EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY, in press

Phonology by itself: Masked phonological priming effects with and without orthographic overlap

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Abstract

The activation of the phonological code plays a central role in visual word recognition. However, it is still unclear how this activation is integrated within this mainly bottom-up process. In the present masked priming study we combined Greek and Spanish, two languages with common phonemes and partially overlapping graphemes to investigate this issue. Greek-Spanish bilinguals performed lexical decisions on Greek and Spanish targets, briefly preceded by either phonologically related or orthographically and phonologically related prime words of the non-target language. Results revealed significant bi-directional cross-script masked phonological priming effects which disappeared under the influence of nearly overlapping orthographic representations. This pattern of effects suggests that there is fast and automatic language non-selective activation of the phonological code during the initial stages of visual word recognition but that this is clearly dependent on the orthographic properties of the input stimulus. The implications of our findings are discussed within the framework of current models of monolingual and bilingual visual word recognition.

Keywords: masked priming, phonology, cross-script, bilingualism

Acknowledgments

Maria Dimitropoulou was the recipient of a post-graduate grant from the Government of the Canary Islands (BOC 241, 02/12/2008). This research has been partially supported by Grants SEJ2006-09238/PSIC, CONSOLIDER-INGENIO 2010 (CSD2008-00048) and SEMA (PSI 2009-08889) from the Spanish Ministry of Science and Innovation. The authors will like to thank the Society of Hispanic Studies in Athens, "Miguel de Cervantes", for the collaboration in the recruitment of participants. Thanks are also due to Joana Cholin, Rob Hartsuiker and Wouter Duyck for their technical support and suggestions. The authors also express their gratitude to Janet van Hell, to Ana Schwartz and to two anonymous reviewers for helpful comments on an earlier draft.

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The masked priming paradigm has been repeatedly used in the study of the processes involved in the early stages of visual word recognition (hereafter VWR). In this paradigm a first letter string (the prime) is masked and only briefly presented (30-60 ms) ensuring that participants are unaware of its existence, while its influence can still be measured on a second string (the target) recognition time (Forster & Davis, 1984; Forster, Mohan, & Hector, 2003). Masked priming studies so far have shown that the initial stages of VWR are mediated by the activation of a word's phonological code (Ferrand & Grainger, 1993; Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006; Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000). Yet, the fact that in most alphabetic languages a common phonological representation between two words involves partly, or even fully, overlapping orthographic representations (e.g., phonologically related words like *made* and *maid* do also involve orthographic overlap), has made it hard to isolate pure phonological effects. The present masked priming lexical decision study makes use of the special orthographic and phonological relationship between Greek and Spanish to study how phonology by itself, and in combination with orthography, influences the early stages of VWR.

Although masked phonological priming effects have been mainly studied in combination with orthographic activation (primes with overlapping orthographic and phonological representations to the targets; e.g., *<u>blu</u>e*-*<u>BLU</u>R*) [1], a large body of evidence obtained with the masked priming paradigm has shown that during the early stages of VWR, phonological activation operates in isolation from orthography following a somewhat different time course: Ferrand and Grainger (1993) proposed that orthographic masked priming effects arise earlier than phonological effects (see also Grainger, Spinelli, Diependaele, Ferrand & Farioli, 2003; Perfetti & Tan, 1998; Pollatsek, Perea, & Carreiras, 2005; Ziegler et al., 2000). This time-course difference has been further confirmed by electrophysiological studies (Carreiras, Perea, Vergara, & Pollatsek, 2009; Grainger et al., 2006; Holcomb & Grainger, 2006; Grainger & Holcomb, 2009).

Based on evidence showing an independent activation of phonology during the initial stages of VWR, some studies have tried to isolate masked phonological priming effects from orthographic effects. These studies have shown that when a target word is preceded by a word or a pseudoword prime with complete or extensive phonological overlap and reduced orthographic overlap with the target (called *homophones* and *pseudohomophones,* respectively), participants make faster and more accurate lexical decisions on the target than when it is preceded by a phonologically unrelated prime or by a prime with equal orthographic but less phonological overlap (i.e., a graphemic control prime; e.g., *mard*-*MAID*; see Berent, 1997; Bowers, Vigliocco, & Haan, 1998; Brysbaert, 2001; Davis, Castles, & Iakovidis, 1998; Ferrand & Grainger, 1992, 1993; Frost & Yogev, 2001; Grainger & Ferrand, 1994;1996; Holyk & Pexman, 2004; Humphreys, Evett & Taylor, 1982; Lukatela, Frost, & Turvey, 1998; Lukatela & Turvey, 2000; Perfetti, Bell, & Delaney, 1988; Perfetti & Bell, 199l; for review, see Rastle & Brysbaert, 2006). Critically, most of the masked priming studies revealing early phonological activation have used pseudohomophonic primes, However, this poses an important limitation in the study of early phonological effects, since the phonological processing of homophones, which are words (e.g., *made*-*MAID*), and of pseudohomophones (e.g., *mayd*-*MAID*), which are pseudowords, may be fundamentally different. According to one of the most influential models of reading aloud, the dual route cascaded model

(DRC; e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), pseudowords (pseudohomophones) are read through the phonologically mediated “indirect” route, favoring phonological activation, while real words (homophones) are mainly processed through the “direct” lexical route, not providing any processing advantage to phonology. Furthermore, according to models that assume the existence of feed-forward and feedback connections from the sub-lexical to the lexical levels of representation (e.g., McClelland & Rumelhart, 1981; Grainger & Jacobs, 1996), pseudowords, lacking specific lexical representation, will activate ortho-phonologically similar attractor words stored in the lexicon (see Davis & Lupker, 2006). In the case of pseudohomophonic primes, one of these words would most probably be the target itself. Thus, considerable processing advantage is provided to the subsequently presented target word. In contrast, a homophonic word prime will map onto its own lexico-phonological representation providing no additional advantage to the target’s phonological representation. However, homophonic word pairs are scarce, especially within languages with shallow orthographies like Spanish (that has almost one-to-one grapheme-to-phoneme correspondences).

Given this limitation, researchers have addressed the issue of early phonological activation by studying bilingual populations, since homophonic word pairs are more abundant across languages. Such extensive cross-language phonological overlap can be found in *cognates* (i.e., translation equivalents with extensive orthographic and phonological overlap, e.g., the Spanish *guitarra* and *guitar*), *interlingual homographs* (i.e., words with different meaning but shared ortho-phonological representations, e.g., *red*, which means *net* in Spanish) or *interlingual homophones* (i.e., words with different meaning, partially different spelling but shared phonological representations, e.g., the Spanish *vil* /bil/ [malign] and the English *bill* /bil/). Dijkstra, Grainger and van Heuven

(1999) used cognates and interlingual homographs to study the influence of phonology in a group of Dutch-English bilinguals performing single presentation lexical decision and progressive demasking tasks to a list of English words (their non-dominant language) that were visually presented to them. The authors orthogonally manipulated the semantic, orthographic and phonological overlap between the Dutch and the English reading of cognates and interlingual homographs. The results of the lexical decision experiment showed that responses were faster and more accurate when there was semantic and/or orthographic overlap across the two readings of the test items, while when the two readings of the words overlapped only in phonology, responses were slowed down and less accurate. The progressive demasking experiment revealed the same pattern of effects in the reaction time analyses. In the error rate analyses, an inhibitory effect emerged for words with overlapping orthography but not for those with overlapping phonology across their two readings. However, the authors did find an inhibitory phonological effect in the accuracy data of a control group of monolingual English speakers performing lexical decisions on the same items as the bilingual group, indicating that the effect could have been caused by some uncontrolled variable of the test materials. In a more recent study Lemhöfer and Dijkstra (2004) used the same set of English items in an attempt to replicate the findings reported by Dijkstra et al. with another group of Dutch-English bilinguals performing two single presentation lexical decision experiments. The authors replicated the facilitative semantic and orthographic effects (in the reaction times), but failed to obtain the inhibitory phonological effect, further suggesting that the inhibitory cross-language phonological effect obtained by Dijkstra et al. with the bilingual group was not that reliable.

