001$, $\eta_p^2 = .17$; $F_2(1,100) = 64.63$, $p < .001$, $\eta_p^2 = .39$. In addition, there was a significant effect of prime-target relatedness, $F_1(2,152) = 9.84$, $p < .001$, $\eta_p^2 = .11$; $F_2(2,200) = 10.95$, $p < .001$, $\eta_p^2 = .10$, and this factor did not interact with Grade, both *F*s < 1. Bonferroni-corrected pairwise comparison showed that the lexical decisions were significantly faster in the phonological condition compared to both the orthographic-control (38 ms) and unrelated conditions (48 ms), $p = .007$ and $p < .001$ respectively. In contrast, the lexical decisions in the orthographic control condition did not differ significantly from those in the unrelated condition (10 ms), $p = .58$. The phonological effect size was computed for each grade using Cohen's d (Cohen, 1988). The phonological effect in each grade was small, $d = .28$ in third grade and $d = .30$ in fifth grade.

The RM-ANOVA on error rates revealed that fifth graders made less errors than third graders, $F_1(1,76) = 10.22$, $p = .002$, $\eta_p^2 = .12$; $F_2(1,100) = 9.76$, $p = .002$, $\eta_p^2 = .09$. In addition, there was a significant effect of prime-target relatedness, $F_1(2,152) = 4.66$, $p = .011$, $\eta_p^2 = .06$; $F_2(2,200) = 4.44$, $p = .013$, $\eta_p^2 = .04$, and this factor did not interact with Grade, both *F*s < 1. Bonferroni-corrected pairwise comparisons showed that there were less errors in the phonological condition than in the orthographic-control condition ($p = .011$). In contrast, neither the phonological nor the orthographic-control condition differed significantly from the unrelated condition in terms of error rate (*p*s > .10).

Data from pseudoword targets were not analyzed because pseudowords are not theoretically relevant as they do not have the lexical representations upon which the priming paradigm is based. Therefore, we constructed only one list of pseudoword targets which was added to each list of word targets. The data from pseudoword processing were not numerous enough to be utilized (e.g., Dimitropoulou et al., 2011; Nakayama et al., 2012).

Discussion

The aim of the present study was to investigate three main issues: first, whether phonological representations can be rapidly and automatically activated in reading by developing readers (Davis et al., 1998; Booth et al., 1999; Ziegler et al., 2014); second, whether or not the phonological contribution changes as a function of reading experience (as found previously in monolingual children by Booth et al., 1999 and Ziegler et al., 2014); and third, whether or not the activation of phonological representations is language-specific in bilingual child readers, as is the case for skilled adult readers (e.g., Brysbaert, 2003).

We examined these issues by performing a cross-language (English-French) masked phonological priming experiment with bilingual third and fifth graders. In order to maximize the phonological process to obtain the purest phonological priming effect, we reduced the amount of orthographic information shared between the prime and target to a minimum. Primes were English word fragments that were either illegal in French or for which print-to-sound conversion was different in English than in French. Three types of prime fragments were selected: phonological primes (e.g., dee-DIMANCHE, pronounced /diː/-/dimɑ̃ʃ/), orthographic-control primes (e.g., doo-DIMANCHE, pronounced /duː/-/dimɑ̃ʃ/) and unrelated primes (e.g., pow-DIMANCHE, pronounced /paʊ/-/dimɑ̃ʃ/). The results showed a phonological cross-linguistic masked priming effect in third and fifth grades revealing three new and important findings: (1) phonological representations are activated in a rapid and automatic way in children; (3) the automatic activation of phonological representations occurs in third and fifth grades; and (2) the activation of phonological representations is not language-specific. Moreover, the degree of activation does not differ between third and fifth graders.

