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Grapheme coding in L2: How do L2 learners process new graphemes?

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Grapheme coding was examined in French Grade 6 and Grade 8 children and adults who learned English as a second language (L2). In Experiments 1 and 2, three conditions were compared in a letter detection task in L2: (1) simple grapheme (i.e., detect "a" in *black*); (2) complex language-shared grapheme (i.e., "a" in *brain*) and (3) complex L2-specific grapheme (i.e., "a" in *beach*). The data indicated that graphemes in L2 words were functional sub-lexical orthographic units for these L2 learners. Moreover, L2-specific graphemes took longer to process than language-shared complex graphemes. Using the same task, Experiment 3 examined phonological influences by manipulating the cross-language congruency of grapheme-to-phoneme mappings (detect "a" in *have* [congruent] vs. *take* [incongruent]). The outcome of this study offers preliminary evidence of graphemic coding during L2 word recognition both at the orthographic and the orthography-to-phonology mapping levels.

Keywords: Grapheme; Second language; Sub-lexical processing; Visual word recognition.

Learning a second language (L2) has become a decisive factor in enabling the population to adapt to the increasingly globalised world. Learners of a L2 are faced with several challenges in order to develop proficiency in reading a L2. They must acquire new lexical representations and we might ask how lexical access operates at different stages of L2 acquisition (Brenders, van Hell, & Dijkstra, 2011; Commissaire, 2012). It also seems likely to be crucial for L2 visual word recognition to build new sub-lexical orthographic representations involving the phonemic correspondences for graphemes that are specific to the L2 (e.g., "oa" or "sh," for French learners of English as a L2), and this is the focus of the present work.

A substantial body of research examining bilingual visual word recognition has investigated whether lexical access can be considered as language non-selective versus selective. In fact, strong support for the co-activation of orthographic lexical representations from both languages during lexical access has been observed over the last two decades among highly proficient adult bilinguals (see Dijkstra & van Heuven, 2002 for a review) and, to a comparable extent, among L2 learners (although there are far fewer studies, see Brenders et al., 2011). This argues in favour of language non-selectivity in lexical access. Nevertheless, words that feature in these interactions across languages are limited in number (Lemhöfer et al., 2008; Vitevitch, 2012) and can be qualified as either cognate words that share orthographic and semantic overlap across languages (e.g., *silence* in English and French) or cross-language neighbours

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that are orthographically similar (e.g., *fire–rire* [*laugh* in French]). However, many L2 words including words that are high in frequency may have L2-specific orthographic patterns (e.g., *think*), even when the L1 and L2 share the same Roman script. These L2-orthographic patterns can be defined in terms of the graphemes that compose them. For instance, English contains many graphemes that do not occur in French (e.g., "oa," "ea," "sh"). Nevertheless, English and French also share some graphemes, though in some cases with a different phonological correspondence (e.g., "ou" maps onto /u/ in French but onto several other phonemes such as /aʊ/ or /ʌ/ in English). Therefore, exactly how L2 words containing these types of graphemes are processed has to be explained.

Some recent monolingual studies may shed light on the role of the grapheme as a functional perceptual unit during visual word recognition. Graphemes can be constituted of one letter, "simple graphemes" (e.g., the four graphemes of the word *belt*), or two or more letters, "complex graphemes" (e.g., such as the grapheme "ea" in the word *bean*). In monolinguals, pseudowords that contained complex graphemes such as *fooph* were named more slowly that those that contained simple graphemes such as *frolp* (Joubert & Lecours, 2000; Rastle & Coltheart, 1998). A similar effect was found using a perceptual identification task for high- and low-frequency words (Rey, Jabobs, Schmidt-Weigand, & Ziegler, 1998; Rey & Schiller, 2005) and nonwords (Bolger, Borgwaldt, & Jakab, 2009) containing either complex or simple graphemes. Interestingly, Rey, Ziegler, and Jacobs (2000) showed that detecting a letter embedded in a complex grapheme (e.g., detecting the letter "A" in *beach*) was slower than detecting this letter in a simple grapheme (e.g., such as the "A" in *black*). This effect was replicated in English and French and with high- and low-frequency words. These graphemic complexity effects have been interpreted as reflecting the fact that the grapheme is a perceptual unit, and as a result, complex graphemes composed of multiple letters such as "ea" compete with single-letter graphemes "e" and "a" (see though Lupker, Acha, Davis, & Perea, 2012, for contradictory findings using the masked primed lexical decision task). This competition would therefore slow down word identification. The absence of an interaction between the effect and word frequency is further evidence for the sub-lexical locus of this effect.

Recent monolingual models have included a stage dedicated to grapheme parsing, which is independent of the grapheme-to-phoneme (GPC) conversion mechanism, called the two-layer associative network (TLA; Houghton & Zorzi, 2003). For instance, the bimodal interactive activation model (Diependaele, Ziegler, & Grainger, 2010; Grainger & Holcomb, 2009) as well as the connectionist dual-process model (CDP+, Perry, Ziegler, & Zorzi, 2007; and CDP++, Perry, Ziegler, & Zorzi, 2013) now integrate local representations for graphemes and give some account for grapheme parsing whose specific role is to convert letters into graphemes, and therefore compute grapheme identities and ordering. Following Houghton and Zorzi (2003), the mechanism of the graphemic buffer proposed in both these monolingual models characterises graphemes as local representations which are grouped following a graphosyllabic structure such as Onset–Vowel–Coda (for a full description, see Perry et al., 2007). For each of these sub-syllabic representations, graphemes are allocated several slots: three slots for the onset, one for the vowel and four slots for the coda. As an example, the word *check* would be represented as CH - - E CK - - - where CH takes the first onset slot (followed by two empty slots), E takes the vowel slot and CK takes the first coda slot (followed by three empty slots). Grapheme parsing is considered to be a serial mechanism that operates from left to right and which is seen as an attentional window that moves along the letters, converting them into graphemes.