Schwartz, Kroll and Diaz (2007), recently tried to dissociate cross-language orthographic and phonological effects in a word naming study with a group of English-

Spanish bilinguals. The authors manipulated orthogonally the degree of orthographic and phonological overlap across English-Spanish cognates. They found consistent inhibitory effects in both the reaction time and the error rate analyses for English and Spanish cognates with high orthographic similarity across their two readings but distinct phonological representations (e.g., *base* /beIs/-*base* / 'base/), thus providing evidence of cross-language feed-forward activation from orthography to phonology. Yet, the fact that all these studies used cognates could have influenced their results, since the co-existent semantic overlap across the two readings of the words could have exaggerated the observed cross-language effects. Indeed, the facilitative effects that have been repeatedly obtained for cognates even with partially overlapping forms (e.g., *tomaat-tomato*) as compared to control words (e.g., Cristoffanini, Kirsner, & Milech, 1986; Font, 2001; van Hell & Dijkstra, 2002) suggest that the common semantic representation between the two readings of a cognate exerts strong feedback activation to their orthographic and phonological representations, thus enlarging the effects of cross-language form overlap (see Costa, Caramazza, Sebastián-Gallés, 2000 for further discussion). Hence, although all these studies are taken as evidence of language non-selective phonological activation (see Dijkstra & van Heuven, 2002) the conclusions drawn regarding the direction of the effects of cross-language phonological overlap are not that straight-forward.

In an effort to obtain evidence of fast and automatic cross-language phonological activation, bilingual studies have employed the masked priming paradigm using interlingual homophones (e.g., the Dutch word *dier* [beast] and the French *dire* [to say]). These studies have reported facilitative effects of comparable magnitude as those found in the monolingual masked phonological priming literature (e.g., Brysbaert, Van Dyck, & Van de Poel, 1999; Brysbaert & Van Wijnendaele, 2003; Duyck, Diependaele, Drieghe, & Brysbaert, 2004; Duyck, 2005; Van Wijnendaele & Brysbaert, 2002). These masked phonological priming effects, just like those obtained so far in monolingual studies, are considered to be a result of the phonemic overlap between primes and targets.

However, there is a caveat in this line of reasoning. In order to examine early phonological activation, the masked primes used (either words or pseudowords) have to be characterized by large phonological overlap with the targets and by limited orthographic overlap (for a discussion, see Rastle & Brysbaert, 2006). Yet, the homophonic and pseudohomophonic primes used so far in monolingual and bilingual studies satisfy only the first condition, but not the second one. Consider, for instance, the homophonic Dutch prime *dier* for the French target *DIRE* (Brysbaert et al., 1999); apart from a complete phonological overlap, these words also have two out of four overlapping graphemes in the same position, while the remaining two letters overlap too, though not in a position-specific manner. Thus, despite the effort to isolate the influence of orthography by using graphemic control primes (e.g., *diep- DIRE*), the unavoidable orthographic overlap could have considerably influenced the obtained effects claimed to be purely phonological. There is indeed evidence suggesting that phonological priming effects are modulated as a matter of co-existing orthographic overlap, with larger phonological priming effects emerging the more orthographically dissimilar the prime and the target are (Carreiras et al., 2005; Frost, Ahissar, Gotesman, & Tayeb, 2003; Haigh & Jared, 2007; Rastle & Brysbaert, 2006). Hence, even though previous research has shown masked phonological priming effects when unrelated conditions are matched to related conditions in terms of the extensive orthographic overlap, the critical question is whether masked phonological priming effects persist with limited or null orthographic overlap in the related conditions.

An efficient way to circumvent the influence of orthography and to examine phonological priming effects in isolation is to use interlingual homophones that belong to a different script (note that the use of different scripts typically precludes the existence of orthographic overlap). In this line, Tzelgov, Henik, Sneg and Baruch (1996) used the Stroop color naming task to study the effects caused by pseudowords in one language that corresponded to a color name in the other language with Hebrew-English bilinguals (*cross-script pseudohomophones*). The authors found Stroop interference effects in those trials in which the color name of these items did not correspond to the ink color in which they were presented (e.g., when the pseudoword "zahov", which sounds like the Hebrew for yellow, was presented in red ink). The most reliable interference effects were obtained with English pseudowords which corresponded to a color name in Hebrew, the participants' native language. However, as previously mentioned, the use of pseudohomophones could have enhanced the appearance of phonological effects (according, for instance, to the DRC model; see also Lukatela and Turvey (1990) for within-language cross-script evidence with pseudohomophones). Thus, the use of homophonic word pairs would be a more conservative strategy to probe the existence of early mandatory phonological effects in reading.

The first masked priming study to obtain evidence of cross-script phonological activation across languages with existing words was carried out by Gollan, Forster and Frost (1997) with Hebrew-English bilinguals performing a lexical decision task. The authors examined masked translation priming effects using translation equivalents that had either overlapping or non-overlapping phonological representations (cognates vs. non-cognates). They found larger priming effects when the Hebrew (L1) primes were the cognate translations of the English (L2) targets, as compared to when they were non-cognate translation equivalents, and concluded that the effects were phonologically mediated (see also Voga & Grainger, 2007). However, Kim and Davis (2003) failed to obtain this cross-script cognate advantage with Korean-English bilinguals. Thus, the existing evidence from cross-script cognate studies has not been conclusive regarding the influence of cross-language phonological overlap and the interactions of the co-existing phonological and semantic codes.

To our knowledge, only two studies with biscriptal bilingual populations have tested interlingual homophones without semantic overlap. Kim and Davis (2003) used a group of Korean-English bilinguals, who performed lexical decisions on English (L2) targets briefly preceded by Korean (Hangul) homophonic primes (L1). The authors found a facilitative phonological priming effect (significant only in a one-tailed *t*-test). Voga and Grainger (2007) used Greek (L1) primes and French (L2) targets with a group of Greek-French bilinguals. The authors included two phonologically related priming conditions, one with an 85% phonemic overlap to the target and one with a 50% phonemic overlap, with their corresponding controls. Though the 50% phonemic prime-target overlap did not lead to any effects, the effects produced in the highly overlapping condition revealed clear processing advantages for phonologically related pairs. Nevertheless, given that the main focus of their study was on the cognate effect, the significance level of this comparison was not reported by the authors. Considering this set of results, the prediction of a masked phonological priming effect with biscriptal bilinguals seems straightforward. The pure phonological nature of such an effect would be of great importance in identifying the influence of phonological activation at the initial stages of VWR.

The present study

The present cross-script masked priming study aims at investigating phonological masked priming effects with and without the influence of overlapping orthographic units in a group of Greek-Spanish bilinguals performing Greek and Spanish lexical decisions. Greek and Spanish have rather transparent orthographies with almost one-to-one grapheme-to-phoneme correspondences (see Protopapas & Vlahou, in press). They furthermore share a number of rhythmic properties, such as lexical stress patterns and similar vowel systems (Sebastián-Gallés, Dupoux, Costa, & Mehler, 2000). More importantly for the purposes of the present study, the grapho-phonemic relationship between Greek and Spanish is of special interest. When comparing both alphabets a subdivision of their letters can be made. Some of their letters have indistinguishable graphemic and identical phonemic representations, others are visually (graphemically) unique to each alphabet but have common phonemic representations, while there are also a few that are graphemically similar (i.e., visually akin) but map onto different phonemes (see Table 1).

--- Insert Table 1 around here ---

By making use of this specific script and language combination we created cross-language prime-target word pairs with either i) extensive phonological and limited orthographic overlap (e.g., the Greek *φύτρο* [bud], pronounced as /'fitro/, and the Spanish *fibra* [fiber], pronounced as /'fiβra/) or with ii) extensive phonological and orthographic overlap (e.g., the Greek *όριο* [limit], pronounced as /'orio/ and the Spanish *ocio* [leisure], pronounced as /'oθio/). For the sake of simplicity, we will refer to Greek-Spanish word pairs with extensive phonological overlap but minimal orthographic overlap as *related P+O-* pairs, and to Greek-Spanish word pairs phonologically and orthographically related as *related P+O+* pairs. Two lexical decision experiments were conducted in order to examine both language directions. In Experiment 1 primes were in Greek (L1) and targets in Spanish (L2), while in Experiment 2 primes were in Spanish (L2) and targets in Greek (L1).

The use of phonologically related but orthographically dissimilar cross-language word pairs (related P+O-) with a cross-script manipulation aims to reveal a pure phonological masked priming effect. When Spanish targets were preceded by related P+O- Greek primes (Experiment 1) we expected to obtain a facilitative phonological priming effect (e.g., Brysbaert et al., 1999). To our knowledge, such an effect would constitute the first evidence of a purely phonological masked priming effect given the cross-script nature of the prime-target pairs used. Furthermore, we expected to replicate this effect in Experiment 2, Greek targets preceded by related P+O- Spanish primes (see Van Wijnendaele & Brysbaert, 2002). On the other hand, the use of prime-target word pairs with extensive phonological and orthographic overlap (related P+O+) aims at exploring whether phonological effects are modulated by the co-activation of the underlying orthographic representation. It should be noted that the predictions for this condition (in both experiments) are not so straightforward given that this is the first time a bilingual cross-script study includes a condition with primes and targets overlapping ortho-phonologically. So far, the intra-script bilingual literature has mainly revealed null or inhibitory effects for completely (i.e., interlingual homographs; e.g., Dijkstra, Van Jaarsveld, & Ten Brinke 1998; von Studnitz & Green, 2002; Lemhöfer & Dijkstra, 2004) or largely (i.e., interlingual orthographic neighbors; e.g., Bijeljac-Babic, Biardeau, & Grainger, 1997) overlapping word forms from a bilingual's two languages. However, when the overlap across the interlingual homographs extends to the semantic level too (i.e., cognates), the effects are facilitative (e.g., Dijkstra et al., 1999; Schwartz et al., 2007). It remains to be seen, whether we will obtain a similar pattern of results with cross-language phonologically and orthographically related word pairs (related P+O+).