A novel outcome of the present study is that, for the first time, a lexical decision experiment using the classic masked-priming paradigm revealed a phonological priming effect in visual word recognition among children. The results from this experiment support the hypothesis that, even in less advanced readers (third graders), phonological representations are rapidly and automatically activated during word recognition. Booth et al. (1999) and Ziegler et al. (2014) reached the same conclusion, however, their conclusions were based on different experimental paradigms. In Booth et al.'s (1999) study, participants were asked to write down the target word after each trial. According to Booth et al. (1999), this task relies more on phonological representations than the lexical decision task. Ziegler and colleagues (2014) used the sandwich priming paradigm, in which the phonological activation before target presentation was substantially longer (total duration of 97 ms) than in our experiment (60 ms). In addition to being of shorter duration, our phonological primes were word fragments, rather than the pseudohomophones used in Ziegler et al's experiment, which did not share enough letters with the target to activate the orthographic lexicon, and therefore could only result in sublexical phonological activation. The fact that we still found phonological priming under these minimal manipulations indicates that connections from orthographic to phonological representations are well-established at the sublexical level among third and fifth graders.

The other significant finding is that the activation of sublexical phonological representations is not language-specific (French and English) in bilingual children. Indeed, French word recognition was facilitated by the presentation of English phonological primes. This suggests that English phonological primes (e.g., dee) activate sublexical phonological representations (e.g., /diː/), which, in turn, are used in the process of French visual word recognition (e.g., DIMANCHE). This finding provides evidence, for the first time among bilingual children, that when phonemes are common to both languages (or phonologically close), the activation of sublexical phonological representations is not language-specific. Note that, based on our study, we are unable to conclude whether sublexical phonological representations are co-activated (Léwy & Grosjean, 2008) or shared (Dijkstra & Van Heuven, 2002, Roelofs, 2003).

The result of this present study is consistent with findings from studies of bilingual skilled readers (e.g., Brysbaert et al., 1999; Van Wijnendaele & Brysbaert, 2002) and suggests that language non-specific phonological activation emerges early in reading development. Additionally, our results show that phonological representations are involved in visual word recognition among bilingual children, as is also the case for skilled bilingual readers (Brysbaert et al., 1999; Van Wijnendaele & Brysbaert, 2002), at least when both languages share the same alphabet. Further research could examine this issue when both languages have different alphabets (for instance, between Greek and French) and when both languages have different writing systems (for instance, between Chinese and English). Overall, our results support the idea that phonological representations play an important role in bilingual reading development and that phonological representations contribute to word recognition in an automatic way for bilingual children.

In our study, the degree of phonological contribution to word recognition did not differ between third and fifth grade children. This suggests that a rapid and automatic phonological contribution is already well developed by third grade, and seems to remain stable while the orthographic processing system is developing (Booth et al., 1999; Lété & Fayol, 2013; Ziegler et al., 2014). This finding challenges the view that advanced readers activate phonological representations in a more effective way than younger readers (Booth et al., 1999). Note that, in the present study, the third grades were above average. This provides some limitation to the interpretation of our results. Even though these children are clearly not as advanced as fifth graders (both main effects of grade on response times (1034 ms in third grade vs. 872 ms in fifth grade) and on error rates (12.81% in third grade vs. 7.49% in fifth grade) clearly show that the third graders' reading system is not yet fully developed), it would be interesting to perform a similar study with average, or below average third graders to examine if they do show weaker phonological priming effects. However, our findings are consistent with Ziegler et al.'s (2014) proposition that the contribution of phonology is constant during the course of reading development.

The error analysis indicates that children in both grades made fewer errors in the phonological priming condition as compared to the orthographic-control priming condition. This suggests that lexical representations were activated by the phonological primes. Unsurprisingly, errors did not reveal a significant difference between the orthographic-control and unrelated priming conditions, as the overlap between the orthographic-control primes and the target was very low. However, it was surprising that we did not find a significant difference between the phonological and unrelated priming conditions. An initial explanation is that the fact that the prime letter string was illegal in French caused a disruption which reduced any beneficial effect on accuracy of the phonological information contained in the prime. An alternative explanation could be that the overlap between prime and target was too narrow to produce an effect on errors. Finally, another explanation could be that, given that our sample of children were good readers, they showed the same error pattern as adult readers. For example, in the study of partial phonological priming by Carreiras et al. (2005), the authors also did not find a significant difference in errors between the phonological, orthographic-control and unrelated priming conditions.

To date, there is no developmental model of reading acquisition for bilingual children. Therefore, we will position our results within the developmental multiple-route model of silent reading for monolingual children (Grainger et al., 2012). After an initial phase of phonological recoding, the explicit and serial processing of letters is replaced by automatic parallel processing of letters for familiar written word forms. Then, during familiar word recognition, sublexical phonological representations are rapidly and automatically activated.