At present, not much is known about sub-lexical orthographic representations (i.e., letters, graphemes, bodies or syllables) in L2 visual word recognition. In theoretical accounts of bilingual visual word recognition, no details about grapheme coding are given in the Bilingual Interactive Activation model (BIA; Dijkstra, van Heuven, & Grainger, 1998); however, in the BIA+ model (Dijkstra & van Heuven, 2002), the authors argue for an Onset–Nucleus–Coda type of sub-lexical phonological coding, although no information is given about the GPC conversion system. The bilingual literature does offer evidence in support of a role for orthographic markers (e.g., language-specific letters or bigrams). This evidence comes from the language decision task, in which participants are asked to decide whether an item is from the L1 or L2, where the presence of orthographic markers has been shown to speed up reaction times (RTs; Casaponsa, Carreiras, & Duñabeitia, 2014; Vaid & Frenck-Mestre, 2002; van Kesteren, Dijkstra, & de Smedt, 2012). This facilitation effect of orthographic markers was also recently uncovered in tasks that do not explicitly focus on language membership. Using a lexical decision task in either L2 (English, Experiment 2) or L1 (Bokmål, Experiment 3), van Kesteren and colleagues (2012) also found that Norwegian-English bilinguals exhibited a facilitation effect for words containing language-specific orthographic markers. This pattern was also recently observed among balanced and unbalanced Spanish-Basque bilinguals using the progressive demasking task (Casaponsa et al., 2014; Experiment 2). The language-switch effect, where lexical decision RTs are longer when the previous item is of a different rather than the same language, has also been reported to be weaker when the target item contains an orthographic marker (Beauvillain & Grainger, 1987; Orfanidou & Sumner, 2005). Though interesting hypotheses have been raised regarding the role of these sub-lexical orthographic markers in processing language membership information in bilinguals (van Kesteren et al., 2012), not much is yet known about sub-lexical processes per se in a second language. In order to assess the role of language specificity of *sub-lexical* orthographic representations during visual word recognition, we decided to focus on the graphemic level. Three experiments using the letter detection task (Rey et al., 2000) were presented to L2 learners with varying lengths of L2 exposure to assess the extent of grapheme coding in a L2.

EXPERIMENT 1

It is anticipated that highly proficient bilinguals may use similar sub-lexical orthographic processing in both L1 and L2, given that such participants have had a long exposure to the second language. In contrast, L2 learners are confronted by the task of establishing processing mechanisms for a large set of novel complex graphemes, many of which in the case of learning an opaque L2 such as English (Seymour, Aro, & Erskine, 2003), will have inconsistent orthography-to-phonology correspondences.

Experiment 1 presents the first attempt to examine: (1) whether graphemes are coded as functional sub-lexical orthographic units in a L2; and (2) whether L2-specific complex graphemes are processed differently from the complex graphemes that are shared across languages. In addition, three groups of native French speakers were selected to contrast length of exposure to written English as a L2: (1) adult University students who have been learning English for approximately 7 years (from Secondary Grade 6); (2) secondary Grade 8 adolescents who have been learning English for approximately 2 and a half years; and (3) secondary Grade 6 children who have been learning English for a few months—though all groups would have been exposed to the oral language since elementary school. None of these participants were used to practicing English outside of the classroom and none had ever lived in a bilingual environment. Their vocabulary as well as proficiency may be considered as rudimentary (see Commissaire, Duncan, & Casalis, 2011 for details about the knowledge and skills reached by these children populations on orthographic and phonological processing in English).

Participants had to perform a letter detection task where they had to detect whether a predetermined letter was present or absent from a following English (L2) target word which appeared very briefly. The rationale was that complex (two-letter) graphemes could be considered to form sub-lexical orthographic units if target letters were detected more slowly when embedded within a complex grapheme as compared to when the target letter corresponded to a simple (single letter) grapheme. Though we could easily hypothesise that complex graphemes within the L1 would be coded as early as Grade 6, given recent letter detection data from Dutch monolingual Grade 4 children (Marinus & De Jong, 2011)— we are currently investigating this issue in French (L1) beginning readers—the question of whether complex graphemes in a L2 such as English, considered as an opaque orthography and only learned for a few months by the younger group of participants, could be processed as orthographic units remains unclear. Thus, we first asked whether detecting a letter within a complex grapheme (e.g., “A” in *beach*) takes longer than when appearing as a one-letter grapheme (e.g., “A” in *place*) in an English (L2) letter detection task, and to what extent this can change with length of L2 exposure. Based on monolingual data, longer detection times in the complex condition as compared with the simple condition would offer support for a grapheme processing mechanism as orthographic units. Our second aim is to examine the graphemic coding process itself by comparing complex graphemes that differ in orthographic familiarity for our L2 learners at varying levels of proficiency. There will be two conditions: (1) complex graphemes that are shared between French (L1) and English (L2) such as "ou" in *house*; and (2) complex graphemes that are English (L2)-specific such as "oa" in *coach*. Two possible outcomes seem most plausible according to the level of proficiency and/or L2 length of exposure of L2 learners. In the most advanced L2 learners, detecting a letter in a L2-specific grapheme could take longer than within a L1/L2 shared grapheme, if we assume language non-selectivity. Indeed, if grapheme frequency is determined by lexical candidates from both French and English, shared graphemes (e.g., "ou") should have a higher frequency, and should thus be activated faster, than L2-specific graphemes (e.g., "oa"). In that case, we could hypothesise that the conflict raised in the letter detection task due to the competition between the letter and the grapheme level is resolved faster in the shared as compared to the L2-specific condition. In the less advanced learners, L2-specific graphemes could be weakly activated as functional orthographic units due to low exposure to these patterns—and possibly slow establishment of GPC correspondences. In such a situation, detecting a letter in the shared condition could take longer than in the L2-specific grapheme condition due to low levels of competition between letter and grapheme levels in the latter case. Another possibility is that unitisation of novel complex graphemes is a fast-developing mechanism (e.g., after a few exposures to print), leading to comparable patterns across the different participant groups. How these mechanisms can precisely be implemented in visual word recognition models during L2 acquisition remains to be addressed and the present study should help to improve understanding of these sub-lexical processes.

Method

Participants. A total of 77 French speakers performed the experimental task, comprising 21 adult students (mean age: 22 years and 4 months, 22;4), 30 secondary Grade 8 children (mean age: 13;9) and 26 secondary Grade 6 children (mean age: 11;7). The adult group was recruited at the Université Lille Nord de France. They were undergraduate students, mostly from the Psychology Department. Some students were recruited from other university departments but none attended any modern language department. These adults had started learning English in secondary Grade 6—although some of them had exposure to the language in Grade 5—and so learned English at school for 7 years. At the time of testing, their only opportunity to practice English consisted of some exposure via media such as music or movies in English and some English classes at university (i.e., 2 hours per week). None of them had ever lived in an English-speaking country and none considered themselves as bilinguals. The children were recruited from two high schools in the Rouen area of France. At each grade, pupils came from the same classroom. Grade 6 children had only a few months of written English learning but had been exposed to the oral language since elementary school. Grade 8 children had been learning English for at least 2 years, from Grade 6. Their practise of the English language consisted of 3–4 hours per week at school and, for some children, additional exposure to the oral language through music and movies, although the latter would also include written subtitles.

