A cross-linguistic investigation of the onset effect in reading aloud : No need to mope about the MOPE

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Chapter 5

Trial by trial: Selecting first or second language phonology of a visually masked word[8]

Abstract

People often process non-native linguistic information. Here, we investigated whether first (L1) and second language (L2) phonologies are automatically activated. Response latencies and event-related potentials (ERPs) were recorded while Russian–English bilinguals read aloud L1 target words (e.g., *РЕЙС* /reis/ 'flight') primed with onset-matching L1 (e.g., *РАНА* /rana/ 'wound') or L2 words (e.g., *РАСК*) and corresponding onset-mismatching primes (e.g., L1: *КАРА* /kara/ 'punishment'; L2: HOPE). Responses were faster to targets preceded by L1 onset-matched than by onset-mismatched primes. No priming from L2 primes was found due to conflicting phonologies (e.g., <P> is /r/ or /p/). These results were supported by the ERPs suggesting that both, L1 and L2 phonologies are simultaneously activated, after which the phonology belonging to the language of the prime is selected. The results provide support for non-selective models of bilingual reading, which assume automatic activation of the non-target language phonology even when it is not required by the task.

[8] This chapter is based on Timmer, K., Ganushchak, A. Y., Mitlina, Y., & Schiller, N. O. (in press). Trial by trial: selecting first or second language phonology of a visually masked word. *Language and Cognitive Processes.*

Introduction

For most of us, reading is effortless and is considered to be an automatic and rapid process. For instance, previous research using the *Stroop* task demonstrated that reading cannot be suppressed because when we name the color of a printed word, the word itself interferes with the color naming (Stroop, 1935). The rapid underlying processes of (silent) reading include the recognition of letters and the conversion into phonological units up to the recognition of the full word (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). However, what happens when a reader knows more than one language? Does the phonology of his/her second language also become automatically activated? Are the L1 and L2 phonology co-activated simultaneously? These are the aims of our study.

A computation model of reading, the *dual-route cascaded* (DRC) model, explains the process of reading through two routes, the lexical and non-lexical route. Through the lexical route, we read high-frequency words and irregular words that access the phonology of the whole word at once. Through the non-lexical route, we read words and nonwords by a rule-based system translating each letter into a phoneme, called grapheme-to-phoneme conversion (GPC; Coltheart et al., 2001; Mousikou, Coltheart, & Saunders, 2010). The phonology is rapidly activated in a serial fashion from left-to-right (e.g., Kinoshita, 2000; Malouf & Kinoshita, 2007; Schiller, 2004). Furthermore, the GPC rules include among others context-sensitive rules (e.g., <c> is pronounced as an /s/ when the following letter is a front vowel such as /e, i, y/). These rules help us to read *regular* words, with ambiguous onset consonants, like CARPET correctly through the non-lexical route.

Another dual-route computational model, partially based on previous models, among which the DRC model is the connectionist dual process (CDP+(+)) model (Perry, Ziegler, & Zorzi, 2007, 2010; Zorzi, Houghton, & Butterworth, 1998). A lexical route very similar to that of the DRC model is implemented in the CDP+ model to explain lexical effects (Perry et al., 2007). In the non-lexical, also called sub-lexical, route the GPC rules from the DRC model are replaced by a simple two-layer network. In this network, the input layer represents a written word through a graphemic buffer, which means not only single letters but also multi-letter graphemes are represented. The output layer represents the phonology belonging to the graphemes. The model can be trained on grapheme-phoneme correspondences and learns further during simulations. During the running phase, reflecting the reading aloud process, context sensitivity is used to potentially differentiate the two pronunciations (e.g., /s/ or /k/) for a grapheme like <c>. The phonological output buffer combines the pronunciations of both routes and chooses the correct output (Perry et al., 2007, 2010). Both the DRC and the CDP++ model explain the process of L1 GPC but do not include L2 GPC rules/correspondences in concurrence (Coltheart et al., 2001; Mousikou et al., 2010).

Another computational model supporting fast and automatic sub-lexical processing of the L1 is the *interactive activation* (IA) model (McClelland & Rumelhart, 1981). This model assumes a single route through which in a bottom-up fashion visual features are converted into letters up to the recognition of the words. A new version of this model, the *bilingual interactive activation* (BIA+) model (Dijkstra & Van Heuven, 2002), has added a bilingual lexicon, in which words of both languages of a bilingual are represented together. Separate language nodes for each language can anticipate the language to be processed based on prior input and, by doing so, inhibit all words from the irrelevant language. In addition, the model extends the assumption of non-selectivity to the sub-lexical level. As discussed by Dijkstra and Van Heuven (2002) this allows for rapid sub-lexical processing of L2 orthography and phonology next to that of the L1. Note, however, orthographic and phonological representations are not implemented in the model itself . To conclude, non-selectivity of the languages is assumed on both the lexical and sub-lexical level.

The masked priming paradigm is often used to investigate sub-lexical orthographic and phonological activation. The so-called *masked onset priming effect* (MOPE), i.e., faster response latencies for onset-related than unrelated prime-target pairs has been often replicated in L1 research (e.g., Kinoshita, 2000, 2003; Kinoshita & Woollams, 2002; Malouf & Kinoshita, 2007; Schiller, 2004, 2007, 2008; Timmer, Vahid-Gharavi, & Schiller, 2012; Timmer & Schiller, 2012). Specifically, the MOPE is suggested to reflect the rapid and automatic GPC process, with faster response latencies for phonological (e.g. *kernel – CARPET*) than orthographic onset-overlap (e.g. *circus – CARPET*; e.g. Mousikou et al., 2010; Schiller, 2007; Timmer et al., 2012; Timmer & Schiller, 2012). Thus, previous researched showed that during reading, the L1 phonology is automatically activated. Does L2 phonology also become activated automatically?