Overall, the specific interlingual manipulation used in this study provides the important methodological advantage of using the same language combination and the same experimental group to study phonological effects with and without the influence of orthography [2]. Furthermore, it allows for the exclusive use of word (not pseudoword) primes which map onto their own lexical representations and not onto the target's (for masked priming effects dependent on the primes' lexicality see Duñabeitia, Perea, & Carreiras, 2009; Duñabeitia, Molinaro, Laka, Estévez, & Carreiras, 2009). As already mentioned, the effects obtained in previous homophone monolingual and intra-script bilingual studies could be better characterized as "ortho-phonological" rather than purely phonological in nature, given the considerable orthographic overlap between primes and targets. Crucially, the combination of related P+O- and related P+O+ prime-target pairs aims at disentangling pure phonological from the so far obtained "ortho-phonological" effects (namely, at exploring phonology by itself). In other words, it offers the possibility to explore the role of phonology in early stages of VWR while controlling for a series of confounded variables, potentially involved in the effects obtained in previous studies.

Experiment 1: Greek (L1) primes and Spanish (L2) targets

Method

Participants. Thirty native Greeks (mean age: 24.8±3) with normal or corrected-to-normal vision participated voluntarily in this experiment. All the participants completed a Greek version of the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). They had been learning Spanish for a mean of 2.9±0.9 years, for 5.0±1.3 hours per week in the same formal context (a Spanish academy in Athens). None of the participants were exposed to Spanish in any other setting apart from this. At the moment of testing all of them reported living in Greece (L1 environment). As calculated by participants' self-ratings of their Spanish proficiency, their overall Spanish proficiency was on average of 5.5±1.3 (0-very low to 10-very high scale).

Materials. We selected 120 Spanish words as targets, taken from the Spanish LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000). Primes were Greek words selected from the GreekLex database (Ktori, Van Heuven, & Pitchford, 2008). Targets in the P+O- condition were preceded by Greek primes that were either i) phonologically related to the targets but with minimal orthographic overlap (related P+O-), or ii) phonologically and orthographically unrelated to the targets (unrelated P+O-). Targets in the P+O+ condition were preceded by Greek primes that were either i) phonologically and orthographically related to the targets (related P+O+) or ii) phonologically and orthographically unrelated to the targets (unrelated P+O+).

In order to select the critical letters on which the orthographic and phonological manipulations were based, 20 Spanish students from the University of La Laguna (Spain) with no previous exposure to the Greek script completed a questionnaire in which they were asked to indicate whether they could recognize Roman letters in the Greek alphabet. From those that were indicated by all the participants as visually indistinguishable only those with overlapping phonological representations (i.e., *a, e, i, o, b, k, t*) were used to find the related prime-target pairs of the P+O+ condition. Correspondingly, the Greek letters that were matched by the participants to Roman letters with distinct phonological representations and the Greek letters that the participants did not match to any Roman letter (but their corresponding phoneme was an existing one in Spanish too) were used to find the related prime-target pairs of the P+O- condition. This way, Greek and Spanish word pairs that had on average 72% of overlapping phonemes were selected for the related P+O- condition. Greek and Spanish word pairs including on average 68% overlapping phonemes and 65% overlapping letters were selected as the critical items for the related P+O+ conditions. Another set of Greek words comprised by letters phonologically and visually unrelated to those comprising the critical Spanish words (less than 9% of overlap) were selected for the P+O- and P+O+ unrelated conditions. Once the critical items were identified, a one-to-one pairing was performed between Greek primes (related and unrelated) and Spanish targets. In order to accurately calculate the amount of orthographic and phonological overlap across the word pairs, they were pairwise matched in word length, allowing for a one-to-one comparison of their letters and phonemes. Note that, such a one-to-one letter-to-phoneme alignment is possible for Greek and Spanish words since both languages have highly transparent orthographies with mostly one-to-one grapheme to phoneme correspondences (see Protopapas & Vlahou, in press; Defior, Martos & Cary, 2002). The related P+O- Greek primes preceding the Spanish targets had a mean of 72% of their phonemes common with the targets (3.5 shared phonemes in the same position within the word) and only a 9% of graphemic overlap (0.4 shared letters in the same position within the word) [3]. The unrelated Greek primes in the P+O- condition overlapped with the targets only on 8% of their phonemes (0.4 shared phonemes in the same position within the word) and orthographically only on 6% of their letters (0.3 shared letters in the same position within the word). The related P+O+ Greek primes preceding the Spanish targets had a mean of 68% of their phonemes common to the targets (3.3 shared phonemes in the same position within the word) and a mean of 65% of letters common to the targets (3.2 shared letters in the same position within the word). On the contrary, the ortho-phonologically unrelated Greek primes overlapped with the targets only on 4% of their phonemes (0.2 shared phonemes in the same position within the word) and on 2% of their letters (0.1 shared letters in the same position within the word).

Furthermore, the Van Orden measure of graphemic similarity (Van Orden, 1987) was calculated for all the prime-target pairs (see also Schwartz et al., 2007; Van Assche, Duyck, Hartsuiker, & Diependaele, 2009). This measure takes into account a set of different variables such as the number of shared single and adjacent letters, the average number of letters of the two words, etc. The final Van Orden score is the ratio between the graphemic similarity of a word to itself divided by the graphemic similarity of that word relative to another word [4]. According to the Van Orden scores the only priming condition with extensive graphemic overlap between primes and targets was the related P+O+ condition (all *ps*<.001). In addition, the three remaining sets of prime-target pairs (i.e., related and unrelated of the P+O- condition and unrelated of the P+O+ condition) did not differ in terms of graphemic similarity (all *ps*>.17). Mean word frequency was matched across all the conditions (for a full description and examples of the experimental materials see Table 2). None of the prime-target pairs were related in any morpho-semantic aspect. Related P+O- prime-target pairs overlapped in initial phoneme while related P+O+ prime-target pairs in initial grapheme and phoneme. This ensured that any possible differences across the two manipulations, P+O- and P+O+, would not reflect facilitation due to the overlap of the initial letter/phoneme (see Kinoshita & Woollams, 2002; a full listing of the materials used in Experiments 1 and 2 along with their phonetic transcriptions according to the International Phonetic Alphabet is presented in the Appendix). An additional set of 120 orthographically legal Spanish pseudowords (e.g., *marle*) were also created for lexical decision purposes. All the pseudowords were pairwise matched in length to the target words (mean length: 4.9±1). None of them was an actual word in Greek. These pseudowords were preceded by Greek prime words, matched in frequency and length to the primes of the target words (mean word frequency: 44.28±128, mean length: 4.9±1). Two lists of materials were constructed so that each target appeared only once in each list, but each time being preceded by a prime corresponding to a different condition. Fifteen different participants were randomly assigned to each list.

--- Insert Table 2 around here ---

Procedure. Participants were tested individually in a quiet room. Stimuli presentation and recording of response times were controlled by a PC. The experiment was run using DMDX (Forster & Forster, 2003). Reaction times were measured from target onset until participant's response. On each trial, a forward mask consisting of a row of hash marks (#'s) was presented for 500ms. Next, the prime was presented in 10pt lowercase Verdana and stayed on the screen for 50 ms (3 cycles; each cycle corresponding to 16.6 ms on the CRT monitor). The prime was immediately followed by the presentation of the target stimulus in 12pt lowercase Verdana. Masks, primes and targets were presented in the center of the screen. The target remained on the screen until the participants responded or for a maximum of 2500 ms. Participants were instructed to press, as quickly and accurately as possible, one of two buttons on the keyboard to indicate whether the target letter string was a legitimate Spanish word or not. They were not informed of the presence of the primes, and none of them reported (after the experiment) conscious knowledge of their existence. Trial presentation was randomized across participants. Each participant received a total of 12 practice trials (6 words and 6 pseudowords) prior to the 240 experimental trials. The experimental session lasted approximately 15 minutes. Task instructions (and interactions with the participants) were given in Spanish. Since the participants who took part in this Experiment also completed Experiment 2, there was at least a three-day gap between the two experimental sessions. The order of the sessions was counterbalanced across participants.

