Brain & Language 134 (2014) 11–22

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Cross-language phonological activation: Evidence from masked onset priming and ERPs

Olessia Jouravlev *, Stephen J. Lupker, Debra Jared

The University of Western Ontario, Canada

ARTICLE INFO

Article history:
Accepted 7 April 2014
Available online 9 May 2014

Keywords:
Bilingual
Word recognition
Phonological priming
Cross-script
ERP
Masked onset priming effect

ABSTRACT

The goal of the present research was to provide direct evidence for the cross-language interaction of phonologies at the sub-lexical level by using the masked onset priming paradigm. More specifically, we investigated whether there is a cross-language masked onset priming effect (MOPE) with L2 (English) primes and L1 (Russian) targets and whether it is modulated by the orthographic similarity of primes and targets. Primes and targets had onsets that overlapped either only phonologically, only orthographically, both phonologically and orthographically, or did not have any overlap. Phonological overlap, but not orthographic overlap, between primes and targets led to faster naming latencies. In contrast, the ERP data provided evidence for effects of both phonological and orthographic overlap. Finally, the time-course of phonological and orthographic processing for our bilinguals mirrored the time-course previously reported for monolinguals in the ERP data. These results provide evidence for shared representations at the sub-lexical level for a bilingual's two languages.

1. Introduction

In 1999, Dijkstra, Grainger, and van Heuven published an article on bilingual word recognition with the subtitle "The neglected role of phonology". The broad question that was raised by those authors is whether phonological representations from one language are activated when bilinguals read in their other language. Since that time, considerable evidence for cross-language phonological activation has been provided in a variety of languages and paradigms, and, further, this evidence has generally been consistent with the Bilingual Interactive Activation (BIA+) model (Dijkstra & Van Heuven, 2002).

In the BIA+, the modelers propose that phonological representations are integrated across languages, and this integration takes place at both the sub-lexical and lexical levels. The sub-lexical phonological level refers to a common pool of phonemes of both languages that are activated directly from orthography in a language-nonselective way. That is, when reading any letter in the Roman alphabet, French–English bilinguals activate all the phoneme representations for that letter in both languages, some of which, for example the phoneme [t] associated with the letter "t", are shared in French and English. Phonological representations are also integrated at the lexical level, the level at which whole-word representations of both languages are stored. For example, in reading the word "pool" French–English bilinguals might activate not only a whole-word representation of this English word, but also a similar sounding representation of the French word "poule" (hen). Thus, the BIA+ has two potential sources of any cross-language phonological effects: sub-lexical and lexical. However, as will be discussed, prior research on cross-language activation of phonology tends to leave open the question of where any previously observed phonological effects might be arising: at the sub-lexical level, at the lexical level, or at both levels. The reason that the issue of the locus of cross-language phonological activation has not yet been resolved is mainly because the tasks previously employed do not allow the effects of lexical vs. sub-lexical phonological activation to be teased apart.

The goal of the present study was to determine whether there is cross-language phonological activation at the sub-lexical level by using the masked onset priming paradigm, a paradigm that is believed to reflect mainly phonological activation outside the lexical level of processing (Forster & Davis, 1991; Grainger & Ferrand, 1996). More specifically, we examined whether English (L2) prime words that share an onset with Russian (L1) target words facilitate target naming. A demonstration of this type of effect would indicate that an interaction between phonologies takes place either pre-lexically or post-lexically. Before describing our masked onset priming, event related potential (ERP) experiment, we review

* Corresponding author. Address: Department of Psychology, University of Western Ontario, London, Ontario N6A 5C2, Canada.
E-mail address: ozhuravl@uwo.ca (O. Jouravlev).

http://dx.doi.org/10.1016/j.bandl.2014.04.003

evidence supporting the claim that there is cross-language phonological activation with a focus on the question of whether the effects could be unambiguously attributed to either the lexical or sub-lexical level.

1.1. Lexical decision experiments

Most commonly, cross-language activation of phonology has been studied using a language-specific lexical decision task, a task presumed to tap mainly into lexical level representations (for a review see Katz et al., 2012). In this task, bilinguals have to decide on the lexical status of a string of letters in either L1 or L2. The critical stimuli are often words that share spelling across languages but have different pronunciations (i.e., interlingual homographs) or words that have the same, or very similar, phonology in the two languages but different spellings (i.e., interlingual homophones). In L2 lexical decision task, bilinguals are slower to decide on the lexical status of interlingual homographs with differing pronunciations in the two languages than matched single language control words (Dijkstra, Grainger, & van Heuven, 1999; von Studnitz & Green, 2002) and are also faster to decide on the lexical status of interlingual homophones than matched controls (Haigh & Jared, 2007; Lemhöfer & Dijkstra, 2004). The important point, however, is that both results suggest that L1 phonological representations are activated when reading words in L2. In L1 lexical decision tasks the evidence for the activation of L2 phonology is somewhat weaker, although not nonexistent. For example, Haigh and Jared (2007) found a very small interlingual homophone effect but only in the error data for English–French bilinguals who performed a lexical decision task in English.

Other research using the lexical decision task to examine cross-language effects of phonology has used the masked priming paradigm, in which briefly presented primes from one language are followed by phonologically similar target words from the other language (Forster & Davis, 1984). Evidence for phonological effects from L1 primes to L2 targets comes from studies with Hebrew–English (Gollan, Forster, & Frost, 1997), Korean–English (Kim & Davis, 2003), Greek–French (Voga & Grainger, 2007), Chinese–English (Zhou, Chen, Yang, & Dunlap, 2010), Japanese–English (Nakayama, Sears, Hino, & Lupker, 2012), and Greek–Spanish bilinguals (Dimitropoulou, Duñabeitia, & Carreiras, 2011). Evidence for L2 to L1 phonological cross-language priming also exists, although, it is not as strong as the evidence for L1 to L2 priming. For example, Gollan et al. (1997) did not find phonological priming effects in an L1 lexical decision task with either Hebrew–English or English–Hebrew bilinguals. Dimitropoulou et al. (2011), however, did report that Greek–Spanish bilinguals produced faster lexical decisions when L2 primes shared phonology (but not orthography) with L1 targets than when they were unrelated words, although no cross-language priming was observed when primes and targets shared both phonology and orthography.

In summary, studies using a language-specific lexical decision task have provided clear evidence for the activation of L1 phonology when reading in L2, although evidence for the activation of L2 phonology when reading in L1 has been demonstrated less consistently. In contrast, priming studies provide clear evidence for the activation of L2 phonology from primes in L1, with weaker evidence for the activation of L1 phonology from primes in L2. Thus, it is clear that phonological representations of one of a bilingual's languages are activated when reading in the other language.

More relevant to the question of present research, however, these studies provide no clear information concerning the locus of the phonological representations producing these effects. The lexical decision task appears to reflect mainly lexical processing as performance in this task is often impacted by such lexical factors as word frequency, language proficiency, and number of orthographic neighbors (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; van Heuven, Dijkstra, & Grainger, 1998) whereas it is often not affected by sub-lexical factors (e.g., spelling-sound consistency and spelling-sound regularity effects are often not observed, Jared, McRae, & Seidenberg, 1990). There is evidence that some sub-lexical factors (e.g., syllable frequency) do have an impact on lexical decision performance (Barber, Vergara, & Carreiras, 2004; Carreiras, Mechelli, & Price, 2006) and, as well, as Neely, Keefe, and Ross (1989) have demonstrated, post-lexical processing can also produce effects in lexical decision experiments. Nonetheless, given the strong influence of lexical factors in the lexical decision task, it is virtually impossible to unambiguously attribute any phonological effects that may arise to sub-lexical activation.

1.2. Masked priming perceptual identification experiments

Cross-language phonological activation has also been investigated using the masked priming perceptual identification task. In this task, participants are asked to identify a target word from one of their languages which is preceded by a briefly presented pseudoword prime that is phonologically similar to target if read according to the grapheme–phoneme correspondence rules of the bilingual's other language. Using this paradigm, Brysbaert, Van Dyck, and Van de Poel (1999) demonstrated that Dutch–French bilinguals were more accurate in identifying L2 (French) targets preceded by primes that were homophonic to those targets according to the grapheme–phoneme correspondence rules of L1 (Dutch) compared to targets preceded by non-homophonic control primes (see also Duyck, Diependaele, Drieghe, & Brysbaert, 2004). An improvement in accuracy of identification of L1 (French) target words preceded by primes that were homophonic to their targets when pronounced using L2 (Dutch) spelling-sound correspondences has also been reported (Van Wijnendaele & Brysbaert, 2002).