In contrast to reading aloud research, in visual word recognition research, using tasks such as lexical decision task (LDT), onset overlap between prime-target pairs was not sufficient to facilitate responses and no MOPE was present (e.g. Carreiras, Ferrand, Grainger, & Perea, 2005a; Forster & Davis, 1991; Grainger & Ferrand, 1996). However, syllable overlap does facilitate responses in L1 visual word recognition (i.e., silent reading; e.g., Carreiras et al., 2005a; Dimitropoulou, Duñabeita, & Carreiras, 2011a; Grainger & Ferrand, 1996; Rastle & Brysbaert, 2006). Further, in the visual word recognition literature, a cross-linguistic priming effect from the L1 to the L2 has been demonstrated (e.g., Brysbaert, Van Dyck, & Van de Poel, 1999; Dimitropoulou et al., 2011a; Duyck, 2005; Gollan, Forster, & Frost, 1997; Kim & Davis, 2003; Voga & Grainger, 2007). Most of these studies use special word types, like cognates (i.e. words that have similar orthography, phonology, and the same meaning in two languages), homophones (i.e. words that sound similar but have a different meaning), and pseudohomophones (i.e. nonwords that sound like real words) which might activate both languages through the meaning of the words and give strong feedback to the sub-lexical word forms (Pecher, 2001; Timmer, Ceusters, & Schiller, submitted). Thus, studies revealing cross-linguistic priming from L1 to L2 cannot be taken as evidence that both L1 and L2 sub-lexical phonology are activated.

Only a few studies have shown that the L2 phonology can also influence L1 production (e.g. Dimitropoulou et al., 2011a; Duyck, 2005; Timmer et al., submitted; Van Wijnendaele & Brysbaert, 2002). Difficulties with these studies are that some use pseudohomophone primes (Duyck, 2005; Van Wijnendaele & Brysbaert, 2002) giving strong feedback from the lexical to the sub-lexical level (Pecher, 2001). In addition, only L2 primes were used. It is possible that this gave additional activation to the L2 language node, thereby strengthening the priming effects. Though, if these studies reflect L2-L1 sub-lexical priming, this cannot be accommodated by the DRC and CDP++ model because they do not have a bilingual extension to explain cross-linguistic priming from L2 to L1 (Coltheart et al., 2001; Mousikou et al., 2010; Perry et al., 2007, 2010). The BIA+ model, however, does assume non-selectivity at both the lexical and the sub-lexical level and can therefore accommodate the above findings (Dijkstra & Van Heuven, 2002).

In the present study, L1 (Russian) and L2 (English) primes are randomly intermixed to investigate whether the phonology corresponding to the language of the word will be activated on a trial-by-trial basis. In addition, we avoided special words such as cognates and only the onset letter of the prime-target pairs were matched to avoid possible overlap from a lexical level that might give feedback to the sub-lexical level. Further, cross-script priming is used in the present study to have a clear distinction between the GPC rules for the L1 and the L2. In Russian (Cyrillic alphabet) and English (Roman alphabet), there are five graphemes (i.e. <P>, <H>, <X>, <C>, <B>) that share the same orthographic symbol, but have different phonological values (pronounced in Russian as /r/, /n/, /h/, /s/ and /v/, respectively). This conflicting situation in grapheme-to-phoneme mapping offers us the possibility to disentangle the phonological activation of two languages.

Thus, in the present study, we investigated whether L1 and L2 phonology are activated rapidly in concurrence and whether the phonology corresponding to the language of the word was activated. Russian (L1) – English (L2) bilinguals read aloud L1 target words primed with either L1 or L2 words. For the Russian primes (L1), we expected to find faster response latencies for the matching condition (e.g. O+P+: *РАНА* /rana/ 'wound' – *РЕЙС* /reis/ 'flight') than the mismatching condition (e.g. O−P−: *КАРА* /kara/ 'punishment' – *РЕЙС* /reis/ 'flight') because in the O+P+ condition prime and target both follow the L1 GPC rules (e.g. <P> as /r/). This is in line with previous findings showing within-linguistic MOPE (e.g. Kinoshita, 2000, 2003; Kinoshita & Woollams, 2002; Malouf & Kinoshita, 2007; Schiller, 2004, 2008). For the English primes, we did not expect to find differences in the response latencies between the orthographic-match condition (e.g. O+P−: *PACK* – *РЕЙС* /reis/ 'flight') and the mismatching condition (e.g. O−P−: *HOPE* – *РЕЙС* /reis/ 'flight') because in the O+P− condition the prime follows the L2 GPC rules (e.g. <P> as /p/) and target both follow the L1 GPC rules (e.g. <P> as /r/) and the MOPE has been shown to be phonological, and not orthographic, in nature (Mousikou et al., 2010; Schiller, 2007; Timmer & Schiller, 2012). Further, unlike non-word priming, which are read according to L1 GPC rules (e.g. Carreiras, Perea, Vergara, & Pollatsek, 2009), the L2 prime in this study is expected to be read according to the L2 GPC rules (e.g., <P> as /p/), which contrasts with the L1 GPC rules used for the L1 target (e.g., <P> as /r/). Thus, if the prime is read as a non-word, phonological facilitation is expected (e.g. O+P−: *PACK* /rask/ – *РЕЙС* /reis/ 'flight'). However, if the prime is processed as an L2 word, no priming should be observed (e.g. O+P−: *PACK* /pak/ – *РЕЙС* /reis/ 'flight').

In addition to the behavioral measure, the online electrophysiological measure can reveal the absolute time course of GPC. A typical component that is associated with masked priming experiments is a so-called N250 component (e.g. Carreiras et al., 2009; Grainger, Kiyonaga, & Holcomb, 2006; Grainger & Holcomb, 2009; Holcomb & Grainger, 2006; Midgley, Holcomb, & Grainger, 2009). The N250 is suggested to be sensitive to the GPC process (Grainger & Holcomb, 2009). As mentioned above, behavioral studies have revealed that masked priming is phonological in nature (Mousikou et al., 2010; Schiller, 2007; Timmer & Schiller, 2012), however, recent EEG studies showed both early orthographic and phonological activation during LDT (Carreiras et al., 2009) and reading aloud (Timmer et al., 2012; Timmer & Schiller, 2012; Timmer et al., submitted). Orthographic priming effects have been demonstrated between approximately 150 ms and 250 ms, which corresponds with the N250 window, after target presentation during silent reading (e.g. Carreiras et al., 2009; Grainger et al., 2006; Holcomb & Grainger, 2006) and between 120 and 180 ms after target presentation during reading aloud (Timmer et al., submitted; Timmer & Schiller, 2012). If these within-linguistic priming results translate to cross-linguistic priming, we expect to see an orthographic effect in the early time window of the N250 because a reading-aloud task is employed.