Results and Discussion

Incorrect responses and reaction times less than 250 ms or greater than 1500 ms were excluded from the latency analysis. The trimming procedure excluded less than 2% of the data. Mean latencies for correct responses and error rates are presented in Table 3. ANOVAs on the reaction times and error rates by participants and items were conducted based on a 2 (Relatedness: related, unrelated) x 2 (Type of relationship: P+O+, P+O-) x 2 (List: list 1, 2) x 2 (Order of sessions: 1, 2) design. The factor Order of sessions was included in order to confirm whether this could have had an impact on the observed results. The factor List was included as a dummy variable (Pollatsek & Well, 1995).

--- Insert Table 3 around here ---

ANOVAs on the reaction times showed a main effect of Type of relationship: targets in the P+O- subset were responded to 17 ms faster than those in the P+O+ subset, $F_1(1, 26)=11.67$, $MSE=732$, $p<.01$; $F_2(1, 112)=7.23$, $MSE=25379$, $p<.01$. The effects of Relatedness and Order of sessions were not significant, all *ps*>.25. Importantly, the interaction of Relatedness with Type of relationship was significant, $F_1(1, 26)=5.54$, $MSE=888$, $p<.05$; $F_2(1, 112)=7.36$, $MSE=1570$, $p<.01$. Pairwise comparisons were performed, showing that participants responded faster (19 ms faster) to P+O- targets when they were preceded by related P+O- Greek primes as compared to when they were preceded by unrelated Greek primes, $F_1(1, 26)=11.58$, $MSE=461$, $p<.01$; $F_2(1, 56)=5.38$, $MSE=1497$, $p<.05$. In contrast, P+O+ targets were responded to 8 ms slower when they were preceded by related P+O+ Greek primes, as compared to when they were preceded by ortho-phonologically unrelated primes, although this difference did not reach significance (both *ps*>.13). Finally, Order of sessions did not interact with either Relatedness or Type of relationship (all *ps*>.20), showing that the fact that half of the participants had been presented in the previous days with the same materials in the inversed sequence (i.e., masked primes had appeared as targets and vice versa) did not affect the present findings.

ANOVAs on the error data showed a main effect of Type of relationship, with P+O- targets being more accurately recognized than P+O+ targets (11.6% vs. 14.2%), although this effect was only significant in the analysis by participants, $F_1(1, 26)=6.32$, $MSE=29$, $p<.05$; $F_2(1, 112)=1.31$, $MSE=350$, $p>.25$). No other effects on the error rate analysis reached significance (all *ps*>.17).

In light of previous evidence showing a modulation of the obtained effects depending on whether the critical word pairs were of the same grammatical category or not (Sunderman & Kroll, 2006), the mean reaction times per condition and the net priming effects were calculated separately for prime-target pairs of the same and of different grammatical categories. This analysis showed that the magnitude of the net priming effects obtained was virtually unaffected by the match/mismatch in grammatical category. In further detail, in the P+O- condition the net priming effects were of 19 ms for prime-target pairs of the same grammatical class and of 15 ms for prime-target pairs of different grammatical class. In the P+O+ condition the net priming effects were of -13 ms for pairs with matching grammatical class and of -6 ms for pairs with mismatching grammatical class [5].

The results of this experiment showed a masked phonological priming effect, only evident when the related Greek primes had extensive phonological but limited or no orthographic overlap to the Spanish targets (related P+O-, e.g., *φύτρο* [bud]-*fibra* [fiber] vs. unrelated P+O-, e.g., *τραγί* [goat]-*fibra*). Interestingly, the facilitative phonological priming effect vanished when Greek primes and Spanish targets overlapped both phonologically and orthographically as compared to the control condition (related P+O+, e.g., *όριο* [limit]-*ocio* [leisure] vs. unrelated P+O+, e.g., *βήμα* [step]-*ocio*).

Up to this point we have found a cross-script masked phonological priming effect with L1 primes and L2 targets. In Experiment 2 we tested the same participants in the inverse language direction (i.e., Spanish (L2) primes and Greek (L1) targets), in order to replicate the cross-script pure phonological priming effect. Previous evidence from bilingual masked priming studies testing intra-script homophones in the L2-to-L1 direction have reported significant phonological priming effects of similar magnitude to those found in the L1-to-L2 direction, though with relatively more proficient bilinguals than the Greek-Spanish group of our study (Brysbaert & Van Wijnendaele, 2003; Van

Wijnendaele & Brysbaert, 2002). Accordingly, we expected to replicate the cross-script masked phonological priming effect obtained in Experiment 1.

Experiment 2: Spanish (L2) primes and Greek (L1) targets

Method

Participants. The same group of participants from Experiment 1 took part in this experiment, with the exception of one participant who did not complete the second experimental session.

Materials. The Spanish words that served as targets in the P+O- and P+O+ conditions in Experiment 1 were now used as related P+O- and related P+O+ primes, respectively. Accordingly, the related P+O- and P+O+ Greek primes from Experiment 1 were now presented as targets. Furthermore, two sets of Spanish words that were phonologically and orthographically unrelated to the Greek targets but matched in a number of properties to the related P+O- and P+O+ primes were presented as unrelated P+O- and unrelated P+O+ primes (for a full description and examples of the materials see Table 2; see also the Appendix). An additional set of 120 orthographically legal pseudowords in Greek (e.g., *κροπή*) pairwise matched to the target words (mean length: 4.9±1) was also created for the purposes of the lexical decision. None of the pseudowords was an actual word in Spanish, and they were all preceded by Spanish word primes matched in length and word frequency to the primes of the word trials (mean word frequency: 33.08±9, mean length: 4.9±1). Two lists of materials were constructed so that each target appeared only once in each list, but each time in a different priming condition. Different participants were assigned to each of the lists.

<u>*Procedure.*</u> The same procedure as in Experiment 1 was followed. The instructions and the interactions with the participants were in Greek.

Results and Discussion

Incorrect responses and reaction times less than 250 ms or greater than 1500 ms (less than 1.5% of the data) were excluded from the latency analyses. Mean latencies for correct responses and error rates are presented in Table 4. ANOVAs were performed following the same design as in Experiment 1.

--- Insert Table 4 around here ---

The main effects of Relatedness, and Order of sessions were not significant (all *ps*>.13). The main effect of Type of relationship only approached significance in the analysis by participants, with targets of the P+O+ subset being responded to 6 ms faster than those of the P+O- subset, $F_1(1, 25)=3.13$, $MSE=325$, $p>.09$; $F_2(1, 112)=.42$, $MSE=333$, $p>.52$. However, the interaction between Relatedness and Type of relationship was significant, $F_1(1, 25)=5.77$, $MSE=515$, $p<.05$; $F_2(1, 112)=10.47$, $MSE=820$, $p<.01$. Subsequent pairwise comparisons showed that participants responded faster (15 ms faster) to P+O- targets when these were preceded by phonologically related but orthographically dissimilar P+O- Spanish primes (related P+O-), as compared to when they were preceded by ortho-phonologically unrelated Spanish primes, $F_1(1, 25)=8.39$, $MSE=342$, $p<.01$; $F_2(1, 56)=9.01$, $MSE=750$, $p<.01$. On the other hand, there was a 6 ms delay for the responses to targets of the P+O+ when they were preceded by partially homographic and homophonic Spanish primes (related P+O+), as compared to when these were preceded by ortho-phonologically unrelated primes, although this difference did not reach significance (both *ps*>.11). Responses were not affected by the order in which participants completed the sessions, as shown by the non-significant interactions between the Order of sessions and either Type of relationship or Relatedness (all *p*s>.57).

ANOVAs on the error data revealed a main effect of Type of relationship, with target words of the P+O+ subset being recognized more accurately than those of the P+O- subset (4.9% vs. 6.7%). This effect was significant only in the analysis by participants, $F_1(1, 25)=8.68$, $MSE=13$, $p<.05$; $F_2(1, 112)= 1.42$, $MSE= 131$, $p>.21$). No other effects reached significance (all *p*s>.15).

Just as in Experiment 1, the mean reaction times per condition and the net priming effects were calculated separately for prime-target pairs of the same and of different grammatical category. The results of this analysis confirmed that the pattern of effects obtained was independent from the match/mismatch in grammatical category. In the P+O- condition the net priming effects were of 20 ms for prime-target pairs of the same grammatical class and of 10 ms for prime-target pairs of different grammatical class. In the P+O+ condition the net priming effects were of -8 ms for pairs with matching grammatical class and of -6 ms for pairs with mismatching grammatical class.