Our findings indicate that this automatic phonological process develops early, at least from third grade, and seems as efficient among third graders as it is among fifth graders. In the present study, priming was cross-language, meaning that sublexical phonological representations are co-activated in both languages. Consequently, a future developmental multiple-route model of silent reading for bilingual children should be able to explain why access to sublexical phonological representations from print is not language-specific.

In sum, this study is the first to demonstrate a cross-language masked phonological priming effect in bilingual children, revealing that: (1) these sublexical phonological representations are rapidly and automatically activated by print; and (2) the same sublexical phonological representations are used in both languages. Interestingly, the phonological contribution to familiar word recognition seems to arise relatively early in reading acquisition and to be stable across grades three and five, which has implications for the further refinement of models of reading development.

References

Alario, F. X., De Cara, B., & Ziegler, J. C. (2007). Automatic activation of phonology in silent reading is parallel: Evidence from beginning and skilled readers. *Journal of Experimental Child Psychology*, 97(3), 205-219.

Booth, J. R., Perfetti, C. A., & MacWhinney, B. (1999). Quick, automatic, and general activation of orthographic and phonological representations in young readers. *Developmental Psychology*, *35*(1), 3-19.

Bowey, J. A., & Muller, D. (2005). Phonological recoding and rapid orthographic learning in third-graders' silent reading: A critical test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, *92*(3), 203–219.

Brenders, P., van Hell, J. G., & Dijkstra, T. (2011). Word recognition in child second language learners: Evidence from cognates and false friends. *Journal of Experimental Child Psychology*, *109*(4), 383-396.

Brysbaert, M. (2003). Bilingual visual word recognition. *Masked Priming: The State of the Art*, 323–344.

Brysbaert, M., Van Dyck, G., & Van de Poel, M. (1999). Visual word recognition in bilinguals: Evidence from masked phonological priming. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(1), 137-148.

Brysbaert, M., & Van Wijnendaele, I. (2003). The importance of phonological coding in visual word recognition: Further evidence from second-language processing. *Psychologica Belgica*, *43*(4), 249–258.

Capliez, M. (2011). Typologie des erreurs de production d'anglais des francophones: segments vs. suprasegments. *Recherche et pratiques pédagogiques en langues de spécialité. Cahiers de l'Apliut*, *30*(3), 44-60.

Carrasco-Ortiz, H., Midgley, K. J., & Frenck-Mestre, C. (2012). Are phonological representations in bilinguals language specific? An ERP study on interlingual homophones. *Psychophysiology*, *49*(4), 531–543.

Carreiras, M., Ferrand, L., Grainger, J., & Perea, M. (2005). Sequential effects of phonological priming in visual word recognition. *Psychological Science*,*16*(8), 585-589.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Davis, C., Castles, A., & Iakovidis, E. (1998). Masked Homophone and Pseudohomophone Priming in Children and Adults. *Language and Cognitive Processes*, *13*(6), 625–651.

Diependaele, K., Ziegler, J. C., & Grainger, J. (2010). Fast phonology and the bimodal interactive activation model. *European Journal of Cognitive Psychology*, *22*(5), 764–778.

Dijkstra, T., & Van Heuven, W. J. (1998). The BIA model and bilingual word recognition. *Localist Connectionist Approaches to Human Cognition*, 189–225.

Dijkstra, T., & Van Heuven, W. J. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition*, *5*(03), 175–197.

Dimitropoulou, M., Duñabeitia, J. A., & Carreiras, M. (2011). Phonology by itself: Masked phonological priming effects with and without orthographic overlap. *Journal of Cognitive Psychology*, *23*(2), 185–203.

Duyck, W., Diependaele, K., Drieghe, D., & Brysbaert, M. (2004). The Size of the Cross-Lingua Masked Phonological Priming Effect Does Not Depend on Second Language Proficiency. *Experimental Psychology*, *51*(2), 116-124.

Ehri, L. C. (1992). *Reconceptualizing the development of sight word reading and its relationship to recoding*. Lawrence Erlbaum Associates, Inc.