Materials. A total of 60 letter-present word trials were constructed (see Appendix 1). These trials were divided into three lists representing the experimental conditions: (1) simple grapheme, where the target letter, A, was presented as a single letter in the word (e.g., *make*); (2) complex shared grapheme, where the target letter was embedded in a complex grapheme that occurs in both English and French (e.g., *hair*) and (3) complex L2-specific grapheme, where the letter was embedded in a complex grapheme that is specific to the English language (e.g., *each*). The simple and complex L2-specific grapheme conditions each contained 24 stimuli, whereas the complex shared grapheme condition only contained 12 stimuli. The unequal number of items was due to linguistic constraints on stimuli selection and our decision to use only high-frequency English words that would have been encountered by L2 school learners.

All the stimuli were four- to five-letter monosyllabic words. Three target letters were chosen for the task: the vowels A, E and O. Once again, due to vocabulary constraints, two target-letter positions were used, either the second or third position in the word. Note that no double-vowel graphemes such as -oo or -ee were used. Stimuli were created on the basis of matched pairs (or triplets, when an item could also be created for the complex shared grapheme condition). As an example, for the target letter "E," the item *best* was presented for the simple grapheme condition (letter length: 4; written frequency: 481; target letter position: 2), whereas the item *read* was presented for the complex L2-specific grapheme condition (letter length: 4; written frequency: 349; target letter position: 2). This one-to-one matching enabled the three conditions to be matched on stimulus length (simple grapheme condition: mean length: 4.42 [standard deviation, *SD*: .5]; complex shared grapheme condition: 4.58 [*SD*: .51] and complex L2-specific grapheme condition: 4.42 [*SD*: .5]) and target letter position. Frequency was estimated using the Children Printed Word Database (CPWD; Masterson, Stuart, Dixon, & Lovejoy, 2003) developed for British monolingual children. The three conditions were also matched for frequency[1] (simple grapheme condition: mean 474 [*SD*: .825], complex shared grapheme condition: 221 [*SD*: 234] and complex L2-specific grapheme condition: 306 [*SD*: 320]) and this was confirmed by an analysis of variance (ANOVA), $F(2,57) < 1$, not significant (n.s). A total of 60 target-absent trials were also constructed in a parallel fashion from the letter-present trials. In order not to induce any response strategy, 68% of the letter-absent words that were used for this condition also included the target letters to be detected (A, E and O; though not the congruent one, e.g., detect A in the word *stop*).

Procedure. A target detection task was performed following the procedure described by Rey et al. (2000). The target letter was first presented for 700 ms in uppercase in the middle of the screen followed by a fixation point for 1,000 ms. The target word then appeared in lowercase for 33 ms. It was replaced by a blank screen presented for 70 ms followed by a 50-ms mask consisting of hashes. Participants had to press "yes" with their dominant hand if they detected the target letter in the word or else "no" with their non-dominant hand. The experiment was preceded by a 10-trial training phase. The whole testing procedure lasted around 15 minutes.

[1] Due to constraints on stimulus selection, two words of very high frequency were included in the simple grapheme condition, which artificially increased the overall mean. Aside from these specific cases, matching between the three conditions was conducted on a 1-to-1 basis as far as possible. Nevertheless, given the sub-lexical locus of the grapheme effect (Rey et al., 2000), this should not bias our data.

Results

Table 1 represents mean RTs and percentage error (and *SD*s) for the letter-present targets. An ANOVA was conducted on RTs and errors both by participants (F_1) and by items (F_2). Group was entered as a between-subjects variable and graphemic condition as a within-subjects variable in the analysis by participants. For each analysis, two effects were of interest and were investigated using orthogonal contrasts: (1) the comparison between the simple grapheme and complex grapheme (shared and L2-specific) conditions; and (2) the comparison between the two complex grapheme conditions, shared and L2 specific.

Reaction times. Data cleaning was performed by removing all RTs below 250 ms and above 2,000 ms and then discarding each data point above 2.5 *SD*s from the mean group RTs (<3% of accurate responses). In addition, two participants (one from each child group) were removed from the analyses due to high error rates (>2.5 *SD*s above mean group accuracy).

The main effect of group was significant both by participants and items, $F_1(2,72) = 35.52$, $p < .001$, $\eta_p^2 = .50$, $F_2(2,114) = 596.15$, $p < .001$, $\eta_p^2 = .91$. This reflected longer RTs for the Grade 6 children compared to the Grade 8 children ($p < .001$) and adults ($p < .001$), and in turn, longer RTs for the Grade 8 children compared to the adults ($p < .001$). Interestingly, the effect of graphemic condition was also significant in both analyses, $F_1(2,144) = 8.10$, $p < .001$, $\eta_p^2 = .10$, $F_2(2,57) = 5.02$,

TABLE 1
Mean RTs in milliseconds and percentage error (and *SD*s) for each participant group (adults, Grade 8, Grade 6) according to graphemic condition in Experiment 1

	Simple grapheme	*Complex shared grapheme*	*Complex L2-specific grapheme*
Adults			
Reaction times	578 (75)	591 (83)	603 (78)
% Error	5.1 (4.4)	3.6 (6.3)	6.8 (8)
Grade 8 children			
Reaction times	727 (122)	750 (132)	756 (108)
% Error	7.8 (5.5)	8.8 (11.9)	9.5 (8.4)
Grade 6 children			
Reaction times	853 (143)	853 (137)	896 (138)
% Error	8 (6.5)	9.7 (9.8)	8.6 (7.3)

$p < .01$, $\eta_p^2 = .15$. The simple condition was responded to faster than the combined complex grapheme conditions, 23 ms, $F_1(1,72) = 9.40$, $p < .01$, $F_2(1.57) = 5.26$, $p < .03$. The difference between the complex shared and the complex L2-specific grapheme conditions was significant in the participant analysis only, 20 ms, $F_1(1,72) = 6.67$, $p < .02$, $F_2(1.57) = 2.67$, $p = .11$. The interaction between group and graphemic condition did not reach significance, $F_1(4,144) = 1.06$, $p = .38$, n.s., $F_2 < 1$, n.s.

Errors. There was an effect of group in both analyses, though only as a trend by participants, $F_1(2,72) = 2.99$, $p = .06$, $\eta_p^2 = .08$, $F_2(2,114) = 6.93$, $p < .01$, $\eta_p^2 = .11$. The effect of graphemic condition was not significant and neither was the interaction between group and graphemic condition, all F values < 1.

Discussion

A main effect of graphemic complexity was observed across our participant groups, which suggests that detecting the presence of a single letter was affected by whether it appeared as a simple or a complex grapheme in the word. More precisely, complex graphemes were responded to slower than simple graphemes, a finding in line with observations on monolingual adults (Rey et al., 2000) and children (Marinus & De Jong, 2011). This implies that graphemes were functional units during visual word recognition in L2. In addition, letters embedded within complex L2-specific graphemes took longer to be detected than letters embedded in complex graphemes shared by the L1 and L2. Although this preliminary finding should be treated with caution, it is consistent with there being some processing cost for novel graphemes that are specific to the L2. Finally, the absence of any interaction with grade indicates that this pattern of grapheme coding appears comparable across these different levels of L2 experience and that complex graphemes constitute an orthographic coding unit in the L2, separable from letters themselves, as early as Grade 6 (see footnote 5 for separate group analyses).