In summary, Experiment 2 provided an exact replication of the cross-script masked phonological priming effect obtained in Experiment 1 with the inverse language order (i.e., Greek primes and Spanish targets). The main result of Experiment 2 was a 15 ms facilitative masked phonological priming effect obtained with Spanish (L2) primes phonologically related but with minimal orthographic overlap to the Greek (L1) targets (related P+O-, e.g., *fibra* [fiber]-*φύτρο* [bud] vs. unrelated P+O-, e.g., *jabón* [soap]-*φύτρο*). This effect was of similar magnitude to that obtained in Experiment 1 (19 ms), with the inversed language order, L1 primes and L2 targets. To our knowledge this is the first evidence of masked phonological priming effects in both language directions using a cross-script manipulation. However, just as in Experiment 1, when orthographic overlap was added to the phonological overlap the facilitative phonological effect disappeared (i.e., a -6 ms difference; related P+O+, e.g., *ocio* [leisure]-*όριο* [limit] vs. unrelated P+O+, e.g., *raza* [race]- *όριο*).

General Discussion

In the present masked priming study we tested the effects of cross-language phonological overlap in isolation and in combination with orthographic overlap in an effort to further elucidate the role of phonology in the early stages of VWR. To this end, a group of Greek-Spanish bilinguals was tested in two experiments that involved phonological and ortho-phonological overlap between cross-script prime-target pairs. Our results revealed facilitative phonological priming effects, with participants responding faster to targets when they were preceded by partially homophonic but not homographic words of the other language (related P+O- condition) as compared to when they were preceded by ortho-phonologically unrelated words. Importantly, this facilitative effect was consistently found independently of prime and target language (Greek or Spanish). However, when the primes shared, to a large extent, both phonological and orthographic units with the targets (related P+O+ condition), the obtained effects did not significantly differ from those obtained with phonologically and orthographically unrelated primes (non-significant 8 and 6 ms differences with Spanish and Greek targets, respectively).

The masked phonological priming effects obtained in both experiments, provide clear evidence of cross-script masked phonological priming effects which, to our knowledge, had been only indirectly observed (Gollan et al., 1997; Kim & Davis, 2003; Voga & Grainger, 2007). Furthermore, our results offer a replication of the facilitative masked phonological priming effects found in previous monolingual and bilingual studies with homophones suggesting that the processing advantage found in the masked priming paradigm reflects the pre-activation of the targets' phonological code by the homophonic primes (e.g., Bowers et al., 1998; Grainger & Ferrand, 1994; Brysbaert et al., 1999; see Ferrand & Grainger, 1994; Rastle & Brysbaert, 2006 for a discussion). It should be noted that previous single word presentation studies with monoscriptal bilinguals have reported both inhibitory and null effects for interlingual homographs with extensive phonological overlap and less orthographic overlap in their L1 and L2 versions (Dijkstra et al., 1999; Lemhöfer & Dijkstra, 2004). However, two points should be made clear. Firstly our results agree with previous masked phonological priming studies (monolingual and bilingual). Secondly, the inhibitory effect found for phonologically overlapping interlingual homographs by Dijkstra and colleagues (1999) was not replicated by Lemhöfer and Dijkstra (2004). As the authors themselves acknowledged, this inhibitory effect "*may not have been based on completely solid grounds*" and proposed that "*test and control items in that condition may have differed on uncontrolled variables*" (p. 541). Hence, the fact that these two studies involving the same materials led to different results precludes a direct comparison between their findings and those of the present study. In addition, the intra-script nature of these two single presentation studies, and of the previous masked phonological priming studies, obstructs the isolation of pure cross-language phonological activation, due to the co-existing orthographic overlap. This confound was minimized in our study: the biscriptal Greek-Spanish language combination made the use of word primes with extensive phonemic overlap but a minimum of a graphemic overlap with the targets possible, thus allowing for pure phonological effects to emerge.

The current pure masked phonological priming effects pose some problems for the DRC model. In the DRC, the phonologically mediated non-lexical route is not fast enough to allow the emergence of phonological effects on such short prime durations (Coltheart et al., 2001). In fact, when Rastle and Brysbaert (2006) succeeded in simulating the effect with the DRC model after changing its parameters and speeding-up the non-lexical route, the model was no longer able to read aloud irregular words or to discriminate between words and pseudowords. A more efficient account of masked phonological priming effects is offered by the bi-modal interactive activation model (BIAM; Grainger & Ferrand, 1994, 1996; Grainger et al., 2003). The BIAM represents a bi-modal version of the Interactive Activation model (McClelland & Rumelhart, 1981), with two levels of orthographic and phonological processing, a sub-lexical and a lexical one. Unlike the DRC, the BIAM assumes fast grapheme-to-phoneme mappings between the sub-lexical levels, since it was designed to account for early phonological influences on VWR. In fact, the recently implemented version of the BIAM model was shown to effectively simulate masked phonological priming effects without losing its ability to accurately discriminate between words and nonwords (Diependaele, Ziegler, & Grainger, in press).

The cross-script masked phonological priming effect we obtained could also be accounted for by the latest version of the Bilingual Interactive Activation computational model of bilingual VWR (BIA+; Dijkstra & Van Heuven, 2002). The model assumes the existence of language non-specific lexical and sub-lexical phonological stores. Accordingly, a given input word activates phonological representations of L1 and L2 words, thus, allowing it to activate a target word in one language with a homophonic prime word of the other language. The cross-script nature of our phonological effects provides strong support for the proposal of a language-independent activation of the phonological representations of the words of a bilingual's languages, showing that this is achieved even in the absence of orthographic overlap.

Notably, the masked phonological priming effects we obtained in both language directions did not differ in magnitude (19 and 15 ms in Experiments 1 and 2, respectively). This was further confirmed by the absence of a significant interaction between Target language and Relatedness in a post-hoc combined analysis of Experiments 1 and 2 including Target language (Spanish, Greek) as a factor (both *p*s>.87). This pattern of effects replicates previous intra-script studies showing similar effects in both language directions (Brysbaert & Van Wijnendaele, 2003; Duyck et al., 2004; Van Wijnendaele & Brysbaert, 2002). Furthermore, the symmetrical pattern of the effects suggests that inter-lingual masked phonological priming effects are independent of the relative frequency of use of L1 and L2 words and are exclusively dependent on the baseline level of activation of the individual phonemes at the sub-lexical level, as the BIA+ model proposes. Since the vast majority of Greek and Spanish phonemes are common across the two languages, every time a Greek or a Spanish word is encountered the same set of phonemes will become activated. Correspondingly, their base level of activation will be very high and they will be rapidly recognized independently of whether the input word is Spanish or Greek, thus leading to phonological priming effects of the same magnitude for both Greek and Spanish targets. According to the BIA+ model's "temporal delay assumption", only effects occurring at the lexical level could be modulated by the language direction since L1 words are generally recognized faster than L2 words (for a discussion see Brysbaert et al., 2002; Dijkstra & Van Heuven, 2002). This was further confirmed in our study by the combined analysis of Experiments 1 and 2. This analysis showed that participants made faster and more accurate lexical decisions when targets belonged to their dominant language (Greek) as compared to when they belonged to their non-dominant language (Spanish).

Initially, the symmetric bi-directional (L1→L2 and L2→L1) effects obtained in the present study with unbalanced bilinguals of a medium level of proficiency in their second language could seem somewhat surprising, given that previous masked priming studies using non-cognate translations as primes and targets (e.g., *dog* and its Spanish translation *perro)* have shown that symmetric bi-directional effects arise only at the highest levels of L2 proficiency (e.g., Duñabeitia, Perea & Carreiras, in press; Gollan et al., 1997; Schoonbaert, Duyck, Brysbaert, & Hartsuiker, 2009). However, unlike non-cognate masked translation priming effects, cross-language masked phonological priming effects are not expected to be affected by the level of L2 proficiency of the participants' since they arise at the sub-lexical level (not at the lexico-semantic levels as masked translation priming effects do) and are thus independent of the relative frequency of use of L1 and L2 words (see Brysbaert et al., 1999; Van Wijnendaele & Brysbaert, 2002). In fact, Duyck et al. (2004), who specifically examined whether L1→L2 masked phonological priming effects are modulated by the level of L2 proficiency of the participants, failed to find any differences in the amount of phonological priming between a group of early balanced and a group of late and unbalanced Dutch-French bilinguals (the latter group had a French proficiency level similar to that reported for Spanish by our bilinguals). Furthermore the L1→L2 effects reported for these two groups and for that of the Brysbaert et al., (1999) study were of the same magnitude as those reported by Van Wijnendaele and Brysbaert (2002) with L2 primes and L1 targets with a group of relatively proficient Dutch-French bilinguals

(7 on a 10-point self-rating scale). This lack of a difference in the magnitude of the cross-language masked phonological priming effects obtained across bilinguals of different proficiency levels is also in line with the BIA+ model's predictions, since the model ascribes these effects to the sublexical level. Hence, it seems that even though our bilinguals had to overcome the limitation of mastering a partially new set of GPCs (due to the fact that Greek and Spanish have partially different scripts) they had efficiently acquired them shortly after starting to learn Spanish, an effect probably potentiated by the fact that Greek and Spanish have largely overlapping phonemes.

