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Activation of Non-Target Language Phonology During Bilingual Visual Word Recognition: Evidence from Eye-Tracking

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Abstract

Russian-English bilingual and English monolingual participants were tested on the Picture-Word Interference task modified for use with an eye-tracker. Distractor words were 1) non-words in English, but viable phonological words in Russian, 2) control bigram matched non-word stimuli, and 3) English translations of the Russian words. Russian-English bilinguals looked at the phonological Russian words more than monolingual participants, and took longer to name pictures accompanied by these stimuli than did monolingual participants. Proportion of eye-movements and reaction times to the other two types of distractor stimuli did not differ for the two groups. These results suggest that phonology of the non-target language is activated automatically during visual word recognition in the target language, even for written stimuli that do not carry orthographic information for the non-target language.

Introduction

The task of reading is hard enough when the reader reads in one language alone. In the case of a bilingual reader, the picture is even more complex: Not only does a bilingual reader need to process the written information in one language, but he or she may have to contend with information from his or her other language that also becomes activated. The activation of the non-target language during reading in the target language is implemented in the Bilingual Interactive Activation (BIA+) model of visual word recognition (Dijkstra & Van Heuven, 1998; 2002). The BIA+ model is a localist connectionist model with elements from both the dual-route models of reading (e.g., Coltheart et al., 1993; Coltheart et al., 2001; Ziegler et al., 2000) and the connectionist models of reading. (e.g., Plaut et al., 1996; Seidenberg and McClelland, 1989; Van Orden and Goldinger, 1994). The BIA+ model proposes that lexical access of a visually presented word in a bilingual is non-selective, i.e., when a word is presented, information for that word, both orthographic and phonological, is activated for both of the bilingual's languages.

Support for such non-selective processing of written information in bilinguals (i.e., activation of the non-target language orthography and/or phonology when involved in a

reading task requiring use of only the target language) has accumulated over the past three decades (e.g., De Groot, Delmaar, & Lupker, 2000; Nas, 1983; Van Heuven, 2000; Van Heuven, Dijkstra, & Grainger, 1998). Activation of non-target language phonological information has been reported for bilingual readers of languages with shared alphabets, such as English and French (Jared & Szucs, 2002), Dutch and English (Dijkstra, Grainger, & van Heuven, 1999), Spanish and Catalan (Costa, Miozzo, & Caramazza, 1999), and Dutch and French (Brysbaert, Van Dyck, & Van de Poel, 1999). Activation of phonological information for the non-target language has also been reported in the case of bilinguals who speak languages with entirely different alphabets, like Hebrew and English (Tzelgov et al., 1996). However, it is still largely unknown whether phonological information for the non-target language is activated when the letter string in the target language carries little resemblance to the non-target language orthography (but see Feldman & Turvey, 1983; Lukatela et al., 1978).

In this experiment, we used a modified Picture-Word Interference (PWI) task to test whether phonological information for Russian is automatically activated during processing of non-words in English. The stimuli were constructed to contain English-specific letters, but constitute viable phonological Russian words. Using head-mounted eye-tracking methodology, we examined Russian-English bilinguals' ability to control their eye-movements to distractor words in the PWI task when these words contained phonological, but not orthographic information for Russian. The proportion of eye-movements to the distractor word signified the degree to which Russian phonological information drew the participants' eye-movements, while the reaction times to naming the target picture stimulus signified the degree to which the Russian phonological word interfered with picture naming in English.

Eye-tracking technology has been used to explore parallel activation of the two languages known to a bilingual during auditory perception tasks (e.g., Marian & Spivey, 2003 a, b). Eye-tracking has also been widely used in research of reading (e.g., Reichle, Rayner, & Pollatsek, 1999; Starr & Rayner, 2001). Unlike automatic eye-movements observed

in response to spoken instructions, eye-movements in reading are thought to be under partial cognitive control. The E-Z Reader model of eye-movement control in reading (Reichle, 1998; Reichle et al., 1999) posits that prior to programming an eye-movement to a particular word, a familiarity check takes place, which indicates whether a word is likely to be recognized by a reader. During this familiarity check, a reader gains information on low-level properties of the word (Engbert, Longtin, & Kliegl, 2002), which causes partial activation of the lexicon (e.g., Deutsch et al., 2002; Starr & Rayner, 2001). Experimental evidence shows that readers obtain both orthographic information (Liu et al., 2002), and phonological information (Wong & Chen, 1999) from the word before it is fixated. Models of eye movement control during reading account only for monolingual reading and it is still largely unknown whether control of eye-movements during bilingual reading is accomplished in the same way.