Before suggesting more advanced theoretical interpretations of these effects, we should note that the small number of items in the complex shared grapheme condition (i.e., 12 words) might constitute a limitation of this experiment. This was due to the constraints of matching written word frequency between the three conditions and of selecting words that would be known by most of our participants. Experiment 2 was designed to further test graphemic coding in L2 by using nonword stimuli in a letter detection task. As previously observed in monolinguals, graphemic effects do not depend on the lexical frequency of the words (Rey et al., 2000), leading to a theoretical interpretation of this effect at a pre-lexical level. So, if the findings of Experiment 1 are robust and unbiased by the small number of items in one of the conditions, then a similar pattern of grapheme coding should emerge in Experiment 2 when using nonwords and a larger number of items in all three conditions.

EXPERIMENT 2

Three groups of L2 learners similar to the participants in Experiment 1 performed a letter detection task in English (L2). In contrast to Experiment 1, the letters to be detected appeared in nonwords, which were constructed using English orthographic patterns.

If the locus of the graphemic effect is indeed pre-lexical and arises during grapheme parsing, then a similar pattern should emerge between Experiment 1 using words and Experiment 2 using nonwords. Participants would be expected to detect letters embedded in complex graphemes more slowly than those presented as a single letter and to perform more slowly when these complex graphemes were L2 specific compared to when the complex graphemes were shared by the L1 and L2. The nonword manipulation allowed for a larger number of items in Experiment 2, especially in the complex shared condition (e.g., detect “A” in *blail*), which should increase power.

Method

Participants. A total of 68 French-speaking participants performed the task, including 18 adult students (mean age: 20;5), 26 children attending secondary Grade 8 (mean age: 13;5) and 24 children attending secondary Grade 6 (mean age: 11;6). All participants were recruited in a similar manner to Experiment 1 and had the same linguistic and socio-economic background. The two groups of children were recruited from the Antony area of Paris, France, and testing took place in February. Proficiency was assessed via a productive vocabulary task (Commissaire et al., 2011), where participants were asked to translate 50 French words into English equivalents (KR-20 = .90). As expected, performances of Grade 6 children were lower than those of Grade 8 children with, respectively, 34% (mean: 17/50, *SD*: 7) and 76% (mean: 38/50, *SD*: 9) accuracy. Grade 8 performances were only marginally lower than adults' whose performances almost reached ceiling with 90% accuracy (mean: 45/50, *SD*: 4).[2]

Materials and procedure. A total of 78 letter-present experimental trials were constructed (see Appendix 2). These trials were divided into three graphemic conditions: (1) simple grapheme, where a target letter such as "A" was presented as a single letter in the pseudoword (e.g., "blane"); (2) complex shared grapheme, where the target letter was embedded in a complex grapheme that occurs in both English and French (e.g., "chail") and (3) complex L2-specific condition where the letter was embedded in a complex grapheme that is specific to the English language (e.g., "nearl"). Each of these conditions contained 26 stimuli. All pseudoword stimuli were constructed using the Wuggy pseudoword generator (Keuleers & Brysbaert, 2010) and were five-letter monosyllables. The two critical target letters were the vowels A and O and they always occurred in the third position in the letter-present trials. Note that for the complex L2-specific grapheme condition, no double vowels such as -oo were used. The three conditions were matched on English bigram frequency, $F < 1$. There were additional seven letter-present filler items for which the target letter was the vowel E.

In addition, a total of 85 letter-absent trials were used to perform the task. These items were constructed in a parallel fashion to the letter-present trials. Again, in order not to induce any response strategy, 78% of the letter-absent pseudowords also included the target letters to be detected (A and O; though not the congruent one, e.g., detect A in the word *stop*).

[2] Many participants from Experiment 1 could not be assessed on this test of vocabulary due to testing problems and so, comparisons of proficiency scores between Experiments 1 and 2 cannot be provided. We wish to note though that the proficiency scores in Grades 6 and 8 participants from Experiment 2 are very comparable to those obtained in a former study involving a large number of participants (Commissaire et al., 2011) and that the multiplicity of schools—and classes—involved in each experiment should favour homogeneity within an age group across experiments.

The procedure was the same as in Experiment 1. The experiment was preceded by a 10-trial training phase using words. Participants were then informed that the following experimental trials would contain nonsense words that were invented but which had an English-like spelling. The whole testing procedure lasted around 15 minutes.

Results

Reaction times. Data cleaning was performed by removing all RTs above 2,000 ms and then discarding each data point over 2.5 *SD*s from the mean group RTs (<3% of accurate word data). Table 2 represents mean RTs and percentage error (and *SD*s) for the letter-present targets

The main effect of group was significant both by participants and by items, $F_1(2,65) = 18.26$, $p < .001$, $\eta_p^2 = .36$, $F_2(2,150) = 497.79$, $p < .001$, $\eta_p^2 = .87$, reflecting longer RTs for Grade 6 as compared to Grade 8 children ($p < .001$) and adults ($p < .001$) and longer responses for Grade 8 children as compared to adults ($p = .05$). The effect of graphemic condition was also significant by participants and items, $F_1(2,130) = 17.34$, $p < .001$, $\eta_p^2 = .21$, $F_2(2,75) = 11.06$, $p < .001$, $\eta_p^2 = .23$. The simple grapheme condition was responded to faster than the combined complex grapheme conditions (shared and specific), 28 ms, $F_1(1,65) = 11.49$, $p < .01$, $F_2(1,75) = 11.32$, $p < .01$. The complex shared grapheme condition was processed significantly faster than the complex L2-specific conditions in both the participant and item analyses, 26 ms, $F_1(1,65) = 30.56$, $p < .001$, $F_2(1,75) = 7.82$, $p < .01$.

TABLE 2
Mean RTs in milliseconds and percentage error (and *SD*s) for each participant group (adults, Grade 8, Grade 6) according to graphemic condition in Experiment 2

	Simple grapheme	*Complex shared grapheme*	*Complex L2-specific grapheme*
Adults			
Reaction times	601 (128)	594 (123)	635 (141)
% Error	8.6 (5.9)	6.3 (5.5)	6.8 (5.2)
Grade 8 children			
Reaction times	697 (119)	711 (123)	731 (142)
% Error	8.1 (8.6)	7.8 (7)	8.6 (7.9)
Grade 6 children			
Reaction times	841 (149)	861 (165)	889 (166)
% Error	8 (8.7)	9.2 (6.5)	11.2 (7.3)

The interaction between group and graphemic condition did not reach significance ($F < 1$).