The perceptual identification task with nonword primes would seem to be a better task for tapping into the sub-lexical stage of phonological processing, as nonwords are not represented in the lexicon. Hence, the results of these experiments appear to provide evidence for the presence of cross-language effects at the level of sub-lexical phonology. A potential problem, however, is that the nonwords used were pseudohomophones which are likely to engage lexical processing. Therefore, one cannot rule out the possibility that, in performing this task, participants would activate homophonic lexical representations (e.g., the pseudoword "KAT" might activate the lexical phonological representation of the word "CAT"), and that it might be phonological activation at the lexical level that is producing any effects. Thus, the locus of the cross-language phonological effect in a perceptual identification task could either be lexical or sub-lexical.

1.3. Naming experiments

In L2 naming tasks, bilinguals are generally slower to name interlingual homographs than matched controls (Jared & Szucs, 2002; Smits, Martensen, Dijkstra, & Sandra, 2006). Further, bilinguals require more time to name L2 words that have a word body that also exists in L1 words, but has different pronunciations in L1 and in L2, compared to L2 words that have a language-specific word body (Jared & Kroll, 2001). Activation of L2 phonology in L1 naming tasks has also been observed, but only if bilinguals had to name a block of L2 words prior to the task (Jared & Kroll, 2001; Jared & Szucs, 2002).

Results from the naming task, therefore, provide good evidence of the impact of L1 phonology on L2 word naming as well as evidence for the effect of L2 phonology on L1 word naming, although only when bilinguals were recently engaged in L2 processing. What's more important, however, is that, similarly to the lexical decision and perceptual identification tasks, phonological effects in the word reading tasks do not have a clear locus. While cross-language spelling-to-sound consistency effects may reflect activation of sub-lexical phonology, and cross-language phonological effects observed in studies with interlingual homographs could be due to sub-lexical phonology, as readers may pronounce words by using grapheme-to-phoneme correspondence rules, those effects may also be due to the retrieval of whole word phonological representations from memory.

1.4. Other considerations

The research summarized above provides clear evidence that L1 reading activates L2 phonological representations and vice versa. A range of tasks has been used to provide this evidence; however, these tasks are all limited in their ability to nail down the locus of cross-language phonological effects, leaving it unclear whether the interaction between phonological representations in the two languages occurs at the sub-lexical level, the lexical level, or both. Nevertheless, a number of researchers who used these paradigms to study cross-language phonological effects have argued that their data do provide support for one or the other of these positions.

Gollan et al. (1997), for example, proposed that the locus of cross-language phonological effects would be sub-lexical or lexical depending on the language proficiency of the bilinguals. Specifically, bilinguals with low language proficiency are more likely to obtain phonological representations of words by assembling individual phonemes (i.e., sub-lexically) than highly proficient bilinguals, who are more likely to rely on lexical representations. As L2 proficiency is usually lower than L1 proficiency, language processing in L2 is more likely to be sub-lexical, while processing in L1 is more likely to be lexical. Therefore, in the case of L2 to L1 priming, the locus is more likely to be sub-lexical than lexical, especially if the L2 proficiency of a bilingual is low, while in the case of L1 to L2 priming the phonological effects are more likely to arise due to the similarity of whole word forms.

In contrast, Zhou et al. (2010) stated that the cross-language phonological priming effects that they found with Chinese–English bilinguals performing naming and lexical decision tasks are purely lexical in both L1 to L2 and L2 to L1 directions. The reason Zhou et al. made this argument is that they claim that this specific group of bilinguals can only process words lexically because Chinese graphemes are always mapped onto phonological representations holistically. There are several points that weaken their conclusion, however. First of all, there is some evidence that visual word recognition in Chinese is actually susceptible to analytic processing (Yeh & Li, 2004). In fact, the authors themselves state that the possibility of sub-lexical processing in their experiments cannot be ruled out completely. Secondly, the postulation of a lexical locus of the phonological priming effect in their study is odd in the face of their failure to find an interaction of L2 proficiency and the size of the cross-language phonological priming effect, an interaction that would be expected due to the fact that more proficient bilinguals should be better in retrieving lexical representations from memory than less proficient bilinguals.

The absence of an interaction of L2 proficiency and the size of the cross-language phonological priming effect was also reported in a study with Japanese–English bilinguals in a lexical decision task with Japanese (L1) primes and English (L2) targets (Nakayama et al., 2012). Further, the size of the phonological priming effect also did not interact with target frequency, a lexically-based effect. These findings were interpreted as an evidence for a sub-lexical locus of the observed phonological priming effect. Similar conclusions have been drawn by Dimitropoulou et al. (2011), who showed that the size of the cross-language phonological effect obtained in a masked priming experiment did not depend on the direction of the priming. Despite apparent differences in native vs. non-native language proficiency, Greek–Spanish bilinguals showed equal priming for Spanish (L2) words preceded by Greek (L1) primes and Greek (L1) words preceded by Spanish (L2) primes. The authors concluded that cross-language phonological effects "are exclusively dependent on the baseline level of activation of the individual phonemes at the sublexical level" (p. 196).

The general conclusion from these experiments, therefore, a conclusion which is consistent with the BIA+ model, is that reading in one language activates sub-lexical phonological representations appropriate to a reader's other language, aiding processing of words in that other language. Unfortunately, most of the evidence for this conclusion is indirect (e.g., failures to find interactions with proficiency or frequency). The present research attempted to garner additional information concerning this issue by examining a phenomenon, cross-language masked onset phonological priming, which does not appear to be a lexical phenomenon. The demonstration of phonological priming in this type of task would provide strong evidence for the interaction of bilinguals' phonologies at the sub-lexical level.

1.5. The present research

As noted, a paradigm that is widely used in bilingual research is the masked phonological priming paradigm. For example, in a study with Greek–English bilinguals Dimitropoulou et al. (2011) examined cross-language priming for phonologically related primes and targets that either did have some letters in common (O+P+) or did not (O−P+). The researchers found facilitation when there was phonological overlap only (e.g., μωρό-mora), but not when there was phonological and orthographic overlap (e.g., όριο-ocio). The authors suggested that the lack of a priming effect in the O+P+ condition occurred because competition between the representations of the prime and target at the lexical level eliminated the benefits of similar phonology, although they did not further evaluate this proposal by examining an O+P− condition. Unfortunately, for reasons discussed earlier, this particular version of the masked priming paradigm (i.e., one in which the target task is lexical decision) cannot clearly point to the locus of any phonological effects. Therefore, our research extends the research of Dimitropoulou et al. by using a variant of masked priming, masked onset priming, which, as will be explained, does not appear to tap into lexical processing. Thus, a demonstration of a cross-language phonological effect in this type of task will serve as strong evidence that the languages of a bilingual do interact at a non-lexical level.

In masked onset priming, critical primes and targets share only onsets. Studies using this paradigm with a naming task have shown that participants are faster to name a target preceded by a briefly presented masked prime that shares its onset with the target (e.g., cake – CAGE) compared to an unrelated prime (e.g., bake – CAGE; Forster & Davis, 1991). This masked onset priming effect (MOPE) has been demonstrated consistently with monolingual speakers in various languages (Dimitropoulou, Duñabeitia, & Carreiras, 2010; Grainger & Ferrand, 1996; Kinoshita, 2003; Schiller, 2008). The general conclusion has been that the MOPE is a purely phonological effect due to the fact that it is an overlap in initial phonemes (e.g., kite – CAGE), but not in initial graphemes (e.g., cent – CAGE), that leads to faster target naming.