In order to examine the influence of phonological activation on VWR when the orthographic code is also activated, a related P+O+ condition was included in Experiments 1 and 2. In this condition the amount of phonological overlap between primes and targets was equated to that of orthographic overlap. In both experiments, this manipulation led to null effects (non-significant differences of 8 and 6 ms for the L1→L2 and the L2→L1 language direction, respectively) as compared to orthographically and phonologically unrelated primes. The fact that the phonological facilitation obtained in the related P+O- condition disappeared with the addition of orthographic overlap in the related P+O+ condition shows a close dependency of the activation of the phonological code on the activation of the underlying orthographic code. In further detail, our results suggest that the conflict created when the orthographic representation of the prime is to a large extent shared with that of the target overwrites the beneficial effects produced by co-existing phonological overlap. Thus, it seems that it is the orthographic relationship between prime and target that determines the emergence or disappearance of phonological effects in the lexical decision task (see Carreiras et al., 2005; Diependaele, et al., in press). This assumption is problematic for the DRC model. When Rastle and Brysbaert (2006) attempted to simulate the masked phonological priming effect repeatedly obtained in the lexical decision task, they found that the model could only simulate the effect, without losing its ability to accurately perform lexical decisions by limiting the influence of the orthographic activation and assuming that lexical decisions are based on activation in the phonological lexicon. However, the elimination of the facilitative phonological effect by the addition of orthographic overlap across primes and targets clearly suggests that orthographic activation is critical for the appearance of masked priming effects in the lexical decision task. Nonetheless, these effects can be easily accounted for by the BIAM, which assumes the existence of inhibitory connections within the orthographic lexicon which can account for the effects we obtained (see also Davis & Lupker, 2006).

The pattern of results obtained in the P+O+ condition resembles those results reported in single presentation lexical decision studies using interlingual homographs (e.g., de Groot, Delmaar & Lupker, 2000; Dijkstra et al., 1998). Still, one might argue that in these studies the degree of orthographic and phonological overlap across the two readings of the interlingual homograph was not controlled. The two studies in which this was controlled for obtained null effects when Dutch-English bilinguals performed English lexical decisions on interlingual homographs whose two readings had extensively overlapping ortho-phonological representations, as it was the case in the related P+O+ condition of our study (Dijkstra et al., 1999; Lemhöfer & Dijkstra, 2004)[6]. This pattern of effects is inversed only when the overlap across words of different languages goes beyond the formal levels of representation; that is when words share their meaning too (i.e., cognates; Dijkstra et al., 1999; Lemhöfer & Dijkstra, 2004; Schwartz et al., 2007). In this case, facilitative effects have been repeatedly reported, suggesting that the orthographic and phonological levels receive strong excitatory activation from the shared conceptual node, via feedback connections. Within the BIA framework, null effects reported in interlingual homograph studies have been interpreted as evidence for cross-language lexical competition between the two readings of the homograph (e.g., Dijkstra & Van Heuven, 2002; Dijkstra, 2005). However, this proposal stands only for bilinguals whose two languages have one common script. Dijkstra and Van Heuven clearly stated that for biscriptal bilinguals no effects of cross-language orthographic interactions are expected. To illustrate this point, the authors used as an example the Chinese-Latin script combination and suggested that in this case there should be two separate sub-lexical orthographic stores which will get activated in a language-specific way (Dijkstra & Van Heuven, 2002, p.183). Nevertheless, the Greek-Roman script combination should not be uncritically accommodated within this framework, given the existence of both script-unique and common letters in these alphabets. Future research should address the still under-defined issue of how visual word recognition is achieved in biscriptal bilinguals.

In conclusion, by combining Greek and Spanish, two languages with partially overlapping scripts, the present study examined the influence of phonology in visual word recognition, both in isolation and in combination to orthography. The consistent facilitative masked priming effects obtained in the pure phonological conditions across the two language priming directions (i.e., from L1 to L2 and vice versa) provide strong evidence in favor of the early and automatic activation of the phonological code during visual word recognition. Our results are best accommodated within the framework of the BIAM and the BIA+ model.

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Appendix

Word stimuli used in Experiments 1 and 2 with their phonetic transcriptions according to the International Phonetic Alphabet. Greek words are presented in bold and control primes in italic.

P+O- condition: **μωρό** /mo'ro/, mora /'mora/, ***στιλ*** /stil/, *aseo* /a'seo/; **φύλο** /'filo/, fila /'fila/, ***ώμος*** /'omos/, *caos* /'kaos/; **πρέσα** /'presa/, prisa /'prisa/, ***τέρπω*** /'terpo/, *vasco* /'basko/; **μυρίζω** /mi'rizo/, mirado /mi'raðo/, ***τιμόνι*** /ti'moni/, *huerta* /'werta/; **μύρο** /'miro/, mira /'mira/, ***έιτζ*** /'eiZ/, *pelo* /'pelo/; **φάρμα** /'farma/, forma /'forma/, ***σοφέρ*** /so'fer/, *mujer* /mu'xer/; **στερώ** /ste'ro/, suero /'swero/, ***πάγος*** /'paɣos/, *cante* /'kan̪te/; **λόχος** /'loxos/, lejos /'lexos/, ***γήρας*** /'ɣiras/, *salud* /sa'lud/; **χάσκω** /'xasko/, justo /'xus̪to/, ***νέκρα*** /'nekra/, *frase* /'frase/; **λινός** /li'nos/, lunes /'lunes/, ***μπήγω*** /'mpiɣo/, *balón* /ba'lon/; **φτάνω** /'ftano/, fauno /'fau̯no/, ***ρόλος*** /'rolos/, *oídas* /o'iðas/; **γράφω** /'ɣrafo/, grifo /'grifo/, ***άποψη*** /'apopsi/, *diván* /di'βan/; **φόρμα** /'forma/, firma /'firma/, ***εύρος*** /'evros/, *canal* /ka'nal/; **φυσερό** /fise'ro/, fisura /fi'sura/, ***αρχινώ*** /arxi'no/, *apogeo* /apo'xeo/; **πείθω** /'piθo/, plazo /'plaθo/, ***χωριό*** /xorɣ'o/, *varón* /ba'ron/; **θαρρώ** /θa'ro/, zorro /'θor̄o/, ***κλαδί*** /kla'ði/, *hedor* /e'ðor/; **πήζω** /'pizo/, piso /'piso/, ***βίδα*** /'viða/, *leer* /le'er/; **φύτρο** /'fitro/, fibra /'fiβra/, ***τραγί*** /tra'ɣi/, *jabón* /xa'βon/; **πράσο** /'praso/, preso /'preso/, ***αήθης*** /a'iθis/, *ópera* /'opera; **λύτρα** /'litra/, litro /'litro/, ***θέρος*** /'θeros/, *monje* /'mõŋxe/; **φωλιά** /fo'lia/, folio /folio/, ***σορός*** /so'ros/, *cisne* /'θizne/; **ρωτώ** /ro'to/, robo /'r̄oβo/, ***ασκώ*** /a'sko/, *rata* /'r̄ata/; **γόης** /'ɣois/, gris /gris/, ***ανία*** /a'nia/, *mito* /'mito/; **πάρλα** /'parla/, perla /'perla/, ***κείθε*** /'ciθe/, *delta* /'del̪ta/;**πόθεν** /'poθen/, pezón /pe'θon/, ***αρωγή*** /aro'ɣi/, *chata* /'ʧata/; **φρονώ** /fro'no/, freno /'freno/, ***φλερτ*** /flert/, *belga* /'belga/; **μασάω** /ma'sao/, museo /mu'seo/, ***ατάκα*** /a'taka/, *lecho* /'leʧo/; **πότης** /'potis/, pubis /'puβis/, ***άμμος*** /'amos/, *latir* /la'tir/; **πράμα** /'prama/, prima /'prima/, ***νεφρό*** /ne'fro/, *rigor* /r̄i'ɣor/; **φίρμα** /'firma/, firme /'firme/, ***ψάλλω*** /'psalo/, *punta* /'pun̪ta/; **πρωί** /pro'i/, proa /'proa/, ***μηνώ*** /mi'no/, *homo* /'omo/; **ραίνω** /'reno/, reino /'r̄ei̯no/, ***τοτέμ*** /to'tem/, *bajar* /ba'xar/; **μάγμα** /'maɣma/, magma /'magma/, ***αμέτι*** /a'meti/, *peine* /'pei̯ne/; **προσώ** /pro'so/, preso /'preso/, ***βρίζα*** /'vriza/, *marea* /ma'rea/; **πρίμα** /'prima/, primo /'primo/, ***ούλος*** /'ulos/, *villa* /'biʎa/; **πλάνο** /'plano/, pleno /'pleno/, ***τρέφω*** /'trefo/, *ideal* /iðe'al/; **γόνος** /'ɣonos/, ganas /'ganas/, ***κλίνω*** /'klino/, *hotel* /o'tel/; **παρωδώ** /paro'ðo/, piropo /pi'ropo/, ***θυμάρι*** /θi'mari/, *paleta* /pa'leta/;**φρέαρ** /'frear/, freír /fre'ir/, ***τούλι*** /'tuli/, *parra* /'par̄a/; **γύρα** /'ɣira/, giro /'xiro/, ***κάζο*** /'kazo/, *reír* /r̄e'ir/; **φράζω** /'frazo/, fruto /'fruto/, ***τύπτω*** /'tipto/, *venta* /'ben̪ta/; **μέλλον** /'melon/, millón /mi'ʎon/, ***όργανο*** /'orɣano/, *llorar* /ʎo'rar/; **ρητός** /ri'tos/, rizos /'r̄iθos/, ***νότια*** /'notia/, *furor* /fu'ror/; **γάνωμα** /'ɣanoma/, genoma /xe'nõma/, ***φούμος*** /'fumos/, *ropaje* /r̄o'paxe/; **χαμός** /xa'mos/, jamás /xa'mas/, ***έξτρα*** /'ekstra/, *sueño* /'sweɲo/; **σολάρω** /so'laro/, salero /sa'lero/, ***τόπλες*** /'toples/, *iguana* /i'ɣwana/; **πάνελ** /'panel/, panal /pa'nal/, ***καράς*** /ka'ras/, *avaro* /a'βaro/; **πιάνω** /'piano/, plano /'plano/, ***ψήφος*** /'psifos/, *líder* /'liðer/; **μωριά** /morɣ'a/, moral /mo'ral/, ***κατής*** /ka'tis/, *pobre* /'poβre/; **πώμα** /'poma/, pomo /'pomo/, ***κιτς*** /ciS/, *mulo* /'mulo/; **φλωρί** /flo'ri/, flora /'flora/, ***καρνέ*** /kar'ne/, *judío* /xu'ðio/; **γρόσι** /'ɣrosi/, grasa /'grasa/, ***μαδάω*** /ma'ðao/, *buque* /'buke/; **μένω** /'meno/, mono /'mõno/, ***είτε*** /'ite/, *amar* /ã'mar/; **φαρσί** /far'si/, farsa /'farsa/, ***μασιά*** /masi'a/, *tinto* /'tin̪to/; **πίσω** /'piso/, peso /'peso/, ***εξής*** /e'ksis/, *base* /'base/; **σώζω** /'sozo/, solo /'solo/, ***πλην*** /plin/, *aire* /'ai̯re/; **θωριά** /θorɣ'a/, zorra /'θor̄a/, ***αμυχή*** /ami'xi/, *limbo* /'limbo/; **προνοώ** /prono'o/, pronto /'pron̪to/, ***ρυτίδα*** /ri'tiða/, *blanco* /'blaŋko/; **γοφός** /ɣo'fos/, gafas /'gafas/, ***γύπας*** /'ɣipas/, *rubio* /r̄uβio/; **φύτρα** /'fitra/, fiera /fiera/, ***μασίφ*** /ma'sif/, *mareo* /ma'reo/.