Ehri, L. C., Nunes, S. R., Stahl, S. A., & Willows, D. M. (2001). Systematic phonics instruction helps students learn to read: Evidence from the National Reading Panel's meta-analysis. *Review of Educational Research*, *71*(3), 393–447.

Elliott, L. C., Smith, P., & McCulloch, K. (1997). *British Ability Scales* (Second Edition). Windsor: NFER-Nelson.

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: implications for group differences in response latency. *Psychological bulletin*, *125*(6), 777.

Ferrand, L., & Grainger, J. (1993). The time course of orthographic and phonological code activation in the early phases of visual word recognition. *Bulletin of the Psychonomic Society*, *31*(2), 119–122.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*(4), 680-698.

Forster, K. I., Mohan, K., Hector, J., Kinoshita, S., & Lupker, S. J. (2003). The mechanics of masked priming. *Masked priming: The state of the art*, 3-37.

Frost, R., Ahissar, M., Gotesman, R., & Tayeb, S. (2003). Are phonological effects fragile? The effect of luminance and exposure duration on form priming and phonological priming. *Journal of Memory and Language*, *48*(2), 346-378.

Gollan, T. H., Forster, K. I., & Frost, R. (1997). Translation priming with different scripts: Masked priming with cognates and noncognates in Hebrew–English bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*(5), 1122.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effects of masked homophone primes. *Journal of Memory and Language*, *33*(2), 218-233.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language*, *35*(5), 623–647.

Grainger, J., & Holcomb, P. J. (2007). Neural constraints on a functional architecture for word recognition. In *Neural Basis of Reading* (P. Cornelissen, P. Hansen, M. Kringelbach & K. Pugh). Oxford: Oxford University Press.

Grainger, J., Lété, B., Bertand, D., Dufau, S., & Ziegler, J. C. (2012). Evidence for multiple routes in learning to read. *Cognition*, *123*(2), 280–292.

Holcomb, P. J., & Grainger, J. (2007). Exploring the temporal dynamics of visual word recognition in the masked repetition priming paradigm using event-related potentials. *Brain Research*, *1180*, 39–58.

Kim, J., & Davis, C. (2003). Task effects in masked cross-script translation and phonological priming. *Journal of Memory and Language*, *49*(4), 484-499.

Lefavrais, P. (1967). *Manuel du test de l'Alouette: test d'analyse de la lecture et de la* dyslexie. Éditions du Centre de psychologie appliquée.

Lété, B., & Fayol, M. (2013). Substituted-letter and transposed-letter effects in a masked priming paradigm with French developing readers and dyslexics.*Journal of experimental child psychology*, *114*(1), 47-62.

Lété, B., Sprenger-Charolles, L., & Colé, P. (2004). MANULEX: A grade-level lexical database from French elementary school readers. *Behavior Research Methods, Instruments, & Computers*, *36*(1), 156-166.

Levenshtein, V. I. (1966). Binary codes capable of correcting deletions, insertions and reversals. *Soviet Physics Doklady, 10 (8),* 707–710. [Russian original (1965) in *Doklady Akademii Nauk SSSR, 163 (4),* 845–848.]

Léwy, N., & Grosjean, F. (2008). The Léwy and Grosjean BIMOLA model. In F. Grosjean (Ed.), *Studying bilinguals* (pp. 201–210). Oxford, UK: Oxford University Press.

Lukatela, G., Eaton, T., Lee, C., & Turvey, M. T. (2001). Does visual word identification involve a sub-phonemic level?. *Cognition*, *78*(3), B41-B52.

Lukatela, G., Frost, S. J., & Turvey, M. T. (1998). Phonological priming by masked nonword primes in the lexical decision task. *Journal of Memory and Language*, *39*(4), 666–683.

Lukatela, G., & Turvey, M. T. (1990). Automatic and pre-lexical computation of phonology in visual word identification. *European Journal of Cognitive Psychology*, *2*(4), 325-343.

Lupker, S. J., & Davis, C. J. (2009). Sandwich priming: A method for overcoming the limitations of masked priming by reducing lexical competitor effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35(3),* 618-639.

Marinus, E., Nation, K., & de Jong, P.F. (2015). Density and length in the neighbourhood: Explaining cross-linguistic differences in learning to read in English and in Dutch. *Journal of Experimental Child Psychology, 139,* 127-147.