More importantly, as noted, previous behavioral research suggests that the locus of the MOPE does not appear to be lexical. Rather, it has been suggested to be either at the stage of the sub-lexical mapping of orthography to phonology (Coltheart, Woollams, Kinoshita, & Perry, 1999; Forster & Davis, 1991), or in the process of planning a speech response (Kinoshita, 2000). In both of these views, the MOPE should be relatively immune to the impact of lexical processing/competition, and, indeed, there is substantial empirical evidence supporting that claim. For example, researchers do not find a MOPE in a lexical decision task (Forster & Davis, 1991; Grainger & Ferrand, 1996), in a lexically contingent naming task (Forster & Davis, 1991; Kinoshita & Woollams, 2002), and in a naming task with high-frequency word targets (Forster & Davis, 1991; but see Malouf & Kinoshita, 2007) or with irregular word targets (Forster & Davis, 1991; Kinoshita & Woollams, 2002). Therefore, it would appear to be a particularly valuable paradigm to use in studying cross-language phonological priming effects, as it allows one to determine whether the interaction of phonologies occurs non-lexically either at the level of sub-lexical or output phonology. Also of note is that more recent evidence suggests that the MOPE may not be as insensitive to orthographic effects as the previous (behavioral) data indicate. Timmer and Schiller (2012) reported that an orthographic MOPE can be seen in ERP data, suggesting that there may be priming of orthographic representations as well as phonological representations in masked onset priming paradigms.

In the present study, ERP data were collected in addition to naming data and conditions were established in order to allow an examination of possible orthographic and phonological effects in terms of prime–target onsets, as well as the time-frames of those effects. Most importantly, these conditions allowed us to assess whether at least part of the cross-language phonological effect is sub-lexical as Dimitropoulou et al. (2011) and Nakayama et al. (2012) suggest. If the interaction of phonologies in the two languages of a bilingual takes place at the level of sub-lexical representations, then, we should see both a priming effect in the latency data and a modulation of brainwaves in the N200/250 component of the ERP that has been associated with pre-lexical processing (Carreiras, Perea, Vergara, & Pollatsek, 2009; Holcomb & Grainger, 2006, 2007). With respect to the orthographic manipulation, although it is unlikely that there would be an effect in the latency data, we might expect to see an effect in the ERP data with the sub-lexical orthographic effect emerging before the sub-lexical phonological effect. To some extent, we can also evaluate the alternative, post-lexical explanation of the MOPE according to which it arises in the process of planning a speech response (Kinoshita, 2000). If this proposal concerning the post-lexical nature of the MOPE is in fact correct, then, we should not see a modulation of brainwaves in the N200/250 ERP component, but rather at the later N400 ERP component that is reflective of lexical and post-lexical processing (Holcomb & Grainger, 2006, 2007).

For this study, we recruited Russian–English bilinguals, a group that has been relatively rarely investigated (but see Jouravlev & Jared, 2014; Kaushanskaya & Marian, 2007; Timmer, Ganushchak, Mitlina, & Schiller, in press). There were a number of reasons for this choice. First, many extensively researched language pairs use the same alphabet which often have similar grapheme–phoneme correspondence rules (e.g., French–English, Dutch–English, and Spanish–English). Therefore, words that sound the same in two languages often have substantial overlap in spelling, making it difficult to tease apart phonological and orthographic effects. The use of languages with different scripts (e.g., Japanese–English, Mandarin–English, and Hebrew–English) allows one to look at phonological effects independent of orthographic influences, but does not provide an opportunity for the simultaneous investigation of any orthographic effects. In contrast, Russian and English afford a testing ground for both orthographic and phonological effects. Although Russian and English use different scripts (Cyrillic and Roman respectively), there are a number of letters that are shared across alphabets (e.g., M, T, K, P, B). What is most interesting for the purpose of the present study is that some of these letters map onto the same sound in both languages (e.g., M, T, K), while other letters do not (e.g., in Russian, P maps onto the sound [r], B maps onto the sound [v]). The presence of these cross-script characteristics allows Russian and English to provide a unique opportunity for investigating cross-language phonological and orthographic priming effects. Further, a language unique script can act as a strong language cue ensuring that a bilingual is in fact processing a prime as a word of that language and not as a word/nonword of the target language.

This particular relationship between the scripts used for Russian and English was recently exploited by Timmer et al. (in press) who also investigated the interaction of languages at the sub-lexical level using the masked onset priming paradigm. In their study, Russian–English bilinguals named L1 (Russian) targets preceded by L1 (Russian) or L2 (English) primes that did not contain any letters that could signal that the word was Russian or English. The primes and targets involved the following types of relations. For the Russian primes, prime–target pairs overlapping orthographically and phonologically (O+P+: PAHA [rana] – PEЙC [reis]) were compared with prime–target pairs having no overlap (O−P−: KAPA [kara] – PEЙC [reis]). For this comparison, a priming effect in the behavioral, but not in the ERP, data was found. For the English primes, prime–target pairs overlapping orthographically but not phonologically (O+P−: PACK – PEЙC [reis]) were compared with prime–target pairs having no overlap (O−P−: HOPE – PEЙC [reis]). For this comparison, a priming effect in the ERP, but not in the behavioral, data was reported. The researchers take these contrasting patterns of results as indicating that L2 primes were indeed processed as English words (hence, there is an O+P− relationship between English primes and Russian targets) rather than Russian nonwords (as doing so would make that condition essentially an O+P+ condition). The researchers also concluded that there is an interaction of the phonologies of a bilingual at the sub-lexical level.

Overall, Timmer et al.'s (in press) experiment seems problematic in a number of ways. First of all, their choice of stimuli was problematic because one third of their primes were homographs (e.g., PACE, COMA, COKE, etc.) or cognates (e.g., BOOM, PEAK, COMMA, etc.), words that might activate lexical representations from both languages. Secondly, it is not clear what could have driven the priming in the behavioral data for the O+P+ vs. O−P− comparison in Russian as there was no evidence for either phonological or orthographic effects in the ERP data. The absence of an effect in the ERP data for the O+P+ vs. O−P− comparison could be the result of a high noise-to-signal ratio that prevented the researchers from seeing a subtle effect (note that there were about 34 trials per condition). Further, the conclusion that the presence of significant differences in the ERP data for the O+P− vs. O−P− comparison in 125–200 ms time-window following English primes is evidence for the interaction of phonologies at the sub-lexical level is puzzling as it was an orthographic rather than a phonological relationship that was being manipulated. The final result that seems puzzling concerning Timmer et al.'s data is that the overlap in the orthography of primes and targets led to what appears to be an inhibition rather than a facilitation effect, as the N250 was more negative going for related than unrelated prime–target pairs. This pattern stands in contrast with the ERP results reported in other priming studies where it is the unrelated prime–target condition that evokes a more negative going response than the related one (Carreiras et al., 2009; Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006).

Thus, although Timmer et al. (in press) suggested that their data provided evidence for the interaction of phonologies at the sub-lexical level, the strength of this evidence is questionable. In the present study, we disentangled orthographic and phonological processing from each other by manipulating orthographic and phonological relationships between primes and targets independently and, thus, allowing a more direct examination of whether the languages of a bilingual interact at the level of phonological and orthographic sub-lexical representations. Phonological effects were measured by comparing the performance of bilinguals on English prime–Russian target pairs that overlapped in onset phonologically vs. English prime–Russian target pairs that had no phonological overlap. The orthographic relationship between phonologically related and unrelated prime–target pairs was controlled for in that the prime–target pairs being contrasted either involved primes and targets that overlapped in the orthography of their onsets (O+P+: title – ТЫКВА [tikva] vs. O+P−: cloud – САНКИ [sanki]), or the pairs had primes and targets with different orthographic onsets (O−P+: viper – ВОБЛА [vobla] vs. O−P−: funny – РОПОТ [ropot]). Thus, we assessed whether there are cross-language phonological priming effects as well as whether those effects are modulated by the orthographic similarity of primes and targets. Similarly, we were able to examine whether cross-script orthographic priming effects are observed and whether they are modulated by the phonological similarity of primes and targets. To do so, we compared the performance of bilinguals on the English prime–Russian target pairs that had the same orthographic onset with performance on the pairs that had a different orthographic onset, both when the onsets had the same phonology (O+P+: title – ТЫКВА [tikva] vs. O−P+: viper – ВОБЛА [vobla]), and when the onsets had different phonologies (O+P−: cloud – САНКИ [sanki] vs. O−P−: funny – РОПОТ [ropot]).