P+O+ condition: **αύριο** /'avrio/, agrio /aɣrio/, ***λεπτά*** /le'pta/, *nuera* /'nwera/; **ισχίο** /i'sxio/, indio /ĩn̪dio/, ***φραπέ*** /fra'pe/, *cuota* /'kwota/; **τόξο** /'tokso/, toro /'toro/, ***χύνω*** /'xino/, *gozo* /'goθo/; **αλεξία** /aleks'ia/, anemia /ã'nẽmia/, ***ήμερος*** /'imeros/, *puñeta* /pu'ɲeta/; **ταψί** /ta'psi/, taxi /'taksi/,

αγάς /a'ɣas/, *huir* /wi̯r/; **αλέα** /al'ea/, atea /a'tea/, ***στοκ*** /stok/, *liar* /liar/; **βρόμα** /'vroma/, broca /'broka/, ***τσιπς*** /'Sips/, *coral* /ko'ral/; **βάζο** /'vazo/, baño /'baɲo/, ***ντου*** /ntu/, *copa* /'kopa/; **βόλεμα** /'volema/, bolera /bo'lera/, ***μεστός*** /me'stos/, *cactus* /'kaktus/; **εξάδα** /e'ksaða/, etapa /e'tapa/, ***χρώση*** /'xrosi/, *tarea* /ta'rea/; **τέμπο** /'tempo/, tebeo /te'βeo/, ***βάδην*** /'vaðin/, *trote* /'trote/; **απόψε** /a'popse/, azote /a'θote/, ***μοίρα*** /'mira/, *horca* /'orka/; **απαξία** /apa'ksia/, afasia /a'fasia/, ***καλύβι*** /ka'livi/, *medrar* /me'ðrar/; **τομέας** /to'meas/, torear /tore'ar/, ***δύναμη*** /'ðinami/, *bayeta* /ba'ǐeta/; **αψίδα** /a'psiða/, axila /ak'sila/, ***κώλος*** /'kolos/, *sazón* /sa'θon/; **όριο** /'orio/, ocio /'oθio/, ***βήμα*** /'vima/, *raza* /'r̄aθa/; **τέλος** /'telos/, tenor /te'nor/, ***θεωρώ*** /θeo'ro/, *ápice* /'apiθe/; **αστός** /a'stos/, actor /ak'tor/, ***θλάση*** /'θlasi/, *dosis* /'dosis/; **άμφιο** /'amfio/, agrio /aɣrio/, ***επέχω*** /e'pexo/, *cloro* /'kloro/; **έξοδο** /'eksoðo/, enojo /ẽ'noxo/, ***ισχύς*** /i'sxis/, *bedel* /be'ðel/; **τέφρα** /'tefra/, tensa /'tensa/, ***έλκος*** /'elkos/, *porte* /'porte/; **βέρα** /'vera/, beca /'beka/, ***τρίο*** /'trio/, *hada* /'aða/; **ερίφιο** /e'rifio/, exilio /ek'silio/, ***κονεύω*** /ko'nevo/, *lanzar* /lan̥'θar/; **οπάλιο** /o'palio/, ovario /o'βario/, ***θαλάμη*** /θa'lami/, *hélice* /'eliθe/; **οζίδιο** /o'ziðio/, oficio /o'fiθio/, ***γελάδα*** /ɣe'laða/, *actuar* /ak'twar/; **βολάν** /vo'lan/, bozal /bo'θal/, ***αράζω*** /a'razo/, *atajo* /a'taxo/; **άγρια** /'aɣria/, ansia /ãnsia/, ***κλήση*** /'klisi/, *pollo* /'poʎo/; **επτά** /e'pta/, esta /'es̪ta/, ***θύμα*** /'θima/, *vida* /'biða/; **όρνιο** /'ornio/, obvio /obβio/, ***άλτης*** /'altis/, *árabe* /'araβe/; **τάμα** /'tama/, tapa /'tapa/, ***σείω*** /'sio/, *celo* /'θelo/; **όπερα** /'opera/, oveja /o'βexa/, ***ανάβω*** /a'navo/, *timón* /ti'mõn/; **ταύτα** /'tafta/, tarta /'tarta/, ***θωμάς*** /θo'mas/, *enano* /ẽ'nãno/; **τόσο** /'toso/, tono /'tono/, ***αφού*** /a'fu/, *sala* /'sala/; **βέργα** /'verɣa/, bella /'beʎa/, ***κρίνο*** /'krino/, *signo* /'signo/; **βάθρο** /'vaθro/, barro /'bar̄o/, ***σκυλί*** /scilí/, *novio* /noβio/; **βέσπα** /'vespa/, bella /'beʎa/, ***σήκος*** /'sikos/, *árbol* /'arβol/; **επτάδα** /e'ptaða/, estafa /es̪'tafa/, ***εποικώ*** /epi'ko/, *músico* /'musiko/; **άντε** /'ante/, arte /'arte/, ***θύρα*** /'θira/, *hija* /'ixa/; **άζωτο** /'azoto/, abeto /a'βeto/, ***εθίζω*** /e'θizo/, *lengua* /lenɣwa/; **αχτίδα** /a'xtiða/, activa /ak'tiβa/, ***συνάζω*** /si'nazo/, *hierba* /'ʤerβa/; **τιράζ** /ti'raz/, tirar /ti'rar/, ***σέβας*** /'sevas/, *sabio* /saβio/; **τάφος** /'tafos/, tarot /ta'rot/, ***πάρκο*** /'parko/, *fogón* /fo'ɣon/; **βορά** /vo'ra/, boca /'boka/, ***παπί*** /pa'pi/, *edad* /e'ðad/; **τάχα** /'taxa/, taza /'taθa/, ***χώνω*** /'xono/, *nube* /'nuβe/; **τέρμα** /'terma/, tersa /'tersa/, ***τροφή*** /tro'fi/, *cojín* /ko'xin/; **βολέ** /vo'le/, bote /'bote/, ***πλαζ*** /plaz/, *raya* /r̄aǐa/; **ανάσα** /a'nasa/, amada /ã'maða/, ***σέρνω*** /'serno/, *durar* /du'rar/; **τελάρο** /te'laro/, tejado /te'xaðo/, ***εμίρης*** /e'miris/, *enviar* /ẽm'biar/; **όπιο** /'opio/, odio /oðio/, ***ζύγι*** /'ziɣi/, *área* /'area/; **αντένα** /a'ntena/, alteza /al̦'teθa/, ***στεργώ*** /ster'ɣo/, *ducado* /du'kaðo/; **αφίσα** /a'fisa/, amiga /ã'miɣa/, ***άνθος*** /'anθos/, *nariz* /na'riθ/; **βάνα** /'vana/, baja /'baxa/, ***ποθώ*** /po'θo/, *caer* /ka'er/; **όραμα** /'orama/, opaca /o'paka/, ***βουνό*** /vu'no/, *lucro* /'lukro/; **τέρας** /'teras/, telar /te'lar/, ***ανάγω*** /a'naɣo/, *chelo* /'ʧelo/; **άλογο** /'aloɣo/, apoyo /a'poǐo/, ***αθώος*** /a'θoos/, *vacío* /ba'θio/; **βάψιμο** /'vapsimo/, batido /ba'tiðo/, ***κουλός*** /ku'los/, *repisa* /r̄e'pisa/; **τρέλα** /'trela/, trepa /'trepa/, ***ώθηση*** **/'oθisi**/, *pinar* /pi'nar/; **άμαξα** /'amaksa/, amada /ã'maða/, ***χρίζω*** /'xrizo/, *sable* /'saβle/; **τένις** /'tenis/, tesis /'tesis/, ***πρήζω*** /'prizo/, *honor* /o'nor/; **τάπα** /'tapa/, tasa /'tasa/, ***οβάλ*** /o'val/, *raíz* /r̄a'iθ/.