Errors. There was no effect of group, $F_1 < 1$, $F_2(2,150) = 2.51$, $p = .09$, nor of graphemic condition, all F values < 1. The interaction between group and graphemic condition was not significant, $F_1(4,130) = 1.45$, $p = .22$, $F_2(4,150) = 1.53$, $p = .20$.

Discussion

As in Experiment 1, a main effect of graphemic complexity was observed, with longer detection times for the complex grapheme conditions (shared and specific) as compared to the simple grapheme condition. Again, longer detection times were also observed for the complex L2-specific than the complex shared graphemes. So, results were highly comparable between Experiments 1 and 2, which suggests that graphemic effects in the letter detection task do not depend on the lexical status of the items. This is consistent with previous findings showing that this effect does not depend on the lexical frequency of the words used and with the theoretical interpretations provided by the monolingual literature which favour a pre-lexical locus of this effect (Rey et al., 2000).

Furthermore, the outcome might be interpreted as reflecting two different levels of sub-lexical processing in L2 visual word recognition since when participants had to detect the letter "A" in a word such as *boat*, the orthographic sequence appeared to be coded automatically as "b," "o," "a" and "t" at the letter level and as "b," "oa" and "t" at the grapheme level. Moreover, the L2 visual word recognition system was sensitive to whether the complex graphemes were orthographically legal in both the L1 and L2 or else legal in the L2 alone, with the latter being associated with a processing cost.

Before exploring the theoretical implications for bilingual models of visual word recognition, it is important to acknowledge the possible influence of a third variable, namely phonology. Although our design focused on the complexity of graphemes in terms of the number of constituent letters, the fact that graphemes are linked to phonemes may also have impacted our findings. Previous studies using the letter detection task have indeed shown the presence of phonemic effects, although these were largely independent of graphemic effects. For example, Rey et al. (2000, Experiment 2) demonstrated that the graphemic complexity effect survived manipulation of the phonemic similarity between the letter to be detected and the phoneme in which it appeared in the target word (see also Rey & Schiller, 2005 for further evidence of the independence of orthographic and phonological mechanisms).

In L2 processing, the level of print-to-sound correspondence congruency across languages is likely to be variable. L2 learners may encounter L2-specific graphemes for which there is no GPC inconsistency with the L1 since the correspondences do not exist in the L1 (e.g., "oa" →/oː/), or else shared graphemes that are consistent across languages (e.g., "t" →/t/). However, they might also encounter graphemes that have incongruent phonemic patterns across the L1 and L2. This is the case for many complex shared graphemes (e.g., "ou" has one main phonological mapping in French, i.e., /uː/ but several in English, e.g., /ʌ/, /aʊ/). In our own materials, for the Experiment 1 words especially, only the simple grapheme condition contained target letters that had a congruent print-to-sound mapping across languages (see Appendix 1). Detecting the letter "A" in a word like *flat* where "a"→ /æ/ as in French could be different from detecting the letter "A" in a word like *make* where the correspondence "a"→ /eɪ/ is legal in English (L2) only. Since these cross-language phonologically congruent items mostly appeared in the simple grapheme condition, an alternative interpretation of our findings could be that the faster processing of simple than complex grapheme was due to the greater congruency of the GPC mapping across languages.

Note that whatever the specific locus of the graphemic effect, either purely orthographic or at the later stage of GPC conversion, this does not undermine our main findings regarding the existence of a graphemic coding level distinct from the letter coding level in L2 visual word recognition.

Thus, the aim of Experiment 3 was to test the role of phonological activation in the letter detection task among L2 learners, especially with regard to the congruency of the GPC mapping of the target letter.

EXPERIMENT 3

Three new groups of French-speaking participants learning English as a L2 performed a comparable letter detection task to those of Experiments 1 and 2. Phonological activation at the graphemic level was examined by comparing words where the target letter had a congruent phonological mapping across languages (e.g., A in *flat*) with words in which there was an incongruent mapping (e.g., A in *make*). This experiment enabled us to test whether L2 learners could be activating sub-lexical phonological codes in the letter detection task and whether letter detection times were affected by the congruency across languages of orthographic-to-phonological mappings.

Method

Participants. The total group of 72 participants consisted of 23 university students (mean age: 21;2), 22 secondary Grade 8 children (mean age: 13;7) and 27 secondary Grade 6 children (mean age: 11;8). The children were recruited from schools in Paris, in the Rouen area, and in the town of Bourges, France. All of the children had been learning English as a L2 from Grade 6 of secondary school. As with our previous participants, none of them had lived in a bilingual environment that involved the English language.

Materials. Forty experimental letter-present word trials were constructed (see Appendix 3). Half of the words contained a grapheme that had a shared phonemic correspondence across languages, whereas the other half contained a grapheme for which the phonemic correspondence in L2 differed from that predicted by L1 GPC conversion rules. Two graphemes that have multiple print-to-sound correspondences in English were used: the graphemes “a” and “i.” For the 20 experimental trials using the grapheme “a,” half were considered to have a cross-language congruent mapping between grapheme and the corresponding phoneme (mean frequency: 303, *SD*: 235), that is “a” →/a:/ (e.g., *fast*) whereas the other half had incongruent mappings (mean frequency: 342, *SD*: 279), either “a” →/eɪ/ (e.g., *game*) or “a” →/o:/ (e.g., *call*). Another 20 experimental trials were constructed for the grapheme “i” that was composed of 10 congruent trials (mean frequency: 299, *SD*: 239), “i” →/ɪ/ (e.g., *kill*) and 10 incongruent trials (mean frequency: 396, *SD*: 538), either “i” →/aɪ/ (e.g., *hire*) or “i” →/3:/ (e.g., *bird*). All of the word stimuli were four- or five-letter monosyllables (mean length: 4.05 letters). The target grapheme was always in position 2 in the word. Words for both graphemes used (A and I) and across congruency status (consistent vs. inconsistent) were matched in frequency, which was estimated using the CPWD developed for British monolingual children (Masterson, Stuart, Dixon, & Lovejoy, 2003). An ANOVA confirmed that word frequency did not vary according to the grapheme used or congruency status (all F values < 1), nor did these factors interact with each other (F < 1). Twenty fillers were also included using either the target letters “O” or “E.” For each of these letters, 10 words were used whose print-to-sound mapping was congruent across languages: “o” →/o:/ (e.g., *born*) or /ɒ/ (e.g., *gone*) and “e” →/ɛ/ (e.g., *next*). Mean length for these words was 4.15 letters and mean frequency was 363, *SD*: 408. Due to stimuli selection constraints, one item was bisyllabic (0.05% of filler words).

For the 60 letter-absent trials, the same letters to be detected were used in similar proportions as for the letter-present trials. Again, all the word stimuli were four- or five-letter monosyllables (mean length: 4.13 letters).