As noted above, evidence for cross-language activation of phonology in priming experiments has been less consistent when targets are in L1 compared to L2, presumably due to both the weaker representations of L2 primes and the rapid processing of L1 targets. Nonetheless, we chose to test Russian–English bilinguals who named L1 targets preceded by L2 primes in our investigation because demonstrating a MOPE in this circumstance would provide considerable support for the shared representation view of bilinguals' language system. The MOPE paradigm, particularly when ERP data are also being considered, does appear to be sensitive enough to detect even small effects. That is, some of the strongest evidence for cross-language phonological effects of L2 words on L1 processing has come from masked priming studies (Dimitropoulou et al., 2011; van Wijnendaele & Brysbaert, 2002; Zhou et al., 2010; but see Gollan et al., 1997), and ERPs provide the fine temporal resolution needed to observe effects that arise early in processing.

2. Method

2.1. Participants

The bilingual participants were twenty-five right-handed native speakers of Russian (mean age 23 years, range 18–33; 11 female), who were recruited at the University of Western Ontario. They were all born in Russia and moved to Canada 6 years previously on average (median 6, range 3–15). The participants were undergraduate or graduate students who reported attending educational institutions in which instruction was provided in English for a mean of 6 years (median 5, range 2–10). As per participants' self-reports, English was currently their most frequently used language (M = 72% of time daily vs. M = 28% for Russian). English was their language of choice in communicating with friends and colleagues (M = 85%), while Russian was mainly used in communication with family members (M = 89%). On a ten-point proficiency scale (1 = none; 10 = very fluent) participants reported native proficiency in Russian (M = 10 for speaking, writing, listening, and reading). The proficiency self-rating in English revealed an average value of 8.79 with slightly more fluency in comprehension (listening: 9.13; reading: 9.13) than in production (speaking: 8.43; writing: 8.49). Participants received $15 for taking part in the experiment.

An additional five bilingual participants were tested but their data were not included in the analyses because of poor quality ERP recordings.

2.2. Materials

The critical stimuli for this experiment were formed from 576 four or five-letter Russian words and 576 four or five-letter English words. The Russian words were used as targets that had to be named by participants. English words served as primes that briefly preceded the targets. Only low frequency items were selected (Russian: M = 4.64, according to the frequency dictionary of modern Russian (Lyashevskaya & Sharov, 2009); English: M = 6.52, according to the CELEX (Baayen, Piepenbrock, & Gulikers, 1995 – mean frequencies are per million) because in the monolingual literature (Forster & Davis, 1991) it has been demonstrated that masked onset priming effects do not arise when high frequency words are named (but see Malouf & Kinoshita, 2007). English prime words were also selected so that at least one of the first two graphemes in these words was language-specific (i.e., it was a letter from the Roman, but not the Cyrillic, alphabet) in order to increase the likelihood that bilinguals were using English spelling-to-sound correspondences when processing English primes.[1] In order to meet the abovementioned requirements in the selection of stimuli, we had to include some primes with complex onsets, although the majority of the primes used in the study had simple onsets.[2]

The onsets of primes and targets involved the following types of relations: (1) overlap in orthography and phonology (O+P+ condition; title – ТЫКВА [tikva]); (2) overlap in orthography, but not phonology (O+P− condition; cloud – САНКИ [sanki]); (3) overlap in phonology, but not orthography (O−P+ condition; viper – ВОБЛА [vobla]); and (4) no overlap in either orthography or phonology (O−P− condition; funny – РОПОТ [ropot]). More examples are provided in Appendix A and the full set of stimuli is available from the first author. There were 144 prime–target pairs for each type of relationship. Each group of prime–target pairs was divided evenly into four sets, allowing the creation of four trial blocks having 144 pairs in each block. Each block had an equal number of items having each type of relation. The order of items within each block and the order of the four blocks were randomized for each participant.

2.3. Procedure

At the beginning of each block, participants were instructed that words, preceded by a fixation point, would be presented on the screen one at a time and that their task was to read those words aloud as quickly and as accurately as possible. All instructions were given in Russian. The experimenter spoke Russian to participants during all stages of the experiment. Instructions and

[1] Prior research using the MOPE paradigm with monolingual participants has demonstrated that at least the first two or three letters of the prime are being processed (Masson & Isaak, 1999; Mousikou, Coltheart, Finkbeiner, & Saunders, 2010; Mousikou, Coltheart, Saunders, & Yen, 2010; Schiller, 2004). Although the present study tests bilinguals, we believe that, similar to monolinguals, bilinguals must be processing at least the first two or three graphemes of the prime. The presence of a language specific L2 grapheme in the second position of the prime word should, therefore, indicate to a participant that this prime is likely to be an L2 word, and hence the first grapheme would be much more likely to be mapped onto an L2 rather than an L1 phonological representation.

[2] The effect of primes with complex onsets on the processing of targets with simple onsets has been empirically demonstrated a number of times (Mousikou, Coltheart, Finkbeiner, et al., 2010; Mousikou, Coltheart, Saunders, et al., 2010; Schiller, 2004), although see Kinoshita (2000) for a conflicting set of results.

stimuli were presented, and naming latencies were recorded to the nearest millisecond using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

At the beginning of each trial, a fixation point appeared in the center of the screen for 500 ms, followed by a forward mask of pound signs (#######) that remained on the screen for 500 ms. The forward mask was immediately replaced by a prime presented for 48 ms. The prime was then replaced by a backward mask of pound signs that was shown for 17 ms. Next, the target was presented for a total of 2000 ms or until the participant made a verbal response that triggered the voice key. Each trial finished with the presentation of a blank screen for 1000 ms in order to allow participants to finish articulating their responses. All stimuli were presented in white text on a black background in upper case letters and in Arial font. To minimize physical similarity between items, the targets were presented in 28 point font, while primes were presented in 20 point font.

Each experimental session started with twenty practice trials during which the sensitivity of the voice key was calibrated. After the calibration was completed, the 576 experimental trials in four blocks of 144 trials each were presented. Each block lasted approximately 10 min for a total of 40 min of testing. Participants took a short break between the blocks. After the experiment, participants filled out a questionnaire assessing their English and Russian proficiency.

2.3.1. EEG recording and preprocessing

The continuous electroencephalogram (EEG) activity was recorded at 32 scalp sites (FP1, FP2, AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO3, PO4, O1, Oz, O2) using ActiveTwo BioSemi active Ag/AgCl electrodes embedded in a custom elastic cap (BioSemi, Amsterdam, The Netherlands). As per BioSemi design, the ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode. The electro-oculogram (EOG) was recorded with electrodes placed above and below the right eye (vertical), and on the outer canthus of each eye (horizontal). All EEG electrode impedances were maintained below 5 kΩ. All bioelectric signals were digitized using ActiView software (BioSemi) at a rate of 500 Hz with a bandpass of 0.1–100 Hz and a 60 Hz notch filter.

Off-line analysis was performed using EMSE Suite software (Source Signal Imaging, San Diego, CA). All data were re-referenced to the mean electric activity of the mastoids and bandpass filtered with cutoffs of 0.1 and 30 Hz. The epochs of interest for critical words were established to be from −100 to 500 ms post-stimulus onset. Trials with latencies less than 450 ms were removed from the ERP analysis (10.23% of the trials were removed) although not from the latency analysis. Further, trials contaminated with EOG activity greater than ±75 microvolts (μΩ) were also removed from the ERP, but not the latency, analyses (8.53% of the trials were removed due to artifacts).

3. Results

3.1. Behavioral data

To reduce the effects of outliers, any reaction times (RTs) slower than 1500 ms or faster than 200 ms were also discarded from the analyses. The total percentage of removed data-points was 3.5%. Participants' mean reaction times were analyzed using a linear mixed effects model with Subjects and Items entered as crossed random factors, and Orthographic Overlap of prime–target onsets and Phonological Overlap of prime–target onsets entered as fixed factors. The analysis was conducted using R (R Development Core Team, 2009) and the R package *lme4* (Bates, Maechler, & Bolker, 2012). Significance values were obtained via Markov Chain Monte Carlo (MCMC) sampling of the posterior parameter distributions (sample size = 10,000). The mean latencies and standard deviations for the four types of relations between primes and targets are given in Fig. 1. No analysis of the accuracy data was conducted as errors occurred on less than 1% of trials.