To conclude, the expected results for the current study would support the idea of non-selectivity of the L1 and L2 not only at the lexical level, but also at the sub-lexical level. In addition, differential ERP waveforms for the English primes may give additional support to the early sub-lexical effects.

Method

Participants

Twenty-four participants (six males; mean age = 26.3, SD = 5.26) took part in the experiment. All were native speakers of Russian with English as a second language. All participants had normal or corrected to normal vision and no one reported dyslexia or other language or neurological disorders. Participants received a financial reward for their participation in the experiment. Data of three participants were discarded due to noisy EEG recordings. Thus, the final analysis was based on the data of 21 participants.

All participants were proficient in English. Their mean self-reported score was 8.3 out of 10; the mean X-Lex score was 3,548 out of 5,000 (SD = 999.8) on the Meara (2005) English proficiency lexical decision test. A self-rating proficiency questionnaire revealed the mean age of first contact with English to be at 8.4 years occurring at school or language courses. They had an average of 18 years of learning experience and had resided in the Netherlands for about 37 months, SD = 53.59. All participants spent an average of 63% of their time using English for study or work purposes.

Materials

Forty Russian target words were each paired with two English and two Russian priming conditions. Thus, the experiment included 160 trials in total and 40 trials per condition. The Russian target words had one of only four possible onset graphemes, which have a different orthography-to-phonology mapping in the two languages (<B>, <C>, <H>, and <P> pronounced in Russian as /v/, /s/, /n/, and /r/, respectively). All primes consisted of letters common to both the Roman and Cyrillic alphabets in order to avoid orthographic cues, which could indicate the language of the prime. Thus, only 11 letters were used to compose the primes, i.e., <E>, <T>, <O>, <P>, <A>, <H>, <K>, <X>, <C>, <B>, <M>. Letter sequences, which are illegal either in Russian or in English, were not used, such that the primes could be read as words in one language as well as pronounceable non-words in the other language. Letter sequences which are legal, but infrequent in one of the languages, were also avoided whenever possible. All target and prime words had simple onsets (one consonant before the first vowel) since previous studies obtained inconsistent results with complex onsets (Kinoshita, 2000; Schiller, 2004). All primes and targets were presented in upper-case letters. This was done because lower-case letters are written differently in the two alphabets. This may have led to early lower-level visual effects, which are normally avoided by using lower case for primes and upper case for targets. However, for the present study, potential lower level visual effects are comparable in both comparisons, and therefore should have the same, if at all, effects across conditions.

Targets and primes were singular nouns of one to two syllables, and were four to six letters long. Prime words were matched for frequency per million, length and number of syllables across conditions and with the target words (see Table 1). The frequency of the English primes was based on the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995). The frequency of Russian targets and primes was based on the Frequency Dictionary of Contemporary Russian (Lyashevskaya & Sharoff, 2008) except for four words, which were absent from the dictionary. Frequency for these words was taken from the old version of the same frequency dictionary (Sharoff, 2003).

Table 1. Mean word frequency per million, word length in letters, and number of syllables per condition.

Language	Condition	Frequency (SD)	Length (SD)	Syllables (SD)
Russian	**Target**	20.45 (21.63)	4.70 (0.94)	1.90 (0.59)
Russian	**O+P+**	26.36 (36.79)	4.63 (1.00)	2.00 (0.39)
Russian	**O–P–**	24.35 (45.48)	4.73 (0.82)	1.90 (0.50)
English	**O+P–**	24.05 (24.73)	4.50 (0.99)	1.38 (0.59)
English	**O–P–**	24.58 (31.99)	4.45 (0.88)	1.38 (0.54)

The following four priming conditions were created: 1) Russian prime, matching onset in both orthography and phonology (e.g., O+P+: *PAHA* /rana/ 'wound' – *РЕЙС* /reis/ 'flight'; Russian grapheme- and phoneme-match condition); 2) Russian prime, mismatching onset in both orthography and phonology (e.g., O–P–: *КАРА* /kara/ 'punishment' – *РЕЙС* /reis/ 'flight'; Russian grapheme- and phoneme-mismatch condition); 3) English prime, onset match in orthography, but not phonology (e.g., O+P–: *PACK* – *РЕЙС* /reis/ 'flight'; English phoneme-mismatch condition); 4) English prime, mismatching onset in both orthography and phonology (e.g., O–P–: *HOPE* – *РЕЙС* /reis/ 'flight'; English grapheme- and phoneme-mismatch condition). Note, that since we were limited to only 11 letters that were common to both the Roman and Cyrillic alphabets, it was impossible to create O–P+ condition for the Russian primes and therefore we could not disentangle orthographic and phonological activation from each other. The complete list of stimuli can be found in the Appendix.

Design and Procedure

Each participant was seated approximately 1 meter from a computer screen. For the experimental task, the participants were instructed to read aloud the Russian target words as quickly and accurately as possible. Their response latencies were measured with a voice-key and in addition their EEG was recorded on-line. The English proficiency level of the participants was measured with a self-rating proficiency questionnaire for the English language (before the experiment; see Table 2 for an overview) and a lexical decision task (Meara, 2005; after the experiment).

The experimental task started with a practice block to familiarize the participants with the task and to check the working of the voice-key. The experimental task was divided into four blocks, each consisting of the forty experimental target words. The four blocks of prime-target pairs were created in such a way that none of the blocks contained the same prime or target twice and that it contained an equal number of trials from each condition. Both the order of blocks and the order of the target words within each block were randomized for each participant. The participants could take a brief break in-between the four blocks.

Each trial consisted of the following sequence: a fixation mark ('+'; between 400 to 700 ms), a forward mask of seven hash marks ('#'; 500 ms), the English or Russian prime word (48 ms), a

Table 2. Mean answers (and standard deviations) to self-rating proficiency questionnaire (range: 0-10 or 100%) and the proficiency test (range: 0-5,000) of Meara (2005).