Note: The slight differences in the phonetic transcriptions observed for some cross-language homophonic prime-target pairs always involved minor variations of the same phonemes (/b/, /d/ and /g/). Importantly, these phonetic variations are not perceivable by Greek-Spanish bilinguals, and they group these three phonemes to the neighbouring ones existing in Greek (Hernández de la Fuente, 2001). This is especially common among unbalanced and late bilinguals, as the ones who participated in our study, since it is more likely for them to fit new sounds of the second language to the perceptually closer sounding ones from their first language, than to create a new phonetic category (Flege & MacKay, 2004).

Table 1

Letters of the Greek and the Roman alphabets. Script specific are graphemes unique to either Greek or Spanish. Unambiguous are those graphemes common to both alphabets that map onto the same phoneme, while ambiguous are graphemes common to both alphabets but corresponding to different phonemes.

Script Specific		Common	
Greek	*Spanish*	Unambiguous	Ambiguous
γ	c	a	η
δ	d	b	ν
ζ	f	e	ρ
θ	g	i	υ
λ	h	k	χ
μ	j	o	ω
ξ	l	t	
π	m		
σ	ñ		
φ	q		
ψ	r		
	y		
	s		
	z		

Table 2

Critical materials of Experiments 1 and 2 with their lexical, orthographic and phonological properties (standard deviations within parentheses) and their phonetic transcriptions. Phonological overlap is given as the number of position specific common phonemes and orthographic overlap as the number of position specific common letters between primes and targets. Percentage of overlap is presented within parentheses.

	Experiment 1					
	P + O -			P + O +		
	Target	Priming Condition		Target	Priming Condition	
		Related	Unrelated		Related	Unrelated
	fibra /'fiβra/ (fiber)	φύτρο /'fitro/ (bud)	τραγί /tra'ɣi/ (goat)	ocio /'oθio/ (leisure)	όριο /'orio/ (limit)	βήμα /'vima/ (step)
Freq.	38 (±71)	41(±92)	41 (±92)	40 (±154)	44 (±127)	44 (±126)
Len.	4.9 (±0.6)	4.9 (±0.6)	4.9 (±0.6)	4.9 (±0.7)	4.9 (±0.7)	4.9 (±0.7)
P.O.		3.5 (72%)	0.4 (8%)		3.3 (68%)	0.2 (4%)
O.O.		0.4 (9%)	0.3 (6%)		3.2 (65%)	0.1 (2%)

	Experiment 2					
	P + O -			P + O +		
	Target	Priming Condition		Target	Priming Condition	
		Related	Unrelated		Related	Unrelated
	φύτρο /'fitro/ (bud)	fibra /'fiβra/ (fiber)	jabón /xa'βon/ (soap)	όριο /'orio/ (limit)	ocio /'oθio/ (leisure)	raza /'r̄aθa/ (race)
Freq.	41 (±92)	38 (±71)	38 (±71)	44 (±127)	40 (±154)	35 (±111)
Len.	4.9 (±0.6)	4.9 (±0.6)	4.9 (±0.6)	4.9 (±0.7)	4.9 (±0.7)	4.9 (±0.7)
P.O.		3.5 (72%)	0.1 (3%)		3.3 (68%)	0.3 (6%)
O.O.		0.4 (9%)	0.2 (4%)		3.2 (65%)	0.3 (5%)

Note: Len., Length measured in number of letters; Freq., Frequency; P.O., Phonological Overlap; O.O., Orthographic Overlap.

Table 3

Mean lexical decision times (in ms) and error rates (within parentheses) for word targets in Experiment 1.

Spanish (L2) targets	Priming Condition		Priming Effect
	Related (R)	Unrelated (UR)	UR-R
P+O-	652 (11)	671 (12.2)	19 (1.2)
P+O+	683 (14.6)	675 (13.8)	-8 (-0.8)

Table 4

Mean lexical decision times (in ms) and error rates (within parentheses) for word targets in Experiment 2.

Greek (L1) targets	Priming Condition		Priming Effect
	Related (R)	Unrelated (UR)	UR-R
P+O-	630 (6.6)	645 (6.7)	15 (0.1)
P+O+	635 (5.5)	629 (4.3)	-6 (-1.2)

Footnotes

Footnote 1: In order to easily identify the overlapping segments (orthographic and/or phonological) across primes and targets these are presented in underlined format throughout the manuscript.

Footnote 2: The Greek-Spanish language combination would have also been ideal to study orthographic effects without the influence of phonology. Unfortunately, this is not possible since the group of Greek letters overlapping visually to Roman ones but with distinct phonological representations is too small to create a sufficiently large list of experimental items (see Table 1).

Footnote 3: Out of the 3.5 (72%) phonemes common across related primes and targets of the P+O- condition, 0.4 (9%) were also visually similar. Word items containing these letters had to be included in the experimental material due to the limited amount of items.

Footnote 4: All the Van Orden graphemic similarity scores (Van Orden, 1987) were calculated in an online application developed by R. Hartsuiker (http://users.ugent.be/~rhartsui/Applet1.html). The procedure followed to calculate the Van Orden score of graphemic similarity for each prime-target pair was as follows: First, 20 students of the University of La Laguna rated the visual similarity between the Greek and the Roman versions of the letters. Those Greek letters that were rated as visually indistinguishable from Roman letters were then replaced in the Greek words by their Roman version. Then, the graphemic similarity scores for each Spanish word was calculated by comparing them to their exact repetitions (e.g., the similarity of *fibra* [fiber] and *fibra*). Following this, the graphemic similarity between each Spanish word and its paired Greek related and unrelated word was calculated (e.g., *fibra-φύτρο* [bud]). Finally, the Van Orden score for each prime-target pair was obtained dividing the first value by the second.

Footnote 5: We thank Janet van Hell for suggesting these analyses.

Footnote 6: Note that in the effect obtained by Dijkstra et al. (1999) for interlingual homographs with shared ortho-phonological representations there was a trend towards inhibition, also evident in our study for the P+O+ condition. This trend reached significance in a further combined analysis of Experiments 1 and 2 in which Target language was included as a factor, $F1(1, 27)=1.56$, $MSE=1006$, $p>.22$; $F2(1, 118)=4.95$, $MSE=1246$, $p<.05$. However, considering that this result was only significant in the analysis by items, we will not draw further conclusions at this regard.