There was a main effect of Phonological Overlap, $t(574) = 6.41$, $p < .001$. Participants named Russian target words that shared the phonology of their onsets with English primes significantly faster ($M = 620$ ms, $SD = 35$) than Russian targets that did not share the phonology of their onsets with English primes ($M = 643$ ms, $SD = 32$). The main effect of Orthographic Overlap was not significant, $t(574) = 1.72$, $p = .09$. The response times to Russian targets having orthographic overlap with their English primes ($M = 629$ ms, $SD = 30$) did not differ significantly from the response times required to name Russian targets that had no orthographic overlap with their English primes ($M = 634$ ms, $SD = 36$). The interaction between Phonological and Orthographic Overlap was not significant, $t(574) = 1.01$, $p = .31$.

3.2. Electrophysiological data

Nine regions of interest were selected, and the response reported in each region is the mean response of the set of electrodes. The regions were (see Fig. 2): (1) left-anterior (AF3, F7, F3), (2) left-central (FC5, C3), (3) left-posterior (CP5, P3), (4) midline-anterior (Fz), (5) midline-central (FC1, Cz, FC2), (6) midline-posterior (CP1, Pz, CP2), (7) right-anterior (AF4, F8, F4), (8) right-central (FC6, C4), and (9) right-posterior (CP6, P4).

Based on previous research (Carreiras et al., 2009; Holcomb & Grainger, 2006; Timmer & Schiller, 2012), we expected that our experimental manipulations might lead to modulations in the ERP patterns in three time-windows: (1) 150–250 ms; (2) 250–350 ms; and (3) 350–450 ms. Mean amplitudes for each experimental condition in each region of interest were obtained for these time-windows and were used as dependent measures in our analyses. For each window, a repeated-measures ANOVA was performed with Phonological Overlap (Yes vs. No), Orthographic Overlap (Yes vs. No), Electrode Region (Anterior vs. Central vs. Posterior), and Laterality (Left vs. Midline vs. Right) as within-subject factors in each analysis (using the Greenhouse–Geisser correction). Fig. 3 shows the waveforms evoked in response to targets in O+P+, O−P+, O+P−, and O−P− conditions. The waveforms evoked in response to targets having orthographic overlap with primes vs. targets having no orthographic overlap with primes (Fig. 4A) and targets having phonological overlap with primes vs. targets having no phonological overlap with primes (Fig. 4B) are also provided.

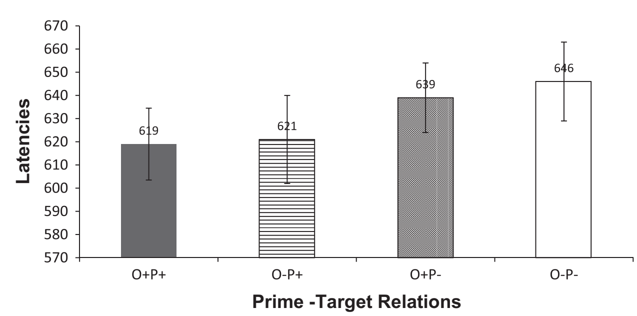

Fig. 1. Mean naming response latencies (in ms) to Russian targets in O+P+, O−P+, O+P−, or O−P− relations with English primes. Error bars represent one standard deviation.

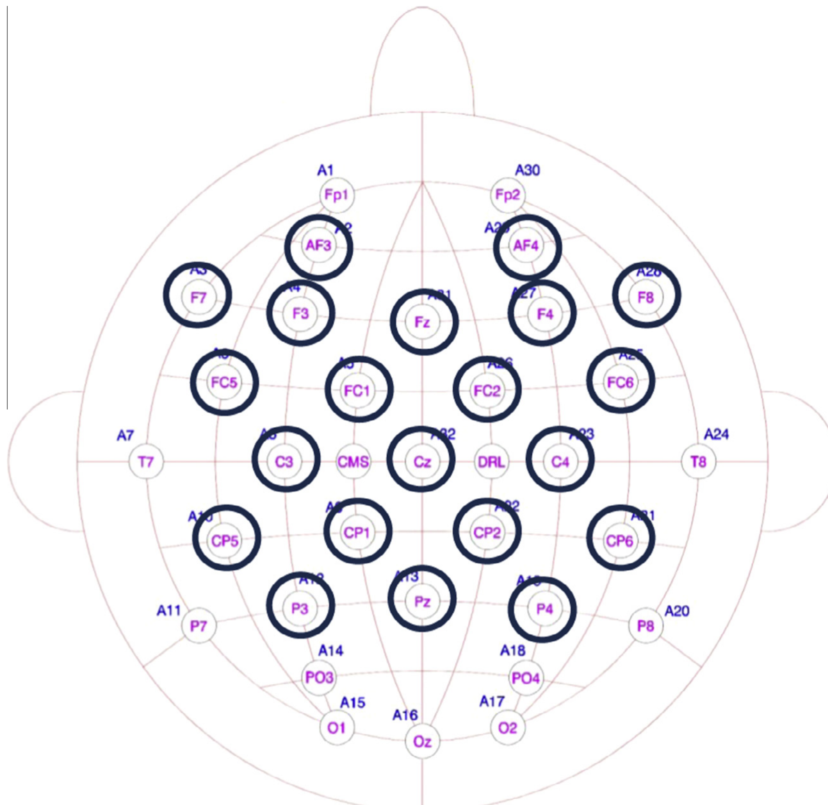

Fig. 2. Electrode montage. Circles indicate electrodes included in the analysis. The electrodes were grouped into the following regions for the analysis: (1) left-anterior (AF3, F7, F3), (2) left-central (FC5, C3), (3) left-posterior (CP5, P3), (4) midline-anterior (Fz), (5) midline-central (FC1, Cz, FC2), (6) midline-posterior (CP1, Pz, CP2), (7) right-anterior (AF4, F8, F4), (8) right-central (FC6, C4), and (9) right-posterior (CP6, P4).

3.2.1. 150–250 ms window

In this time-window, there was a significant main effect of Orthographic Overlap, $F(1,24) = 17.35$, $p < .001$, $\eta_p^2 = .42$. The amplitudes of brainwaves in response to targets overlapping with primes orthographically ($M = 2.06$, $SD = 0.36$) were significantly less negative compared to targets preceded by primes with no orthographic overlap ($M = 1.53$, $SD = 0.33$). In contrast, the main effect of Phonological Overlap was not significant, $F(1,24) = 2.45$, $p = .13$, $\eta_p^2 = .09$. There was no significant difference in the amplitudes of brainwaves in response to targets overlapping with primes phonologically ($M = 1.88$, $SD = 0.37$) compared to brainwaves evoked by targets that had no phonological overlap with their primes ($M = 1.70$, $SD = 0.32$). The interaction between Orthographic Overlap and Phonological Overlap was not significant, $F(1,24) = 0.21$, $p = .66$, $\eta_p^2 = .01$. Overall, the activity was more left-lateralized, $F(2,48) = 3.80$, $p = .03$, $\eta_p^2 = .14$. Laterality interacted with Electrode Region, $F(4,96) = 4.99$, $p = .01$, $\eta_p^2 = .17$. Brain activity was more negative at posterior than anterior regions in the left hemisphere, while no difference of this sort was observed in the right hemisphere. The interaction between Orthographic Overlap and Electrode Region was marginally significant, $F(2,48) = 3.21$, $p = .06$, $\eta_p^2 = .13$, with a priming effect being more evident at posterior than anterior sites. All other main effects and interactions were not significant (all Fs < 2.17).

3.2.2. 250–350 ms window

The main effect of Phonological Overlap was significant, $F(1,24) = 13.31$, $p = .001$, $\eta_p^2 = .37$. The amplitudes of brainwaves evoked by targets that overlapped with primes phonologically ($M = 1.77$, $SD = 0.40$) were significantly less negative than the amplitudes of brainwaves evoked by targets with no phonological overlap with their primes ($M = 1.20$, $SD = 0.41$). The main effect of Orthographic Overlap was not significant, $F(1,24) = 2.89$, $p = .10$, $\eta_p^2 = .11$, although, in this time-window, the amplitudes of brainwaves in response to targets overlapping with primes orthographically ($M = 1.65$, $SD = 0.44$) were slightly less negative than to targets preceded by primes with no orthographic overlap ($M = 1.32$, $SD = 0.38$). The interaction between Orthographic Overlap and Phonological Overlap was not significant, $F(1,24) = 0.12$, $p = .74$, $\eta_p^2 = .01$. Further, there were significant main effects of Laterality, $F(2,48) = 8.13$, $p = .002$, $\eta_p^2 = .25$, and Electrode Region, $F(2,48) = 12.12$, $p = .001$, $\eta_p^2 = .34$, with activity being more negative over the anterior sites of the brain and in the left hemisphere. The interaction between Phonological Overlap and Electrode Region approached significance, $F(2,48) = 3.03$, $p = .09$, $\eta_p^2 = .11$, with the priming effect being more evident at anterior than posterior sites. Finally, there was a significant interaction of Phonological Overlap, Electrode Region, and Laterality, $F(4,96) = 3.56$, $p = .02$, $\eta_p^2 = .13$. A larger priming effect was observed at anterior than posterior regions in the left hemisphere, while no difference of this sort was observed in the right hemisphere. All other interactions were not significant (all Fs < 2.52).