	Means	(SD)
Age starting to learn English	8.0	(2.75)
Active skills	8.0	(1.13)
Passive skills	8.4	(0.96)
% of speaking English during a day	61.9	(28.87)
% of reading English during a day	67.9	(30.36)
% of listening English during a day	58.1	(26.24)
LDT score (0 – 5000; Meara, 2005)	3,550	(1,037.30)

backward mask of seven hash marks ('#'; 17 ms), and the Russian target word. The target word disappeared from the screen when a response was given or a maximum of 2s had elapsed. The trials were separated by a blank screen (1s). All items were presented in black upper-case letters on a white background in the center of the screen. They were presented in Courier New with a font size of 18.

Apparatus and Data Acquisition

The BioSemi ActiView software was used to register the EEG signal from thirty-two electrode sites arranged in the 10/20 system. Further, six external electrodes of the flat type were applied to record: 1) eye-blinks (one electrode above and one below the left eye), 2) horizontal eye-movement (one to the external canthi of each eye), 3) offline re-referencing (an electrode placed at each mastoid). All electrodes were of the Ag/AgCl type and the EEG signal was sampled at a rate of 512 Hz.

Data Analysis

The EEG signal was filtered with a high-pass filter of 0.01 Hz/24 dB and a low-pass filter of 40 Hz/24 dB. The Gratton, Coles and Donchin (1983) algorithm was used to correct the ocular artifacts. Other artifacts were removed based on the following criteria: trials with amplitudes below –200 µV, above +200 µV, or including a voltage step of 50 µV within 200 ms. Further, epochs of 600 ms time-locked to the onset of the target word were created. A 200 ms pre-stimulus baseline between –300 ms and –100 ms was applied to avoid prime processing during the baseline correction. The ERP grand averages were calculated separately for each of the four conditions over participants.

Results

Behavioral Data

Naming latencies shorter than 200 ms and longer than 1,000 ms (0.12% of the data) were counted as outliers and excluded from the RT analysis. Voice key errors (1.13% of the data) and incorrect responses (0.09% of the data) were also excluded. Due to the low error rate, no statistical analysis was carried out on the error trials.

Two mixed-effects model analyses were carried out, one for the English primes (O–P–: grapheme- and phoneme-mismatch vs. O+P–: grapheme-match) and another for the Russian primes (O–P–: grapheme- and phoneme-mismatch vs. O+P+: grapheme-match). In both analyses, participants and target items were included concurrently as random factors (Brysbaert, 2007; Quené & Van den Bergh, 2008). To remove the intrinsic positive skew and the non-normality of the distribution, a logarithmic transformation was applied to the RTs (Keene, 1995; Limpert, Stahel, & Abt, 2001; Quené & Van den Bergh, 2008).

For the Russian primes, the grapheme- and phoneme-match (O+P+) condition yielded response latencies that were 11 ms faster compared to the grapheme- and phoneme mismatch (O–P–) condition ($F(1,1590) = 11.35$, $p < .005$, $\eta_p^2 = .410$). For the English primes, the was no difference in response latencies between the grapheme-match but phoneme-mismatch (O+P–) condition and the grapheme- and phoneme mismatch (O–P–) condition ($F(1,1591) = 1.87$, *ns*, $\eta_p^2 = .048$). For an overview of the RTs and error rates see Table 3.

Table 3. Mean response latencies in ms (and standard error) per condition over all participants.

Language	Condition	RT (SE)	error %
Russian	**O+P+**	570 (11.71)	0.09
Russian	**O–P–**	581 (11.71)	0.44
English	**O+P–**	578 (12.68)	0.16
English	**O–P–**	581 (12.68)	0.28

Electrophysiological Data

Trials that were considered artifacts were removed from the analysis (16.13% of the data). The number of kept trials was on average 34 trials (SD = 4.8) and equally distributed over the conditions.

The 125-200 ms time window was determined based on visual inspection of the grand averages. Note that our timing is slightly earlier than previous visual word recognition research (e.g., Carreiras et al., 2009; Grainger et al., 2006; Holcomb & Grainger, 2006). The difference is most likely due to task differences since the chosen time window is similar to previous reading aloud studies (Timmer et al., 2012; Timmer & Schiller, 2012). The mean amplitudes for this time window were submitted to repeated measures ANOVAs. Similar to behavioral analysis, Russian and English primes were analyzed separately. The Greenhouse-Geisser correction was applied. Both for the English and the Russian primes, two ANOVA's were run. One ANOVA was run with Condition (match vs. mismatch) and Localization (anterior: AF3, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, vs. posterior: PO3, PO4, P7, P3, Pz, P4, P8, CP5, CP1, CP2, CP61) as independent factors. A separate ANOVA was run with Lateralization (left: AF3, F3, F7, FC1, FC5, C3, T7, CP1, CP5, P3, P7, PO3, vs. right: AF4, F4, F8, FC2, FC6, C4, T8, CP2, CP6, P4, P8, PO4) as an independent factor instead of Localization. ERP waveforms for the English and Russian primes can be found in Figures 1 and 2, respectively.

125-200 ms

English primes. The analysis revealed larger positive amplitudes for the grapheme- and phoneme-mismatch condition (O–P–: *HOPE – РЕЙС* /reis/ 'flight') than the grapheme-match condition (O+P–: *PACK – РЕЙС* /reis/ 'flight'; $F(1,20) = 5.10$, $MSe = 19.59$, $p < .05$). The interaction between Condition and Localization was not significant ($F(2,40) = 1.90$, $MSe = 7.17$, *ns*). There was also no interaction between Condition and Lateralization ($F < 1$).

Russian primes. There was no main effect of Condition ($F < 1$). The interactions with spatial factors Localization and Lateralization were not significant (both *Fs* < 1).