The same procedure as in Experiments 1 and 2 was followed. The experiment was preceded by a 10-trial training phase. The whole testing procedure lasted around 15 minutes.

Results

Reaction times. Data cleaning was performed by removing all RTs above 2,000 ms and then discarding each data point more than 2.5 *SD*s from the mean group RTs (<3% of accurate word data). In addition, three participants (one from each group) were removed from the analyses due to high error rates (>2.5 *SD*s above mean group accuracy). Table 3 represents mean RTs and

TABLE 3
Mean RTs in milliseconds and percentage error (and *SD*s) for each participant group (adults, Grade 8, Grade 6) according to congruency in Experiment 3

	Congruent	*Incongruent*
Adults		
Reaction times	553 (108)	568 (108)
% Error	5.5 (7.6)	6.6 (8.1)
Grade 8 children		
Reaction times	711 (101)	737 (106)
% Error	9.3 (5.8)	8.6 (7.6)
Grade 6 children		
Reaction times	857 (139)	837 (132)
% Error	11.9 (9.7)	9.4 (8.8)

percentage error (and *SD*s) for the letter-present targets.

The main effect of group was significant both by participants and by items, $F_1(2,66) = 38.09$, $p < .001$, $\eta_p^2 = .54$, $F_2(2,76) = 537.83$, $p < .001$, $\eta_p^2 = .93$, reflecting longer RTs for Grade 6 children as compared to both Grade 8 children ($p < .01$) and adults ($p < .001$) and longer times for Grade 8 children as compared to adults ($p < .001$). The effect of congruency was nonsignificant, all F values < 1, but the interaction between group and congruency was significant by participants, $F_1(2,66) = 3.43$, $p < .04$, $\eta_p^2 = .09$, and as a trend by items, $F_2(2,76) = 2.86$, $p = .06$.

Separate ANOVAs were conducted for each grade to explore the interaction between group and congruency further. This was motivated by the observation that variance across the three participant groups strongly differed, Levene test, $F(2,67) = 3.40$, $p < .05$—expectedly due to great age difference between some of the groups—and so, this lack of homogeneity across groups would tend to hinder any statistical effect to arise. Note that we acknowledge that this analysis does not allow us to make proper group comparisons. Thus, when analysed separately, the effect of congruency was nonsignificant at Grade 6, $F_1(1,25) = 1.50$, $p = .23$, $F_2(1,38) = 1.37$, $p = .25$, almost reached significance by participants at Grade 8, $F_1(1,20) = 3.92$, $p = .06$, F_2 $(1,38) = 2.17$, $p = .15$, and was significant by participants in the adult group, $F_1(1,21) = 5.56$, $p < .03$, $\eta_p^2 = .21$, F_2 $(1,38) = 1.10$, $p = .30$. When significant, this effect revealed that letter detection times were slower for incongruent as compared to congruent print-to-sound mappings.

Errors. The effect of group was significant, though as a trend in the participant analysis, $F_1(2,66) = 3.03$, $p = .06$, $F_2(2,76) = 5.89$, $p < .01$, $\eta_p^2 = .13$. Neither the effect of congruency nor the interaction between group and congruency achieved significance, all F values < 1.

Discussion

The present experiment examined cross-language congruency effects for GPC correspondences during a letter detection task in L2. When the target letter was present in the words, congruency was manipulated so that half of the words contained a letter with a phonemic correspondence that was congruent with the L1 ("a" →/a:/ or "i" →/ɪ/) and the other half had a letter with a phonemic correspondence that was incongruent with the L1 ("a" →/eɪ/ or /o:/ or "i" →/aɪ/ or /3:/).

Data analysis revealed that this congruency effect was significant in the adult group, significant as a trend in the Grade 8 group and nonsignificant for the Grade 6 group. So, in the groups who had the longest length of exposure to the L2, letters in the L2 target word that corresponded with the L1 GPC correspondences were detected faster than when the same letters occurred with a L2-specific correspondence. Detecting the letter "A" in *black* where "a" →/a/ as in French took less time than detecting "A" in *take* where "a" →/eɪ/, which is an English-specific GPC correspondence.

The observation of a congruency effect in some of the participant groups reveals first of all that phonological codes were automatically activated in the letter detection task, even though the target word was presented very briefly (34 ms). This is in line with previous reports of phonological effects with this paradigm (Gross, Treiman, & Inman, 2000; Lange, 2002). More specifically, it also indicates that phonology can be activated during a L2 visual word recognition task by L2 school learners and that these participants had a good knowledge of the L2 GPC correspondences used in the present stimuli. Indeed, the presence of a congruency effect suggests that participants knew how to decode these English words. Congruency effects were, however, not significant in the Grade 6 group and this is consistent with findings by Commissaire, Duncan, and Casalis (2011), who reported chance level in L2 decoding skills among a similar group of participants.

At the theoretical level, the congruency effect may be interpreted as reflecting the influence of L1 sub-lexical phonology. All three correspondences used in the stimuli for both target letters "A" and "I" were legal and occurred in the English (L2) language (see Berndt, Reggia, & Mitchum, 1987 for conditional probabilities of GPC correspondences in English), whereas only one of these correspondences occurred in French (L1, "a" →/a/ and "i" →/ɪ/). The observation that detecting a letter when it corresponded to a congruent correspondence across languages ("A" in *have*) was faster than when corresponding to an incongruent one ("A" in *take*) may indicate that the congruent connections may have been stronger than the incongruent ones. This finding may be easily understood within the BIA+ model of visual word recognition (Dijkstra & van Heuven, 2002), which assumes that sub-lexical phonology is activated non-selectively. Given the imbalance between L1 and L2 proficiency and exposure, stronger exposure would be anticipated for the congruent than the incongruent GPC correspondences, and so connections that are shared across languages could have been activated faster than those that are specific to the L2. Discussion of how these findings might be related to observations from Experiments 1 and 2 can be found in next section.