3.2.3. 350–450 ms window

In this time-window, there was a significant main effect of Phonological Overlap, $F(1,24) = 5.03$, $p = .04$, $\eta_p^2 = .17$. The amplitude of brainwaves in response to targets overlapping with primes phonologically was reduced in negativity ($M = 2.17$, $SD = 0.70$) compared to targets preceded by primes with no phonological overlap ($M = 1.68$, $SD = 0.62$). The main effect of Orthographic Overlap was not significant, $F(1,24) = .38$, $p = .54$, $\eta_p^2 = .02$. The brainwaves evoked by targets overlapping with

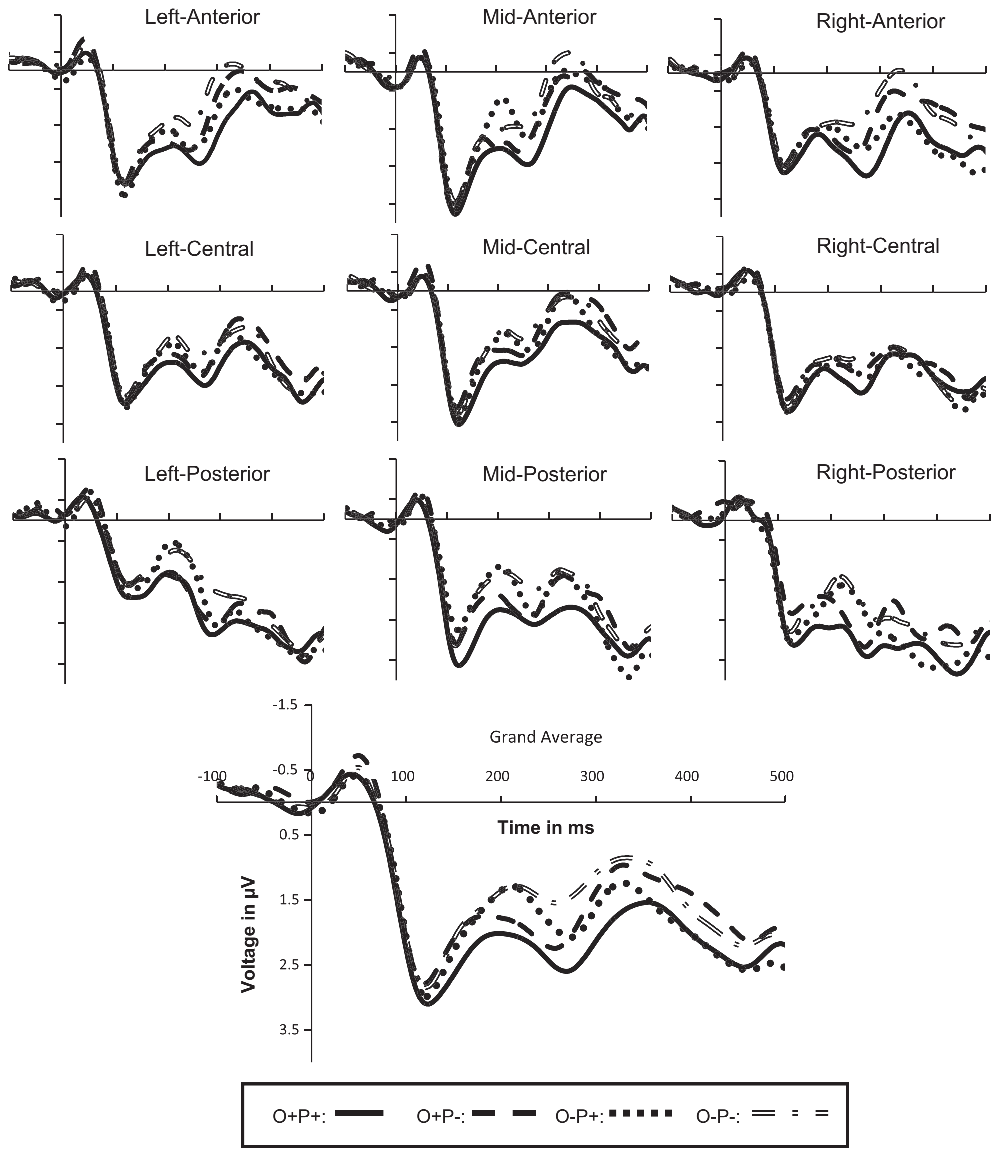

Fig. 3. ERP waveforms from nine regions of interest and grand average ERPs of Russian–English bilinguals responding to targets in the O+P+ condition (solid line), the O+P− condition (dashed line), the O−P+ condition (dotted line), and the O−P− condition (dashed–dotted line). The presence of orthographic overlap between prime and target (O+P+ vs. O−P+ and O+P− vs. O−P−) led to significant modulation of brainwaves in the 150–250 ms time-window. The presence of phonological overlap between prime and target (O+P+ vs. O+P− and O−P+ vs. O−P−) led to significant modulation of brainwaves in the 250–450 ms time-window.

primes orthographically ($M = 1.86$, $SD = 0.60$) and targets having no orthographic overlap with their primes ($M = 1.98$, $SD = 0.71$) were of comparable magnitude. The interaction between Orthographic Overlap and Phonological Overlap was not significant, $F(1,24) = 0.16$, $p = .92$, $\eta_p^2 = .01$. There were significant main effects of Laterality, $F(2,48) = 9.42$, $p = .001$, $\eta_p^2 = .28$, and Electrode Region, $F(2,48) = 11.74$, $p = .001$, $\eta_p^2 = .33$, with activity being more negative over the central and anterior than posterior sites of the brain and in the left than right hemisphere. There was also a significant interaction of Phonological Overlap, Electrode Region, and Laterality, $F(4,96) = 5.37$, $p = .001$, $\eta_p^2 = .18$. A larger priming effect was observed at anterior than posterior regions in the left hemisphere, while no difference of this sort was observed in the right hemisphere. All other interactions were not significant (all $Fs < 1.68$).

In summary, the latency data showed an L2-to-L1 priming effect due to phonological similarity but no priming effect due to orthographic similarity. In contrast, in the ERP data, evidence of effects of both phonological and orthographic similarity was found. The impact of L2 orthography on L1 word naming was registered in the 150–250 ms time-window, while the impact of L2 phonology on L1 word naming was observed in the 250–350 ms and 350–450 ms time-windows. The neural activity reflecting orthographic effects was mainly localized at posterior areas of the brain, while for phonological effects there was anterior localization of the neural activity.