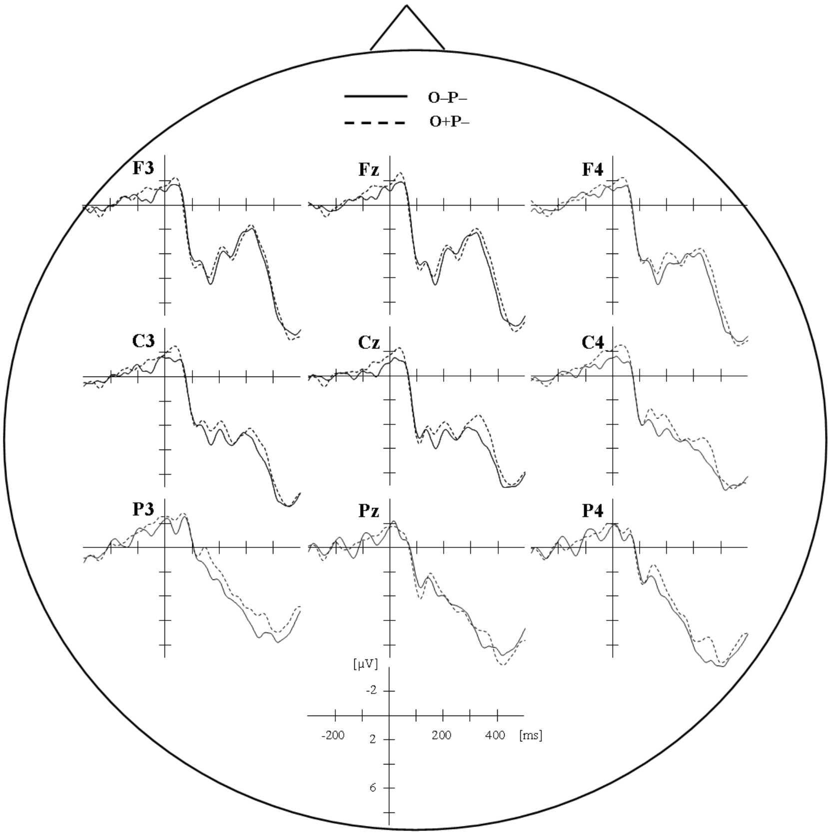

Figure 1. Averaged stimulus-locked ERP waveforms displaying the two English prime conditions: 1) grapheme- and phoneme mismatch (O–P–; solid black lines; e.g., *HOPE – РЕЙС* /reis/ 'flight'); 2) grapheme match (O+P–; dashed black lines; e.g., *PACK – РЕЙС* /reis/ 'flight').

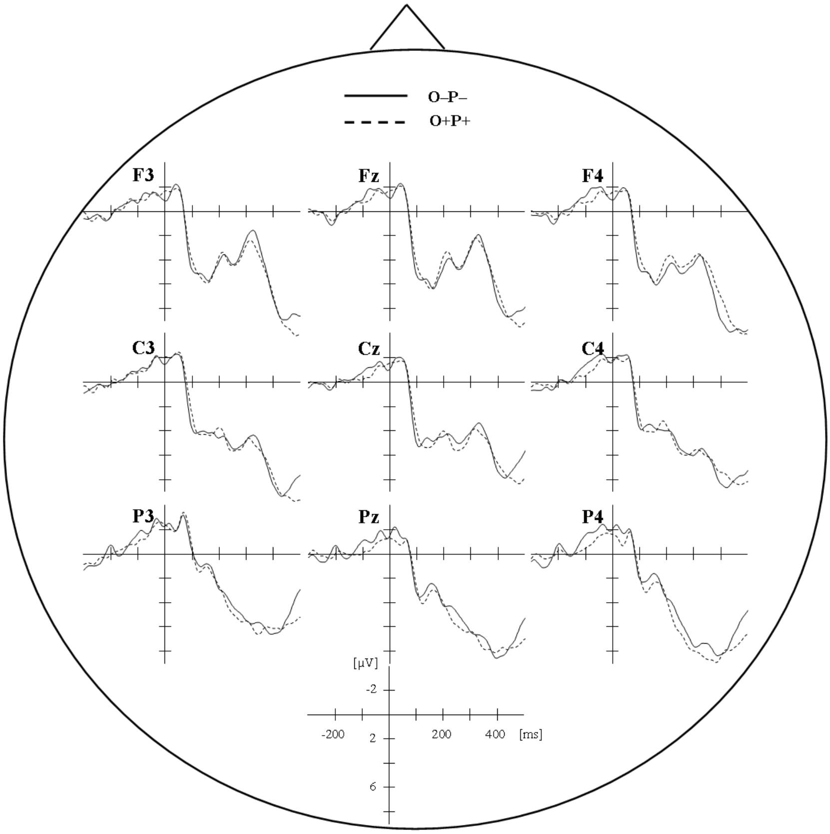

Figure 2. Averaged stimulus-locked ERP waveforms displaying the two Russian prime conditions: 1) grapheme- and phoneme mismatch (O–P–; solid black lines; e.g., *КАРА* /kara/ 'punishment' – *РЕЙС* /reis/ 'flight'); 2) grapheme match (O+P+; dashed black lines; e.g., *РАНА* /rana/ 'wound' – *РЕЙС* /reis/ 'flight').

Discussion

The current study investigated whether both L1 and L2 sub-lexical phonological representations of a bilingual are rapidly and automatically activated during an L1 reading aloud task. As expected, the behavioral results revealed a priming effect for the Russian (L1) primes but not for the English (L2) primes. For the Russian primes, we found faster response latencies in the O+P+ condition (e.g. *РАНА* /rana/ 'wound' – *РЕЙС* /reis/ 'flight') than in the O–P– condition (e.g. *КАРА* /kara/ 'punishment' – *РЕЙС* /reis/ 'flight'). Because prime-target pairs had both orthographic and phonological overlap, it cannot be determined whether the effect is phonological or orthographic or both in nature. However, earlier studies have shown that the effect has a phonological basis (e.g. Mousikou et al., 2010; Schiller, 2007; Timmer et al., 2012; Timmer & Schiller, 2012). Therefore, it is not surprising that for the English primes, response latencies between the O+P– condition (e.g. *PACK – РЕЙС* /reis/ ‘flight’) and the O–P– condition (e.g. *HOPE – РЕЙС* /reis/ ‘flight’) did not differ.