Masterson, J., Dixon, M., & Stuart, M. (2002). *The Children's Printed Word Database*, from http://www.essex.ac.uk/psychology/cpwd/

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review*, *88*(5), 375-407.

Nakayama, M., Sears, C. R., Hino, Y., & Lupker, S. J. (2012). Cross-script phonological priming for Japanese-English bilinguals: Evidence for integrated phonological representations. *Language and Cognitive Processes*, *27*(10), 1563-1583.

Perfetti, C. A. (1992). The representation problem in reading acquisition. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 145–174). Hillsdale, HJ: Erlbaum.

Perfetti, C. A., Bell, L. C., & Delaney, S. M. (1988). Automatic (prelexical) phonetic activation in silent word reading: Evidence from backward masking.*Journal of Memory and Language*, *27*(1), 59-70.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin*, 114, 510–532.

Rastle, K., & Brysbaert, M. (2006). Masked phonological priming effects in English: Are they real? Do they matter? *Cognitive Psychology*, *53*(2), 97–145.

Roelofs, A. (2003). Shared phonological encoding processes and representations of languages in bilingual speakers. *Language and Cognitive Processes*, *18*(2), 175-204.

Share, D. L. (1995). Phonological recoding and self-teaching: *sine qua non* of reading acquisition. *Cognition*, *55*(2), 151–218.

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of Experimental Child Psychology*, *72*(2), 95–129.

Van Wijnendaele, I., & Brysbaert, M. (2002). Visual word recognition in bilinguals: phonological priming from the second to the first language. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(3), 616-627.

Voga, M., & Grainger, J. (2007). Cognate status and cross-script translation priming. *Memory & Cognition*, *35*(5), 938-952.

Zeguers M.H.T., Snellings, P., Huizenga, H.M., & van der Molen, M.W. (2014). Time course analyses of orthographic and phonological priming effects during word recognition in a transparent orthography. *Quarterly Journal of Experimental Psychology, 67(10),* 1925-1943.

Zhou, H., Chen, B., Yang, M., & Dunlap, S. (2010). Language nonselective access to phonological representations: Evidence from Chinese–English bilinguals. *The Quarterly Journal of Experimental Psychology*, *63*(10), 2051-2066.

Ziegler, J. C., Bertrand, D., Lété, B., & Grainger, J. (2014). Orthographic and phonological contributions to reading development: Tracking developmental trajectories using masked priming. *Developmental Psychology*, *50*(4), 1026–1036.

Ziegler, J. C., Ferrand, L., Jacobs, A. M., Rey, A., & Grainger, J. (2000). Visual and phonological codes in letter and word recognition: Evidence from incremental priming. *The Quarterly Journal of Experimental Psychology: Section A*, *53*(3), 671-692.