4. Discussion

The present study examined L2 to L1 phonological and orthographic priming in Russian–English bilinguals using the masked onset priming paradigm and ERP recordings. The participants were asked to read aloud Russian target words that were preceded by English primes. The onsets of L2 primes and L1 targets involved the following types of relations: (1) an overlap in orthography and phonology (O+P+ condition; title – ТЫКВА [tikva]); (2) an overlap in orthography, but not in phonology (O+P− condition;

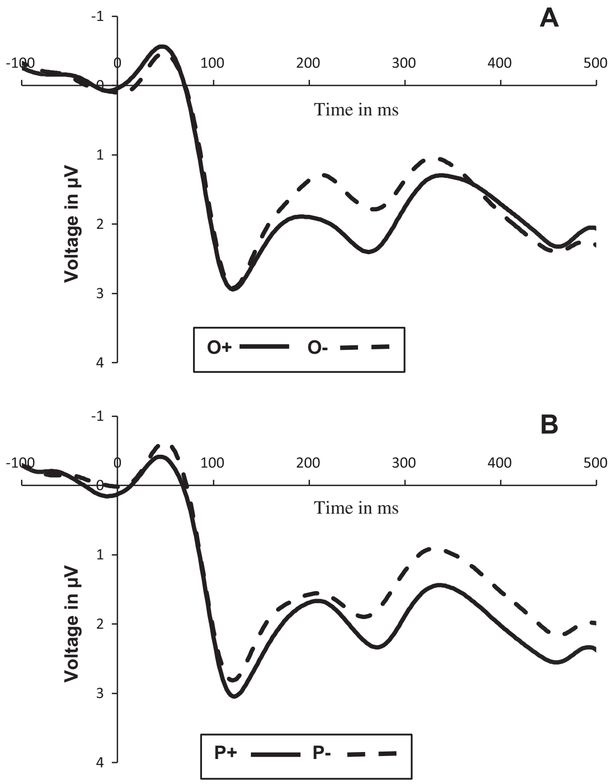

Fig. 4. Grand average ERPs of Russian–English bilinguals responding to targets in O+ vs. O− conditions (A), and P+ vs. P− conditions (B).

cloud – САНКИ [sanki]); (3) an overlap in phonology, but not in orthography (O−P+ condition; viper – ВОБЛА [vobla]); and (4) no overlap either in orthography, or phonology (O−P− condition; funny – РОПОТ [ropot]). Behavioral and ERP data were analyzed to assess the effects of phonological and orthographic overlap of English primes and Russian targets on the bilinguals' naming performance. In the ERP data, an analysis was conducted in three time-windows: 150–250 ms, 250–350 ms, and 350–450 ms.

The broad goal of the present research was to evaluate cross-language phonological and orthographic effects in the masked onset priming paradigm in an attempt to better understand the nature of shared representations in bilinguals' two languages. The demonstration of such effects in the masked onset priming paradigm, a paradigm that is believed to reflect activation at the non-lexical stages of processing, would provide direct evidence that cross-language phonological and, potentially, orthographic priming effects do occur at a non-lexical level. More specifically, the experiment allowed us to address a number of questions: (1) Is there evidence for a phonologically-based MOPE when using L2 primes and L1 targets? (2) Is there evidence for an orthographically-based MOPE when using L2 primes and L1 targets? (3) If either effect exists, is it dependent on the nature of the other factor? (4) What is the time-course of either of these types of priming effects? Below each question will be discussed separately.

4.1. L2–L1 phonological priming

Russian–English bilinguals, reading in their native language, were affected by the phonology generated by reading words from their non-native language, as there was evidence for a MOPE in both behavioral and ERP data. Behaviorally, bilinguals were faster to name Russian words preceded by phonologically overlapping English primes compared to unrelated primes. In the ERP data, the presence of phonological overlap between primes and targets was linked to the modulation of neural responses, specifically a reduction in negativity during 250–350 ms and 350–450 ms time-windows. Apparently, despite the irrelevance of English (prime) words to the task, their phonological representations were activated and they facilitated the processing of Russian (target) words, impacting both latencies and neural responses to those words.

To our knowledge, the current investigation is the first one to demonstrate L2-to-L1 phonological priming in both participants' response latencies and their ERP responses. These findings are in line with behavioral studies that previously reported L2-to-L1 phonological priming (Dimitropoulou et al., 2011, O−P+ condition; Lee, Nam, & Katz, 2005; van Wijnendaele & Brysbaert, 2002), but stand in contrast to studies in which no L2-to-L1 priming effect was observed (Dimitropoulou et al., 2011, O+P+ condition; Gollan et al., 1997). The difference in results might arise due to the nature of the tasks used. The studies that have not found an L2-to-L1 phonological priming effect have all used masked priming with a lexical decision response. The lexical decision task is undoubtedly less sensitive to the activation of phonological representations than the naming task. Furthermore, the present study extends research on the phonological MOPE, previously demonstrated in monolinguals (Forster & Davis, 1991; Kinoshita, 2003), and bilinguals performing the task solely in their L2 (Timmer & Schiller, 2012), to bilinguals performing the task with L2 primes and L1 targets. As argued previously, a successful demonstration of a cross-language, phonological MOPE serves as evidence that the phonologies of two languages spoken by a bilingual do interact at a non-lexical (i.e., sub-lexical or post-lexical) level.

4.2. L2–L1 orthographic effects in masked onset priming

The present results also provide information concerning whether masked onset priming can be produced based just on orthographic overlap between primes and targets. In previous behavioral research examining the MOPE in monolingual (Grainger & Ferrand, 1996; Kinoshita, 2003; Schiller, 2008), and bilingual readers (Timmer & Schiller, 2012; Timmer et al., in press), there was no evidence for an impact of orthographic overlap. Similarly, in our study, the presence of common initial letters in primes and targets did not influence naming latencies. We did, however, find a cross-script orthographic priming effect in our ERP data. More specifically, there was a reduction in the negativity of neural responses in the presence of orthographic overlap between primes and targets. The suggestion that the MOPE might not be completely immune to the impact of the orthography has been made previously (Timmer & Schiller, 2012; Timmer et al., in press). However, the orthographic priming effect in the ERP data reported in those studies was in the direction opposite to what we have found. Timmer et al. found an increase in the negativity of neural responses in the presence of orthographic overlap between primes and targets. Although the reason for these differences in the ERP data is not clear to us, we believe that the previous ERP results along with the present ERP results suggest that an orthographic effect does exist, although, it is not strong enough to be observed in the latency data of a naming task. Any orthographic effect in the masked onset priming paradigm is, of course, most likely to arise at the sub-lexical level.

4.3. The influence of orthographic similarity on L2–L1 phonological priming

In our results, there was no evidence that the degree of orthographic overlap of primes and targets has an impact on the size of the phonological MOPE. We observed equivalent cross-script phonological priming effects in L1 both when primes and targets shared the orthography of their onsets and when they had different orthographic onsets. Note that this pattern stands in contrast to the findings by Dimitropoulou et al. (2011), who reported that in a standard masked phonological priming study using a lexical decision task there was a significant priming effect in their O−P+ vs. O−P− comparison but not in their O+P+ vs. O+P− comparison. Dimitropoulou et al. suggested that the lack of priming in the O+P+ condition was due to competition between the orthographic representations of the prime and target at the lexical level that eliminated the benefits of similar phonology. This claim is consistent with the idea that the lexical decision task is strongly affected by lexical processing whereas the present paradigm is mainly affected by sub-lexical processing, making the present paradigm more suitable for investigating sub-lexical phonological effects.

4.4. Time-course of orthographic and phonological priming effects

On the basis of prior work combining masked priming and ERP measurements (Carreiras et al., 2009; Grainger & Holcomb, 2009; Grainger et al., 2006), if we were to observe a modulation of the ERPs due to orthographic overlap between primes and targets we expected it in earlier time-windows, with any modulation of the ERPs due to phonological overlap arising in later time-windows. In fact, the orthographic priming effect emerged in the first time-window (150–250 ms) examined. These results are identical to those reported in the Carreiras et al. study in which Spanish monolinguals performed a lexical decision task on words preceded by orthographically or phonologically similar masked primes.

In addition, in the present study, the phonological L2-to-L1 priming effect also showed the expected pattern, being registered in the second (250–350 ms) and in the third (350–450 ms) time-windows. Carreiras et al. did report that phonological priming effects start to emerge later in comparison to our results (in the 350–550 ms time-window). However, the discrepancy in the time of the onset of the phonological effect between the studies might be due to the differences in the tasks employed. In a naming task, the processing of phonology is a crucial component, whereas participants in Carreiras et al.'s study made lexical decisions, which could have engaged phonological processing to a lesser degree. In word naming tasks, phonological effects often emerge earlier than 350 ms, presumably due to the centrality of phonological activation to performing the task. For example, Timmer and Schiller (2012) reported a decrease in negativity due to the phonological overlap of primes and targets as early as the 180–280 ms time-window.