GENERAL DISCUSSION

The present study examined whether graphemes can be shown to be functional coding units during L2 visual word recognition for L2 learners with varying L2 exposure. In the first experiments, three groups of French speakers, namely adults, Grade 8 and Grade 6 adolescents who were learning English as a L2, had to judge whether a predetermined letter was present or absent from a word (Experiment 1) or a nonword (Experiment 2). In both experiments, three conditions were created in which the letter appeared: (1) as a single-letter grapheme (e.g., detect "A" in *black*), (2) as a complex grapheme that was shared between L1 and L2 (e.g., detect "A" in *chair*) and (3) as a complex grapheme that was specific to the L2 (e.g., detect "A" in *beach*). The rationale was that longer latencies in finding a letter embedded in a complex grapheme as compared to a simple grapheme would reflect the cost in simultaneously processing letters and graphemes; that is, for a word such as *boat* that contains the complex grapheme "oa," two sub-lexical processes would be activated (potentially in a parallel fashion) to detect each of the four letters, and the three graphemes,[3] and this would lead to some competition which takes some time to be resolved (Rey et al., 2000). In addition, we were interested in whether detection times would differ according to the language specificity of the grapheme by comparing complex shared versus L2-specific graphemes. Results showed that, as early as Grade 6, graphemes constitute an orthographic coding unit, at a different level from letters. That is, detecting a letter embedded in a complex grapheme such as "oa" took longer than when it was presented as a simple grapheme. This was found in both Experiments 1 and 2, regardless of whether the item in which the letter to be detected occurred was a word or a nonword, revealing that the locus of this effect is indeed pre-lexical. In addition, results from both these experiments also showed longer detection times for the complex L2-specific grapheme condition as compared to the complex shared grapheme condition.

So, the grapheme was shown to be a functional unit in L2 visual word recognition among the three groups of L2 learners. Here we must acknowledge that though no interaction with group was observed, examination of our data reveals that the graphemic effect was not always numerically robust as would be expected across groups and experiments.[4] Indeed, this graphemic effect has mostly been demonstrated in monolingual adults (Rey et al., 2000) and only more recently in monolingual children as young as 10 years old

[3] Note that considering the existence of graphemic coding does not argue against the evidence that is found in monolingual literature for a bigram coding mechanism (Dandurand, Grainger, Duñabeitia, & Granier, 2011) as these sub-lexical processes are not mutually exclusive (see Grainger & Ziegler, 2011).

[4] At Grade 6, data from both Experiments 1 and 2 showed a significant grapheme effect (Experiment 1: $F_1(2,48) = 4.84$, $p < .02$, $\eta_p^2 = .17$; Experiment 2: $F_1(2,46) = 6.43$, $p < .01$, $\eta_p^2 = .22$). Planned comparisons in Experiment 2 showed the same pattern of results described in the whole group analysis (longer processing for complex [L2-specific + shared] conditions as compared to the simple condition, $F_1(1,23) = 5.49$, $p < .03$, and longer time for L2 specific as compared to shared complex condition, $F_1(1,23) = 9.55$, $p < .01$), whereas the pattern of results observed in Experiment 1 slightly differed given the lack of numerical difference between the simple and the complex shared condition (simple vs. complex conditions, $F_1(1,24) = 2.10$, $p = .16$, n.s., but still longer time for L2-specific as compared with shared complex condition, $F_1(2,24) = 8.54$, $p < .01$). At Grade 8, results from Experiment 2 were congruent with what was observed in the whole group (main grapheme effect: $F_1(2,50) = 5.92$, $p < .01$, $\eta_p^2 = .1$; simple vs. complex conditions: $F_1(1,25) = 6.98$, $p < .02$; complex shared vs. L2-specific conditions: $F_1(1,25) = 4.59$, $p < .05$) but, surprisingly, no main effect of grapheme condition was observed in Experiment 1 ($F_1(2,58) = 1.85$, $p = .17$, n.s.). In the adult groups, the main graphemic effect was significant in both Experiments 1 and 2 (Experiment 1: $F_1(2,40) = 3.72$, $p < .04$, $\eta_p^2 = .16$; Experiment 2: $F_1(2,34) = 7.29$, $p < .01$, $\eta_p^2 = .30$) but the specific patterns examined via planned comparisons slightly differed across experiments (Experiment 1: simple vs. complex conditions, $F_1(1,20) = 5.08$, $p < .04$; complex shared vs. L2-specific conditions: $F_1(1,20) = 2.10$, $p = .16$, n.s.; Experiment 2: simple vs. complex conditions, $F_1(1,17) = 1.27$, $p = .28$; complex shared vs. L2-specific conditions, $F_1(1,17) = 23.28$, $p < .001$). Whether this instability is due to the task itself, the fact it is in L2 or the developmental nature of this study remains unclear.

(Marinus & De Jong, 2011). Future developmental studies would enable a better understanding of how this mechanism might evolve with time in both L1 and L2. Nevertheless, our finding of an effect of language specificity of the graphemes suggests that, though perceived as units, novel L2-specific graphemes require additional processing time as compared to shared graphemes; that is, the conflict between letter and grapheme levels took more time to be resolved for the novel L2-specific complex graphemes compared to shared graphemes, possibly due to the higher frequency of the latter. Here it is important to remember that if these complex L2-specific graphemes had not been coded as graphemic units, or were only weakly activated, detection times would have been faster compared to shared graphemes, not slower. Thus, our data seem to suggest that processing L2-specific graphemes as units is a fast-developing mechanism during visual word recognition in L2, as the Grade 6 group had no more than a few months—around five—of L2 print exposure.

Nevertheless, two alternative explanations stemming from the outcome of monolingual studies remain to be checked. On the one hand, work on letter recognition has highlighted the need to consider grapheme frequency as an important variable when tapping into sub-lexical processes (New & Grainger, 2011). Though the language specificity comparison could somehow be assimilated to a subjective frequency comparison for French learners of English, it is important to check for grapheme frequencies within the L2.[5] Based on the information provided by Berndt et al. (1987), we found that there was no difference between language-shared and L2-specific complex graphemes with regard to their print frequency in English, $t < 1$. Therefore, the processing cost found for L2-specific graphemes could not be attributed to this factor. On the other hand, monolingual studies also suggest that the grapheme complexity effect could be position dependent (Brand, Giroux, Puijalon, & Rey, 2007) and may arise only when the letter to be detected occupies the second position in the grapheme (e.g., detect "A" in a "ea"). Interpretation of this effect refers to a serial scanning of the letters composing complex graphemes; in contrast, position-independent effects support the idea of grapheme parsing as a parallel mechanism. The influence of this variable remains under debate given the contradictory findings in monolingual literature (see Peereman, Brand, & Rey, 2006 or Marinus & De Jong, 2011) but to investigate this question and to rule out any bias due to this variable, the results of the present study were reanalysed after discarding all such items (i.e., 7 items out of 24 from the complex L2-specific grapheme condition in Experiment 1; 6 items out of 26 for the complex L2-specific grapheme condition in Experiment 2). With this reduced data set where target letters occupied only the first position of the grapheme (e.g., "o" in "oa"), the outcome was unchanged with similar graphemic and language specificity effects emerging, suggesting that the grapheme parsing mechanism is not serial and that graphemes are indeed coded as perceptual units.