Recent research with bilinguals suggests that phonological information for the non-target language is automatically activated when reading in the target language. However, phonological activation for the non-target language when reading in the target language has not yet been explored for bilingual speakers whose two languages have partially overlapping alphabets. For these speakers, letter strings with alphabet-specific symbols often contain phonologically meaningful information for the non-target language. Russian-English bilinguals are faced with exactly this type of alphabetic overlap (Figure 1). Given the properties of the Russian Cyrillic alphabet and the English Roman alphabet, it is possible to test whether phonology of the non-target language is activated when its orthography is only partially present in the target language letter string. Consider the word COBA, which is the Russian word for “owl.” COBA can be transcribed using the Roman alphabet, SAVA, which includes letters specific to the English alphabet. Letter strings like SAVA constitute phonological, but not orthographic, representations of Russian words. When they are presented to the Russian-English bilinguals, only phonology, but not orthography, associated with corresponding Russian words, should be activated.

The activation of the non-target Russian language during picture naming in English was measured using a modified PWI task. The objective of the PWI task is to name pictures, while ignoring the words also present on the screen. The interference from the distractor word is thought to arise due to the automatic reading of the word, which then interferes with selection of the appropriate name for the picture at the level of the lexico-semantic system. Thus, reading during this task is largely automatic; in fact, it is counter-productive to the successful and fast completion of the task. Unlike a classic PWI task, where a written stimulus is presented inside a picture, we separated the written stimulus and picture presentation, such that a picture was in one quadrant of the computer screen, while a written stimulus was in another quadrant of the computer screen. The instructions to the participants were the same as in the regular PWI task: To ignore the word, and name the picture. In the regular PWI task, these instructions do not prevent reading of the words because the words are presented inside

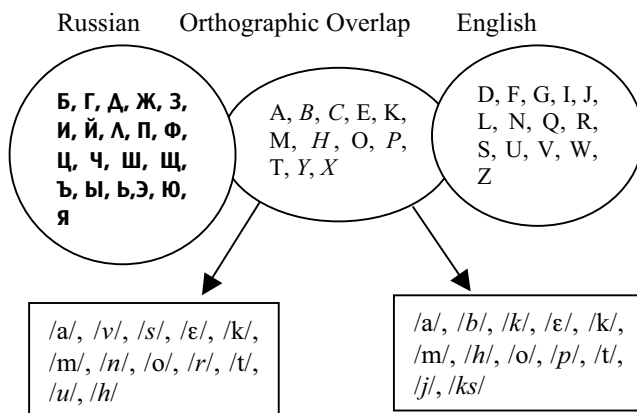


Figure 1: Overlapping symbols in orthographies of Russian and English, and the associated phonemes in each language.

the picture, and therefore, the participants necessarily look at them. In the modified PWI task, the word and the picture are in different locations on the screen so that the participant sees that there is a word, but does not need to look at it in order to recognize the picture. We tracked the participants’ eye-movements while they were completing the task in order to determine whether particular words drew more eye-movements than others.

Based on the models of cognitive control of eye movements in reading (Reichle, 1998; Reichle et al., 1999), the proportion of eye-movements to distractor stimuli during the modified PWI task should be indicative of the degree to which participants were able to control their eye-movements to the written stimuli. The stimuli presented as distractors on the PWI task words were 1) phonological Russian words, 2) English translations of the Russian stimuli, and 3) control stimuli (non-words in both Russian and English that were controlled for English bigram frequencies to equal phonological Russian stimuli). We hypothesized that if phonology of Russian is automatically accessed even when the orthographic shape of the word is not Russian (i.e., contains English-specific letter symbols), Russian-English bilingual readers will make more eye-movements to the phonological Russian words than the monolingual English speakers. Consequently, we hypothesized that if the phonological information for Russian activates the lexico-semantic information for Russian, Russian-English bilinguals will have longer reaction times to the pictures accompanied by the phonological Russian words than monolingual English speakers.