The absence of orthographic priming in the present study suggests that the prime in the L2 O+P– condition (e.g. *PACK – РЕЙС* /reis/ ‘flight’) was processed according to the L2 GPC rules (e.g., <P> as /p/), which mismatches with the target where the L1 GPC rule is applied (e.g., <P> as /r/). If the prime was processed as an L1 non-word, instead of an L2 word, we should have found a facilitation effect, since there would be not only orthographic overlap but also a phonological overlap between prime and target (i.e. *PACK* would have been read as /rask/). Previous research showed that non-word primes behave similarly to L1 word primes (e.g. Carreiras et al., 2009). Therefore, taken together our results, suggest that the L1 and L2 phonologies are co-activated but that the phonology which matches an existing word rapidly dominates the one that does not match an existing word, by means of top-down interactions (see Drieghe & Brysbaert, 2002). Thus, when a phoneme activates multiple phonological representations a verification check is initiated to select the appropriate representation.

The DRC model (Coltheart et al., 2001; Mousikou et al., 2010) and the CDP++ model (Perry et al., 2007, 2010) cannot explain our behavioral results because the model only takes L1 GPC rules or grapheme-phoneme correspondences into account. Therefore, the DRC and the CDP++ model can explain the facilitation for the Russian primes (L1-L1) but not the absence of facilitation for the English primes (L2-L1) because if only the L1 GPC rules are automatically activated, the English primes should be read as Russian nonwords and thus the L2 O+P– condition would become an L1 O+P+ condition (e.g. *PACK* as a Russian nonword becomes /RASK/) and facilitation compared to the O–P– condition should be observed. Our results show no such facilitation. This suggests that both pronunciations (/r/ and /p/) are activated, however the phoneme corresponding to the real word gets boost in activation (compared to a phoneme corresponding to a non-word) and consequently is selected (Drieghe & Brysbaert, 2002; Luketa & Turvey, 1994). These results provide support for non-selective sub-lexical phonological processing, of both the L1 and L2, during word reading in bilinguals. All models of reading (aloud) should include L1 and L2 GPC rules. Thus, the DRC model needs to incorporate an extension for L2 GPC rules. A simple extension to the non-lexical route and the lexical-route would suffice. In the non-lexical route, L2 GPC rules that deviate from the L1 GPC rules should activate multiple print-to-sound-associations, one for each language (e.g. <P>: /p/ in English and /r/ in Russian). This multilingual print-to-sound-association rule would be similar to context-sensitive rules (e.g., <c> is pronounced differently depending on the following letter) included in the GPC rules of the non-lexical route in the DRC model (Dijkstra & Van Heuven, 2002). In the lexical route, not only L1 words, but also the L2 words, should be included to create a bilingual lexicon similar to the BIA+ model (Dijkstra & Van Heuven, 2002; Van Wijnendaele & Brysbaert, 2002).

The BIA+ model not only suggests a bilingual lexicon but also bilingual sub-lexical activation (Dijkstra & Van Heuven, 2002). They suggest rapid sub-lexical conversion from orthography to phonology for both L1 and L2. However, due to feasibility issues phonological codes have not been implemented yet. The present results show the importance of implementing phonology in the model. For the present results, the simultaneous activation of both L1 and L2 GPC rules means that for the grapheme <P>, two print-to-sound-associations are activated, namely /r/ for Russian and /p/ for English. For the Russian prime in the match condition (e.g. *PAHA* /rana/ ‘wound’), the /r/ phonology dominates, and for the English prime in the match condition (e.g. *PACK*), the /p/ phonology dominates. This explains the facilitation for the Russian primes, which match in phonology (e.g., *PAHA* /rana/ ‘wound’), but not the English primes (e.g. *PACK*), which do not match in phonology, to the target word (e.g. *РЕЙС* /reis/ ‘flight’). Because previous research has revealed that the MOPE is phonological in nature (e.g., Mousikou et al., 2010; Timmer et al., 2012; Timmer & Schiller, 2012), the current results support two cross-linguistic print-to-sound-associations.

Furthermore, the behavioral results are in line with previous studies on cross-linguistic L2-L1 priming using a blocked design in which all primes were in the L2 (e.g., Dimitropoulou et al., 2011a; Van Wijnendaele & Brysbaert, 2002). In the present study, both L1 and L2 primes were intermixed, which shows that the phonology belonging to the language of the prime is activated and selected on a trial-by-trial basis. The advantage of cross-script languages used in the present experiment was also used by Dimitropoulou and colleagues (2011a). They revealed cross-script phonological L2-L1 priming in Greek-Spanish bilinguals but no priming when phonology *and* orthography overlapped. This seems contradictory to the present findings, however, upon closer inspection it is clear that the two studies have different comparisons. First, Dimitropoulou and colleagues reveal facilitation for prime (L2)- target (L1) pairs that match in phonology. In the present experiment, we do not find facilitation because we look at a match in orthography and not phonology for L2-L1 priming. Second, for the O+P+ vs. O–P– comparison, Dimitropoulou and colleagues do not show facilitation and suggest that the advantage of phonological overlap is eliminated when orthography also overlaps to a large extend. In the present study, we find significant facilitation for the O+P+ vs. O–P– comparison. Note, however, that Dimitropoulou and colleagues’ comparison was cross-linguistic (L2-L1) though ours is within-linguistic (L1-L1). This is in line with previous literature where significant priming effects have been reported when both orthography and phonology overlap during reading aloud (e.g., Forster & Davis, 1991; Horemans & Schiller, 2004) and during visual word recognition (e.g., Carreiras et al., 2009).

Taken together, our behavioral results suggest that during reading aloud sub-lexical orthographic and phonological representation of both L1 and L2 are rapidly activated. However, we cannot exclude that the present results are modulated by an effect of language. The priming effect for O+P+ vs. O–P– comes from a within-language comparison (L1-L1), though the absence of an orthographic priming effect between O+P– vs. O–P– comes from a between language comparison (L2-L1). Switching languages between prime and target is suggested to reflect higher processing costs than when prime and target are from the same language (i.e. masked code-switching). For example, Dimitropoulou and colleagues (2011b) investigated masked code-switching in a LDT task, where Greek-Spanish bilinguals read L1 target words preceded by two related conditions (L1 repetition prime and L2 translation prime of the target) and two unrelated conditions (L1 and L2). The study showed 27 ms slower response latencies for the between-language conditions (L2-L1) compared to the within-language conditions (L1-L1). If we look closer at the data, we see that the code-switching effect is driven by the related conditions, where the between-language condition is 53 ms faster than the within-language condition. However, in the unrelated conditions, the difference between the between- and within language condition was only 1 ms. This is similar to our finding where both the unrelated conditions in the L1-L1 and L2-L1 show an RT of 581 ms. Therefore, it seems the masked code-switching effect is not as straight forward as suggested and might be affected by more factors than only language; e.g., degree of semantic overlap between target and prime. Thus, we believe that our results are unlikely to be due to a language effect.