Overall, the present results indicate that the time-course of cross-language orthographic and phonological priming in bilinguals, naming L1 words preceded by L2 masked primes, is very similar to the time-course of within-language orthographic and phonological priming in monolinguals. That is, there is an early phase (150–250 ms) of orthographic processing, during which an impact of orthographic overlap can be observed but no impact of phonology is evident. In a later time-window (250–350 ms), the effect of orthographic overlap disappears, and the impact of phonological overlap is observed. In the third time-window (350–450 ms), the effect of orthographic overlap is absent, while the impact of phonological overlap continues, although it is reduced in size. Thus, there was little evidence that the time-course of bilingual orthographic and phonological processing differs significantly from that of monolinguals.

As was discussed previously, prior research had not clearly indicated whether the phonological MOPE was a sub-lexical or post-lexical effect (Coltheart et al., 1999; Forster & Davis, 1991; Kinoshita, 2000). The present data provide some insight concerning this issue. The fact that a modulation of the brainwaves in response to phonologically overlapping prime–target pairs started as early as 250 ms post-stimulus presentation, a period when lexical access may not yet have been achieved, indicates that at least part of the MOPE does occur at the level of sub-lexical phonology, supporting our main conclusion. We should note, however, that the modulation of the brainwaves due to the phonological onset priming did continue up to 450 ms post-stimulus presentation. There are several possible explanations of this later phonological priming in the ERP data. First, Russian–English bilinguals managing two different scripts (that are often ambiguous in their grapheme-to-phoneme mappings) in one task might be relatively slow in completing sub-lexical phonological processing. Hence, what we see in the 350–450 ms time-window might be the wrapping up of the sub-lexical processing (note the decrease in the size of the phonological priming effect in the 350–450 ms vs. 250–350 ms time-window). Alternatively, this modulation in the 350–450 ms time-window might be reflective of phonological lexical processes. Although it is likely that the MOPE is quite insensitive to lexical processing, it might be the case that the ERP data can reveal some evidence for the interaction of phonologies at the level of lexical representations. If so, the MOPE would then result from facilitation in the processing of targets due to their overlap in onsets with primes at both sub-lexical (as seen in the behavioral and the ERP data) and, to a smaller extent, lexical levels (as seen in the ERP data). Finally, the presence of phonological priming in this later time-window might be consistent with the idea that the phonological MOPE is, to some degree, a post-lexical effect driven by the pre-activation of speech response codes. Therefore, the overall phonological priming observed in the MOPE paradigm might be a combination of facilitation at all three levels.

4.5. Theoretical implications

Our finding of a cross-language L2-to-L1 masked onset phonological priming effect adds to the evidence that the architecture of the bilingual lexicon is such that interactions occur between phonological representations of a bilingual's two languages. In addition, these results provide evidence that at least some component of this interaction occurs at the level of sub-lexical phonology. Furthermore, the finding in our ERP data of a masked onset orthographic priming effect even when primes and targets contained many language-specific letters suggests that there are similar interactions at the orthographic sub-lexical level.

These conclusions are consistent with the architecture of the BIA+ (Dijkstra & Van Heuven, 2002) that posits the existence of shared pools of lexical and sub-lexical representations for both languages of a bilingual. We assume that the BIA+ would give the following account of our findings. When the English prime words are presented, all sub-lexical orthographic nodes consistent with the visual information would be activated, and these in turn would send activation to any lexical orthographic nodes consistent with that sub-lexical information. Simultaneously, the sub-lexical orthographic nodes would send activation to sub-lexical phonological nodes that were consistent with the activated letters, and these in turn would send activation to lexical phonological nodes that were consistent with the activated phonemes. When the Russian target appears, a similar process would occur, however, the letters and phonemes that were shared with the prime word would already be partially activated. The orthographic priming effect that was observed in an early time-window in the ERP data presumably arose from the activation of shared letter nodes. Similarly, the phonological priming effect would have arisen from the activation of shared phonemes.

Note also that, although the BIA+ also posits shared phonological representations at the lexical level, it is not clear that it could actually explain a phonological facilitation effect arising at that level. The reason is that in the BIA+ model, activated lexical nodes are presumed to inhibit one another. Thus, according to the BIA+, the lexical phonological node for the English prime word would have inhibited the activation of nodes for other phonologically similar words, including the node for the Russian target word, potentially producing an inhibitory phonological priming effect. In the BIA+ framework, therefore, a phonological facilitation effect observed in the present study is much more consistent with the idea that the interaction of phonologies occurs at the sub-lexical level.

In summary, the present study provides direct evidence that cross-language phonological priming effects do occur at the sub-lexical level. More specifically, we observed facilitation in the behavioral latencies and a reduction in negativity in the ERP brainwaves in a masked onset priming paradigm, a task that seems to be tapping into sub-lexical stages of processing. Further, our ERP data provided evidence that the MOPE is not only phonological, but also orthographic. To our knowledge, the present research is the first to demonstrate cross-language phonological and orthographic priming effects using the MOPE paradigm. Finally, the presence of an effect of L2 (prime) words on the processing of L1 (target) words, which has been demonstrated only inconsistently in the previous literature, serves as strong evidence for the shared representation view of bilinguals' language systems.

Appendix A

Examples of English primes and Russian targets used as stimulus materials. O+P+ refers to overlap in orthography and phonology. O+P− refers to overlap in orthography only. O−P+ refers to overlap in phonology only. O−P− refers to no overlap either in orthography or phonology.

O+P+: kick – КАБАК [kabak]; kitty – КИСЕТ [kiset]; kiss – КАЗНА [kazna]; king – КЕПКА [kepka]; krone – КАПОТ [kapot]; cigar – САДОК [sadok]; cider – СУРИК [surik]; civil – СОЛОД [solod]; cinch – САНКИ [sanki]; circa – СИЛОС [silos]; mile – МАЙКА [maika]; minor – МЕСТЬ [mest']; milky – МЕРИН [merin]; minus – МИГОМ [migom]; mirth – МИСКА [miska]; twist – ТЕСАК [tesak]; tiger – ТАБОР [tabor]; twice – ТАБУН [tabun]; truck – ТОПКА [topka]; tweet – ТУЧКА [tuchka].

O+P−: knob – КОФТА [kofta]; knack – КОЛОС [kolos]; knoll – КИСКА [kiska]; knock – КАМИН [kamin]; knurl – КУБИК [kubik]; clove – САБЛЯ [sabl'a]; clown – САЗАН [sazan]; cloud – САЧОК [sachok]; crate – СОКОЛ [sokol]; cream – СУШКА [sushka]; birch – ВЕНИК [venik]; blade – ВЕСЛО [veslo]; brand – ВИСОК [visok]; bribe – ВАЛКА [valka]; blood – ВОЛАН [volan]; pilot – РЕБРО [rebro]; pitch – РЕЗНЯ [rezn'a]; pizza – РЕШКА [reshka]; plane – РОЛИК [rolik]; pride – РОБКО [robko].

O−P+: clone – КАЗАХ [kazah]; claim – КАЛАЧ [kalach]; crane – КОЙКА [koika]; crowd – КУМИР [kumir]; cross – КУПОЛ [kupol]; scope – САЛЮТ [sal'ut]; sauce – СЕЧКА [sechka]; solid – СОТКА [sotka]; solve – СУДАК [sudak]; swear – СЕДЛО [sedlo]; verge – ВАЛЕТ [valet]; video – ВАЛУН [valun]; virus – ВИШНЯ [vishn'a]; vivid – ВОПЛЬ [vopl']; vague – ВУАЛЬ [vual']; reach – РАЗОМ [razom]; repel – РАХИТ [rahit]; rifle – РУЧЕЙ [ruchei]; radio – РОХЛЯ [rohl'a]; rocky– РЕЗВО [rezvo].

O−P−: dense – КАДЫК [kadik], death – КАЛЫМ [kalim]; diary – КЕГЛИ [kegli]; doubt – КОНЁК [kon'ok]; dream – КОСЯК [kos'ak]; lemon – САЙРА [saira]; label – СЕРНА [serna]; larva – СИЛАЧ [silach]; laugh –СЫНОК [sinok]; local – САРАЙ [sarai]; glade – ВЕЛЮР [vel'ur], goose – ВАЗОН [vazon]; glaze – ВОЛХВ [volhv]; greed – ВИРШИ [virshi]; guide – ВЕДРО [vedro]; flare – РЕДИС [redis]; flock – РИФМА [rifma]; fever – РУБЕЦ [rubets]; flank – РАЧОК [rachok]; fluid – РУБКА [rubka].

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