Methods

Participants

Fifteen Russian-English bilingual speakers (Mean Age=24.27 years, SD=4.80) and 15 English monolingual speakers (Mean Age=21.00 years, SD=4.68) participated in the experiment. All Russian-English bilingual participants were born in the former Soviet Union, and immigrated to the United States at a mean age 14.56 years (SD=5.35). All bilingual participants filled out a Language Experience and

Bilingual Status Questionnaire (LEABS-Q) at the end of the experiment. LEABS-Q is a comprehensive questionnaire containing questions about language proficiency, modes and ages of language acquisition, current language usage, etc. (Marian, Blumenfeld, and Kaushanskaya, 2003). Self-reported proficiency measures were later determined based on the participants' answers.

Reading fluency and reading comprehension were assessed by administering a passage reading task in English to the monolingual participants, and in English and Russian to the bilingual participants. When tested in English, bilingual participants were found to read orally with similar speed, $t(28)=0.94$, $p=0.36$, have as many errors while reading, $t(28)=0.75$, $p=0.46$, and comprehend as much of the content, $t(28)=0.96$, $p=0.35$, as the monolingual participants. For bilingual speakers, fluency of reading, $t(14)=1.89$, $p=0.08$, and comprehension of content, $t(14)=0.38$, $p=0.71$ were comparable for Russian and English. However, bilingual participants were significantly faster when reading in English ($M=2.71$ words/sec, $SE=0.12$) than in Russian ($M=2.12$ words/sec, $SE=0.11$), $t(14)=4.44$, $p<0.01$.

Design

Two dependent variables were considered: reaction time, and proportion of eye-movements to the word. The experiment followed a 4x2 Mixed Design with two independent variables – condition (no word, phonological Russian word, non-word control stimulus, and English word) as a within-subjects variable, and group (bilingual vs. monolingual) as a between subjects variable. For the proportion of eye-movements data, condition variable included only three levels (phonological Russian word, non-word control stimulus, and English word).

Materials

Twenty-three target pictures of common concrete objects were selected from the IMSI MasterClips picture database; all pictures were transformed into black-and-white drawings of equal size using PhotoShop.

Twenty-three words that were semantically related to picture names, i.e. belonged to the same superordinate category, were selected. The 23 words were then translated into Russian to create stimuli that were phonological representations of Russian words, spelled using the English alphabet. For instance, for the picture of a duck, the distractor word selected was *chicken*, which translates to YTKA in Russian, and yields UTKA when spelled using the English alphabet.

Control stimuli for the phonological Russian stimuli were constructed by creating non-words comparable to Russian phonological words in length and bigram frequencies. Paired-samples t-tests confirmed that Russian phonological stimuli ($M=4355.02$, $SE=2244.50$) and phonological controls ($M=4263.35$, $SE=2362.53$) were similar in their bigram frequencies ($t(22)=0.36$, $p>0.05$).

For each picture, there were 4 conditions: (1) picture – no word, (2) picture – English semantic distractor, (3) picture – phonological Russian semantic distractor, and (4) picture –

non-word control stimulus. The picture-no word condition was used as a baseline, to establish that eye-movements to words, if occurred, were due to the presence of the word in a particular location, and not to the location itself. For each condition, a panel divided into four quadrants was constructed – a picture was placed into the middle of one quadrant, and the word was placed into the middle of another quadrant. For each condition, a picture and all the words in the three conditions were placed in the same quadrants; the positions of pictures and words were counterbalanced across the four possible quadrants. To increase the time between target picture presentations, 16 filler picture stimuli were added to the experiment.

Apparatus

All stimuli were presented on a G5 Macintosh Monitor using SuperLab experimental software. Naming times were measured from the presentation of the picture to the onset of triggering the microphone response by the participant's voice. A headband-mounted ISCAN eyetracker was used to record participants' eye-movements during the PWI task. A scene camera, joined to the view of the tracked eye, provided an image of the participant's field of view. A second camera, which provided an image of the participant's left eye, allowed the ISCAN software to track the center of the pupil and the corneal reflection; gaze position was indicated by white crosshairs superimposed over the image generated by the scene camera. The output was recorded onto a digital mini-tape via a Cannon Digital Camera; it was later loaded into the FinalCut Editing software for frame-by-frame playback analysis.

Procedure

All participants were tested individually. Training for the Picture-Word Interference task was presented first. Each picture used in the PWI task was presented in the middle of the screen; the participant was instructed to name it into the microphone.