In terms of theoretical modelling, these data shed some light on the necessity for bilingual visual word recognition models such as BIA and BIA+ to attempt to integrate those sub-lexical units that seem to be functional perceptual units for L2 learners. Reference is made to such a level in BIA+, namely the TLA (Houghton & Zorzi, 2003; see also Perry et al., 2007), which has been described in monolingual models as comprising both a grapheme parser and a GPC conversion system. Our language specificity comparison emphasises the need for such a level to also integrate the distinction between L1/L2 shared graphemes from L2-specific graphemes, for which a representation would need to be constructed progressively. As language non-selectivity appears to be a major organisational mechanism in the bilingual visual word recognition system (Dijkstra & van Heuven, 2002), this distinction between L2-specific and shared graphemes would probably be implemented as different activation levels representing different frequency in print—or subjective frequency—to modulate to proficiency.

Therefore, our data suggest that graphemes are perceptual units that are processed in a parallel fashion, which are quickly acquired in a L2, although processing differences remain according to familiarity. Nevertheless, the specific locus of this effect, orthographic and/or phonological, requires further consideration. Although Experiments 1 and 2 focused on an orthographic characteristic of graphemes, namely complexity in terms of number of letters, it is also possible that phonological activation arose during visual word recognition and that the phonemic counterpart of each grapheme could also have influenced our results. In fact, although independent, the two sources of

[5] We thank an anonymous reviewer for making this point.

graphemic effects, i.e., orthographic and phonological, are known to affect letter detection times in monolinguals (Lange, 2000; Rey et al., 2000; Rey & Schiller, 2005). In L2 tasks, the patterns of phonological activation appear complex since: (1) for graphemes that are L2 specific, the GPC correspondence is novel (e.g., "ea" →/iː/); (2) for graphemes that are shared between the L1 and L2, the corresponding phoneme may be congruent across languages (e.g., "a" →/a/) or (3) graphemes can be shared but can have an incongruent mapping across languages (e.g., "a" →/eɪ/).

When examining our experimental items, especially the Experiment 1 words, we observed that the simple grapheme condition contained either a congruent or an incongruent mapping across languages. In contrast, mappings in the two complex grapheme conditions were either incongruent across languages (e.g., in the shared condition, "ou" in *house* is pronounced as /u/ in French) or contained novel mappings (e.g., in the L2-specific condition). In order to investigate the extent to which the mix of congruent and incongruent GPC correspondences in the simple grapheme condition could have affected our data, this factor was manipulated in the letter detection task of Experiment 3. The target letters appeared either in a congruent GPC correspondence across languages (e.g., "a"→ /a/ as in *black*) or an incongruent correspondence, which was in fact L2 specific (e.g., "a" →/eɪ/ as in *take*). Data from this experiment revealed different congruency patterns according to the length of L2 exposure with a robust congruency effect (i.e., longer detection times for incongruent than congruent correspondences) only in the adult group. There was a trend for a similar effect at Grade 8 but no evidence of an effect at Grade 6. So, it might be possible that some part of the graphemic effect is underpinned by phonological influences as items with congruent mappings seem to be processed faster and these only occurred in the simple grapheme conditions of Experiments 1 and 2. Nevertheless, this effect is only likely to have influenced the graphemic effects shown by the most proficient participants given that no clear phonological congruency effect emerged for the two adolescent groups.

As for our goal of examining the developmental dynamics of L2 graphemic coding, there was surprisingly no interaction between the graphemic effect and participant group in Experiments 1 and 2, which suggests that graphemes were coded as functional units after only a few months of L2 written exposure in Grade 6 (see footnote 5 for details about group analyses). It is interesting to contrast this with the phonological findings from Experiment 3, where the cross-language congruency effect of the GPC correspondences was only observed for those participants with the longest exposure to the L2. Although one could argue that the adolescent groups did not activate phonological information during the letter detection task (see though Booth, Perfetti, & MacWhinney, 1999) for quick phonological activation in monolingual word recognition), it seems equally possible that accurate GPC correspondences within the L2 take some time to be established and that incorrect decoding of the L2 words might explain the non-significant findings in the adolescent groups. Future studies on grapheme coding would probably benefit from assessing learners' reading skills in L2 as well as orthographic (i.e., lexical orthographic knowledge; sensitivity to orthographic regularities) and phonological (i.e., decoding) processing skills (Commissaire et al., 2011).

In sum, this study showed that grapheme coding also arises during L2 visual word recognition and pointed to the differential mechanisms that could be at play in L2 learners according to the language typicality of the orthographic patterns and of cross-language congruency of the GPC correspondences. This highlights the need for bilingual word recognition modelling to integrate those sub-lexical constraints into models (e.g., BIA+; Dijkstra & Van Heuven, 2002) though future investigations will be necessary to better understand developmental trends in the acquisition and processing of these sub-lexical units, both at the orthographic and phonological levels.

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APPENDIX 1: EXPERIMENTAL STIMULI FROM EXPERIMENT 1 (LETTER-PRESENT TRIALS)

Simple grapheme condition. hard*; ball; make; flat*; what; than*; plane; whale; black*; work; love*; word*; spot*; stop*; shot*; worse; horse; those*; smoke*; clock*; best*; neck*; dress*; spell*

Complex shared grapheme condition: hair*; wait*; your; hour; loud; laugh; paint; south; mouth; noise; chair*; cloud

Complex L2-specific grapheme condition: says; ears; each; read; fear; does; town; road; boat; play; year; shoe; know; slow; board; toast; teach; heart; beach; bread; dream; brown; float; crowd

Note. * represents those items for which the target letter to be detected had a phonemic counterpart that could be considered as consistent with L1 grapheme-to-phoneme conversion rules.

APPENDIX 2: EXPERIMENTAL STIMULI FROM EXPERIMENT 2 (LETTER-PRESENT TRIALS)

Simple grapheme condition. blane; blape; blove; bralt; chack; closk; drane; flone; flosh; frone; glosh; knolt; phode; plack; prack; quove; shage; shoth; slane; snock; spall; spove; stagh; storn; swack; thack

Complex shared grapheme condition: blail; broud; chail; choin; clauk; crauk; droin; floil; floun; fraik; frauk; groil; groun; knour; proil; scauf; shauk; shoil, slaik; slout; snoud; spair; spoir; staur; swaum; traik

Complex L2-specific grapheme condition: blays; browd; coath; croat; deach; doath; feath; floan; frawn; frowl; groam; groel; kloat; nearl; peagh; prayl; shoam; skown; slayd; spawt; stoes; stown; thays; trowl; vrawl; whoat

APPENDIX 3: EXPERIMENTAL STIMULI FROM EXPERIMENT 3 (LETTER-PRESENT TRIALS)

Congruent condition. card; dark; farm; fast; half; hard; last; past; path; bark; fish; gift; give; hill; kill; kiss; milk; sick; wish; miss

Incongruent condition. game; name; same; take; wake; call; salt; talk; wall; walk; five; nine; rice; wife; time; bird; dirt; girl; first; birth