Appendix A

French target words and English primes

French target word		**PH prime**			**OC prime**			**UR prime**	
	Phon. of beginning of the target	Ortho.	Phon.	% phono	Ortho.	Phon.	% ortho.	Ortho.	Phon.
GRIFFE	gʀi	gree	gri:	75	groa	grəʊ	33	splu	splʌ
PRISE	pʀi	pree	pri:	75	proo	pru:	40	swoo	swu:
STYLE	sti	stee	sti:	75	stoa	stəʊ	20	craw	krɔː
BILLE	bi	bea	bi:	67	baw	bɔː	20	goa	gəʊ
CHOC	ʃɔ	shaw	ʃɔː	67	shea	ʃi:	25	twir	tw3:
FAUTE	fo	faw	fɔː	67	fae	fi:	40	dei	deɪ
NICHE	ni	nea	ni:	67	nur	n3:	20	woo	wʊ
RIRE	ʀi	rea	ri:	67	roa	rɔː	25	sna	sneɪ
ROUGE	ʀu	roo	ru:	67	roe	rəʊ	40	fie	fi:
VIDE	vi	vee	vi:	67	voo	vu:	17	snu	snʌ
VILLE	vi	vea	vi:	67	vow	vaʊ	20	ske	ske
BLOUSON	blu	bloo	blu:	60	bloa	bləʊ	43	knea	ni:
BRILLER	bʀi	brea	bri:	60	brae	brɔː	29	choo	tʃuː
BRISER	bʀi	bree	bri:	60	braw	brɔː	33	shou	ʃaʊ
FRISSON	fʀi	frea	fri:	60	frow	fraʊ	33	spaw	spɔː
GLISSER	gli	glea	gli:	60	gloo	glu:	29	scow	skaʊ
GRIFFER	gʀi	grea	gri:	60	groa	grəʊ	29	smoo	smu:
PRISON	pʀi	prea	pri:	60	praw	prɔː	33	gho	gəʊ
PROUVER	pʀu	proo	pru:	60	prow	praʊ	43	blea	bli:
STYLO	sti	stea	sti:	60	stoo	stu:	40	drow	draʊ
TRISTE	tʀi	trea	tri:	60	traw	trɔː	33	spla	splæ
TROUVER	tʀu	troo	tru:	60	trow	traʊ	43	snai	sneɪ
BEAUCOUP	bo	boar	bɔː	50	bray	breɪ	25	spoi	spɔɪ
BROUILLARD	bʀu	broo	bru:	50	broa	brɔː	30	flee	fli:
CHIFFRE	ʃi	shee	ʃi:	50	thor	θɔː	14	spoo	spu:
CISEAUX	si	cea	si:	50	coa	kəʊ	14	wou	wʊ
CLIENT	kli	clea	kli:	50	clow	klaʊ	33	droo	dru:
CRITIQUE	kʀi	cree	kri:	50	croa	krəʊ	25	gloa	gləʊ
FAIBLE	fɛ	fea	fe	50	fey	feɪ	17	jee	dʒɪə

LIVRE	li	lea	li:	50	loa	ləʊ	20	sno	snɔː
NIVEAU	ni	nee	ni:	50	noo	nu:	17	wer	w3ː
PLIAGE	pli	plea	pli:	50	plow	plaʊ	50	sche	ski:
QUITTER	ki	kee	ki:	50	ska	skaɪ	0	slo	slɔː
RIDEAU	ʀi	ree	ri:	50	roa	rɔː	17	slu	slʌ
SCHÉMA	ʃe	sha	ʃɛ	50	swi	swi	17	wor	w3:
SOURIS	su	soo	su:	50	soa	səʊ	33	drea	dri:
SPIRALE	spi	spee	spi:	50	spou	spʌ	29	cloa	kləʊ
CRINIÈRE	kʀi	crea	kri:	43	croo	kəʊ	25	splo	splɔː
CHAUSSETTE	ʃo	shor	ʃɔː	40	shie	ʃi:	10	slee	sli:
CHAUSSURE	ʃo	sho	ʃɔː	40	whi	wɪ	11	twi	twi
DIMANCHE	di	dee	di:	40	doo	du:	12	pow	paʊ
DIZAINE	di	dea	di:	40	dow	daʊ	14	gow	gaʊ
DOSSIER	do	daw	dɔː	40	dwi	dwi:	14	twa	twɒ
FILLETTE	fi	fee	fi:	40	fow	faʊ	12	wai	weɪ
MILIEU	mi	mea	mi:	40	moa	məʊ	17	hoo	hʊ
MINUIT	mi	mee	mi:	40	moa	məʊ	17	poa	pəʊ
TONNERRE	to	taw	tɔː	40	thu	θʌ	12	hei	haɪ
CAUCHEMAR	ko	coar	kɔː	33	chea	tsi:	11	shir	ʃ3:
FOURCHETTE	fu	foo	fu:	33	foa	fəʊ	20	jea	dʒe
ROBINET	ʀo	roa	rɔː	33	roo	ru:	29	zea	zi:
DIFFICILE	di	dea	di:	28	dwe	dwE	11	smo	sməʊ

Note. PH prime, phonological prime; OC prime, orthographic-control prime; UR prime, unrelated prime; Phon., phonetic (for English primes, we reported the most frequent grapheme-phoneme conversion. For example, the letter string *oa* is more frequent pronounced /əʊ/ as in the word *goal* (/gəʊl/) than /oa/ as in the word *boa* (/boa/)) ; Ortho., Orthography; % phono, percentage of phonemes shared between the PH prime and the target; % ortho, percentage of letters shared between the PH prime, the OC prime and the target. Letters underlined indicate the orthographic overlap between phonological primes and targets and hence, between orthographic-control primes and targets.