The Picture-Word Interference task was presented next. Prior to initializing the task, the calibration of the eye-tracking equipment was completed. To increase the sensitivity of equipment, calibration was done on 9 fixation points. The fixation values were then mapped onto the corresponding monitor locations; the fixation location was indicated by a white cross-hair that moved synchronically with the eyes. After successful calibration, the PWI task was initiated. Each participant was instructed to fixate on the cross that appeared prior to each picture stimulus; he/she was also instructed to name pictures into the microphone as fast and as accurately as possible, and ignore the text on the screen.

At the end of the experimental session, two proficiency measures were administered to each participant. The first was the reading ability measure: Each participant read a short passage in English into the microphone, and answered 8 multiple-choice questions about it afterwards. Each bilingual subject also read a short passage in Russian, and answered 8 multiple-choice questions about it. Lastly, the LEABS-Q was administered to each participant.

Coding

Reaction times were recorded using SuperLab software by measuring the time between the presentation of the picture and the initiation of the vocal response into the microphone. Accuracy was assessed by reviewing the participant's recorded performance. The eye-tracking data, consisting of super-imposed cross-hairs onto the field of view, were coded for proportion of eye-movements to the distractor words. Eye-movements to the distractor word were considered to have occurred when the crosshairs have crossed into the quadrant containing the word. Ten percent of the data were coded by a second, independent coder, who did not speak Russian. Point-to-point reliability for coding of proportions of eye-movements was 96%.

Results

Trials on which participants made errors accounted for 4.40% of the data. Picture naming errors were analyzed separately, while errors like false starts were omitted from the analyses.

Reaction times

A 4x2 Anova with condition (no word, Russian words, Phonological controls, and English translations) as a within-subjects variable, and group (monolingual and bilingual) as a between-subjects variable yielded a main effect of condition, $F(1, 28)=8.39, p<0.01$, and a significant two-way interaction between condition and group, $F(1, 28)=5.35, p<0.05$ (Figure 2).

Post-hoc pair-wise comparisons for condition adjusted for multiple comparisons using the Bonferroni method revealed that both groups had shorter reaction times to pictures without distractor words ($M=809.70, SE=14.93$) than to pictures accompanied by Phonological Russian words ($M=861.77, SE=16.73$), $p<0.05$, Phonological controls ($M=852.80, SE=16.75$), $p<0.05$, or English translations ($M=855.36, SE=16.47$).

Post-hoc pair-wise comparisons between groups for each

condition revealed that bilingual participants had longer reaction times to Phonological Russian words ($M=912.80, SE=23.66$) than monolingual participants ($M=810.74, SE=23.66$), $F(1, 28)=9.30, p<0.01$. There was no significant difference between bilinguals' and monolinguals' reaction times to Phonological controls $F(1, 28)=3.28, p>0.05$, to pictures alone, $F(1, 28)=1.48, p>0.05$, or to English translations, $F(1, 28)=0.17, p>0.05$.

Proportion of Eye Movements to the Word

A 3x2 Mixed Ancova, with condition (Phonological Russian words, Phonological controls, and English translations) as a within-subjects variable, and group (monolingual and bilingual) as a between-subjects variable, with speed of reading as a covariate, was used to analyze the proportion of eye movements to the three types of distractor words.

Results revealed a main effect of group, $F(1, 27)=4.44, p<0.05$, with bilinguals looking more at the written stimuli ($M=0.46, SE=0.04$) than monolinguals ($M=0.34, SE=0.04$) and a marginally significant interaction between condition and group, $F(1, 27)=3.74, p<0.06$ (Figure 3).

Post-hoc Univariate Analyses of Covariance revealed that bilinguals looked more at the Phonological Russian words ($M=0.50, SE=0.05$) than monolinguals ($M=0.31, SE=0.05$), $F(1,27)=7.66, p<0.05$, but the two groups did not differ in their proportion of looks to the Phonological controls, $F(1, 27)=2.11, p>0.05$, or the English translations, $F(1,27)=2.09, p>0.05$.

Error Analysis

On the PWI task, monolingual participants committed 11 mis-naming errors, where a picture was named using the distractor word (for example, naming a picture of the chicken "duck"). Bilingual participants committed 8 mis-naming errors. Of these, 5 were committed with the English distractors being the word stimuli. The Mann Whitney test for independent samples revealed that monolingual speakers of English misnamed more pictures using the English