In addition to the behavioral results, we also collected ERP data. Contrary to our expectations, we found no ERP differences for the Russian prime (L1) comparison (O+P+ vs. O–P–). We would like to tentatively propose here that opposing effects of both orthographic and phonological co-activation in the O+P+ condition might cause the absence of the priming effect in the ERPs for the Russian comparison. However, for the English primes, the ERPs revealed less positivity for the O+P– condition than the O–P– condition in the 125-200 ms ERP time window. This result corresponds with early sub-lexical orthographic within-language priming between 120-180 ms during a masked priming reading-aloud task (Timmer & Schiller, 2012). The timing of these priming effects is slightly earlier than during visual word recognition where orthographic priming is found approximately between 150-250 ms after target presentation (e.g., Carreiras et al., 2009; Grainger et al., 2006; Holcomb & Grainger, 2006).

The orthographic priming effect found in the present study suggests that the GPC process has an early locus in the non-lexical route of the DRC model (Coltheart et al., 2001; Mousikou et al., 2010). The timing is in line with a meta-analysis of reading suggesting GPC occurs about 150-330 ms after target presentation (Indefrey & Levelt, 2004; Indefrey, 2011). Masked priming studies in Persian and English also revealing voltage deflection in this early time window (Timmer et al., 2012; Timmer & Schiller, 2012) corroborate that the MOPE, which reflects the GPC process, has an early locus. Thus, these results provide additional evidence against a late locus of the GPC process, suggested by the speech-planning account to take place during the preparation of the speech plan (Kinoshita, 2000; Kinoshita & Woollams, 2002). If this were the case, the ERP signal would be affected approximately between 330 ms and 600 ms (Indefrey & Levelt, 2004; Indefrey, 2011). In addition, our ERP results are in line with a rapid verification stage, which could be initiated when multiple phonological representations correspond to one orthographic representation (e.g. <P>: /p/ in English and /r/ in Russian; see also Drieghe & Brysbaert, 2002

Similar to our behavioral results, we also investigated whether our ERP data was affected by the language manipulation rather than by phonological activation. Chauncey and colleagues (2008, 2011) found that masked code-switching effects affected the N400 for L1 targets, and also the N250 for L2 targets during a semantic categorization task. Duñabeitia and colleagues (2010) found that the N250 was also modulated when targets were in the L1. To investigate whether there was a masked code-switching effect in the present study, we compared the unrelated conditions of the L1-L1 and the L2-L1 prime-target pairs. We did not show an effect of language switching between prime and target in the 125-200 ms time window (both Localization and Lateralization $F < 1$) nor an interaction with location (respectively, $F < 1$ and $F(1,20) = 1.22$, $MSe = 1.62$, *ns*). This suggests that it is unlikely that the language manipulation modulated the results in the present study. The discrepancy between our results and the studies mentioned above could be due to different reasons. For example, the present study used reading aloud and the other studies used a semantic categorization task (Chauncey et al., 2008, 2011; Duñabeitia et al., 2010). Also, Chauncey and colleagues (2008, 2011) showed that masked code-switching effect was not as clear for the 50 ms prime duration as for the 100 ms prime duration. In the present study, we used a 48 ms prime presentation. The differences in masked code-switching effects are an interesting line for further investigation; however, in the present data, we find no evidence for the masked code-switching effects.

To conclude, the present data suggest rapid and automatic activation of the sub-lexical phonology of both the L1 and the L2 whereby the phonological representation belonging to the language of the word is selected supporting computational models of reading that suggest non-selective processing not only at the lexical level, but also at the sub-lexical level. The present computational models of visual word recognition should also account for GPC rules or grapheme-phoneme correspondences from multiple languages within one system. This means that the DRC model should extend their L1 GPC rules with a set of L2 GPC rules and that the CDP++ model should incorporate multiple languages such that the model can learn different grapheme-phoneme correspondences depending on the language of the prime. The ERP results seem to suggest that the language of a masked prime is recognized at an early stage, during the non-lexical route, and not during speech-preparation.

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Appendix

Target	Russian primes		English primes	
	O+P+	**O–P–**	**O–P+**	**O–P–**
ВИНО /vʲɪno/ ‘wine’	ВЕРА /ˈvʲerə/ ‘faith’	ТЕМА /ˈtʲemə/ ‘topic’	BOOT	TAPE
ВИНА /vʲɪˈna / ‘guilt’	ВАТТ /vat/ ‘watt’	КОРТ /kort/ ‘court’	BOOM	TOMB
ВЕРХ /vʲerx/ ‘top’	ВАТА /ˈvatə/ ‘cotton wool’	ХАОС /ˈxaəs/ ‘chaos’	BATH	PACT
ВЕКТОР /ˈvʲektər/ ‘vector’	ВАРЕВО /ˈvarʲɪvə/ ‘brew’	МАРЕВО /ˈmarʲɪvə/ ‘mirage’	BATCH	TOMATO
ВОЛЯ /ˈvolʲə/ ‘will/freedom’	ВЕКО /ˈvʲekə/ ‘eyelid’	КАРЕ /kɐˈrɛ/ ‘bob(haircut)’	BEAM	TEXT
ВУЛКАН /vʊlˈkan/ ‘volcano’	ВОСТОК /vɐsˈtok/ ‘east’	НАРОСТ /nɐˈrost/ ‘growth/gnarl’	BAMBOO	TATTOO
ВОИН /ˈvoɪn/ ‘warrior’	ВЕНА /ˈvʲenə/ ‘vein’	НАЕМ /nɐˈjəm/ ‘recruitment’	BEAK	MEAT
ВАННА /ˈvannə/ ‘bath-tub’	ВОРОТ /ˈvorət/ ‘collar’	МОТОР /mɐˈtor/ ‘engine’	BEACH	TEMPO
ВАМПИР /vɐmˈpʲir/ ‘vampire’	ВЕРЕСК /ˈvʲerʲɪsk/ ‘heather’	КОСМОС /ˈkosməs/ ‘space’	BOOTH	MOCHA
ВАЗА /ˈvazə/ ‘vase’	ВЕТО /ˈvʲetə/ ‘veto’	ТЕСТ /tɛst/ ‘test’	BOAT	MOCK
НЯНЯ /ˈnʲæ nʲə/ ‘nanny’	НЕОН /nʲɪˈon/ ‘neon’	ТОРТ /tort/ ‘cake’	HEAP	BOMB
НЕРВ /nʲerf/ ‘nerve’	НОТА /ˈnotə/ ‘note’	МОСТ /most/ ‘bridge’	HOOK	TACT
НИМБ /nʲimp/ ‘halo’	НОРА /nɐˈra/ ‘hole’	КОРА /kɐˈra/ ‘bark’	HACK	PATE
НУЖДА /nʊʐˈda/ ‘need’	НОСОК /nɐˈsok/ ‘sock’	КАТЕР /ˈkatʲɪr/ ‘motor boat’	HEATH	CACHE
НИТКА/ˈnʲitkə/ ‘thread’	НАСОС /nɐˈsos/ ‘pump’	ТЕСТО /ˈtʲestə/ ‘dough’	HEMP	PATCH
НЕГОДЯЙ / nʲɪgɐˈdʲaj/ ‘scoundrel’	НОВАТОР /nɐˈvatər/ ‘innovator’	ТАРАКАН /tərɐˈkan/ ‘cockroach’	HAMMOCK	COMPOTE
РУДА /rʊˈda/ ‘ore’	РОСТ /rost/ ‘height’	ТАКТ /takt/ ‘tact’	PEAK	TEAM
РИТМ /rʲitm/ ‘rhythm’	РОСА /rɐˈsa/ ‘dew’	КОСА /kɐˈsa/ ‘plait/bar’	PACE	COOK
РИСК /rʲisk/ ‘risk’	РОТА /ˈrotə/ ‘troop’	ВЕХА /ˈvʲexə/ ‘milestone’	POEM	CAMP
РЕЕСТР /rʲɪ’jestr/ ‘register’	РАМКА /ˈramkə/ ‘frame’	МАСКА/ˈmaskə/ ‘mask’	POCKET	MAMBA
РУКАВ /rʊˈkaf/ ‘sleeve’	РОТОР /ˈrotər/ ‘rotor’	МЕРКА ˈmʲerkə/ ‘measure’	PEACH	COMBO
РЕЗЬБА /rʲɪzʲˈba/ ‘carving’	РАСКАТ /rɐsˈkat/ ‘roll’	КАРМАН /kɐrˈman/ ‘pocket’	PACKET	TOOTH

Continuation of Appendix

Target	Russian primes		English primes	
	O+P+	O–P–	O–P+	O–P–
РИНГ /rʲink/ ‘boxing ring’	РАМА /'ramə/ ‘frame’	МЕРА /'mʲerə/ ‘measure’	POET	BABE
РЕЙС /rʲejs/ ‘trip/flight’	РАНА /'ranə/ ‘wound’	КАРА /'karə/ ‘punishment’	PACK	HOPE
РОЖЬ /roʂ/ ‘rye’	РАСА /'rasə/ ‘race’	МАРТ /mart/ ‘March’	PATH	BATE
РАДАР /rɐ'dar/ ‘radar’	РОКОТ /'rokət/ ‘roll/boom’	ВЕТКА /'vʲetkə/ ‘branch’	PEACE	BEAT
РЕМОНТ /rʲɪ'mont/ ‘repair’	РАКЕТА /rɐ'kʲetə/ ‘rocket’	МАНЕРА /mɐ'nʲerə/ ‘manner’	POTATO	BOTTOM
РАГУ /rɐ'gu/ ‘haricot’	РЕКА /rʲɪ'ka/ ‘river’	ТОСТ /tost/ ‘toast’	PEEP	MEMO
САЛО /'salə/ ‘bacon’	СЕРА/'sʲerə/ ‘sulphur’	МЕНА /'mʲenə/ ‘exchange’	COMA	MOTH
САЛАТ /sɐ'lat/ ‘salad’	СОТКА /'sotkə/ ‘acre; 100m2’	КОВКА /'kofkə/ ‘forging’	COMMA	POMP
СЕТКА /'sʲetkə/ ‘net’	СОВОК /sɐ'vok/ ‘scoop’	КАРАТ /kɐ'rat/ ‘carat’	COMET	TABOO
СЕНАТ /sʲɪ'nat/ ‘senat’	СОСНА /sɐ'sna/ ‘pine’	КАСКА /'kaskə/ ‘helmet’	COMB	MOTTO
СЕЛО /sʲɪ'lo/ ‘village’	СОВА /sɐ'va/ ‘owl’	ТАРА /'tarə/ ‘packaging material’	COCA	HATE
САТИРА /sɐ'tʲirə/ ‘satire’	СЕКТОР /'sʲektər/ ‘sector’	РЕКТОР /'rʲektər/ ‘rector’	COMBAT	KEBAB
САНИ /'sanʲɪ/ ‘sledge’	СОРТ /sort/ ‘sort’	КОМА /'komə/ ‘coma’	COAT	PECK
СЕКТА /'sʲektə/ ‘sect’	САВАН /'savən/ ‘grave-clothes’	КАТОК /kɐ'tok/ ‘ice rink’	CACAO	POKE
САБЛЯ /'sablʲə/ ‘sword’	СЕВЕР /'sʲevʲɪr/ ‘north’	МЕТАН /mʲɪ'tan/ ‘methane’	COACH	MOTE
СИРОП /sʲɪ'rop/ ‘syrup’	СОНЕТ /sɐ'nɛt/ ‘sonnet’	КАССА /'kassə/ ‘cash desk’	CAKE	MATH
САЛЮТ /sɐ'lʲʉt/ ‘firework’	СОСКА /'soskə/ ‘pacifier’	МЕТКА /'mʲetkə/ ‘mark’	COKE	BEECH
СОКОЛ /'sokəl/ ‘falcon’	СЕНО /'sʲenə/ ‘hay’	МАССА /'massə/ ‘weight’	CAPE	MATE