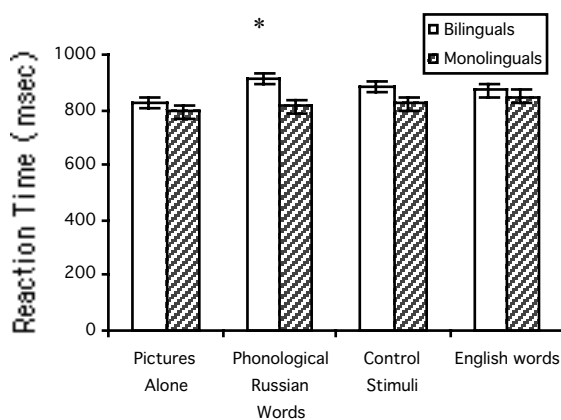


Figure 2: Reaction times of bilingual and monolingual participants when naming pictures alone, pictures, accompanied by phonological Russian words, by bigram-matched non-word control stimuli, and by English words.

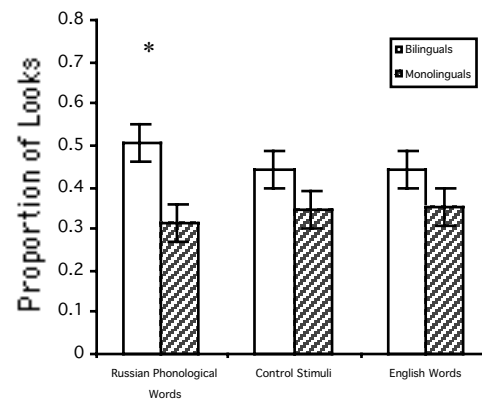


Figure 3: Mean proportion of looks to distractor stimuli made by bilingual and monolingual participants when distractors were phonological Russian words, bigram-matched non-word control stimuli, and English words.

distractor words than bilingual participants, Mann Whitney $U(15)=73.50, p<0.06$.

Three mis-naming errors were committed by bilingual participants with distractors being phonological Russian stimuli, such as naming a picture of a *collar* “sleeve,” when the distractor word on the screen was RUKAV, a phonological word for “sleeve” in Russian. This number was not significantly different from the number of errors committed by monolingual participants, Mann Whitney $U(15)=90.00, p>0.05$.

It is interesting to note that while interference of Russian written stimuli did occur during naming of pictures in English, none of the bilingual participants had switched into Russian when naming pictures. Instead, a spontaneous translation of the Russian distractor into English had occurred, and this, in turn, interfered with naming of the picture. This pattern of errors is consistent with the observation made by Costa, Miosso, and Caramazza (1999), who suggested that items from two languages, while activated in parallel, do not compete for selection during production.

Discussion

Russian-English bilinguals looked at English non-words that composed meaningful phonological Russian words more than monolingual English speakers, while the proportions of eye-movements made to control non-word stimuli and to English translation equivalents were comparable for the two groups. This finding suggests that phonological information in the non-target language drew bilinguals’ eye-movements. Therefore, phonological information for the non-target language was automatically activated for these stimuli. According to models of eye movement control in reading, the stimuli that carried phonological information for Russian drew the bilinguals’ eye movements because these stimuli carried meaningful information for them, but not for monolingual speakers of English.

Literature on eye movements during reading suggests that before fixating a word, a reader obtains useful information from its parafoveal preview; this information is used by the reader to decide whether to fixate on the word or not (Reichle et al., 1999; Starr & Rayner, 2001). While the E-Z Reader model of eye-movement control in reading posits cognitive control of eye-movements during reading of sentences (Reichle, 1998), it also seems to explain the behavior of the participants in this experiment, where they recognized single words. The decision to look at the word during the modified Picture Word Interference task appears to be dictated by the amount and quality of information a reader gleans from its parafoveal preview. Russian-English bilinguals were better able to control eye-movements to English non-word stimuli that did not carry any phonological information for Russian, than to English non-word stimuli that did carry phonological information for the non-target language.

Testing bilinguals who speak languages with partially overlapping alphabets allows for separating the contributions of orthographic codes and phonological information they carry to the parallel activation of the two languages when processing print. Our findings are in line

with connectionist models of visual word recognition (e.g., Plaut et al., 1996; Seidenberg & McClelland, 1989; Van Orden & Goldinger, 1994), which propose that phonological information for a word is automatically activated. The only way to obtain interference effects from phonological Russian words is by activation of the Russian language via its phonology because the orthographic information for Russian is not present in these stimuli. The dual-route models of visual word recognition, while allowing for an indirect phonological route to the lexicon, postulate that this route is specialized for reading non-words (e.g., Coltheart et al., 2001; Ziegler et al., 2000).

Russian-English bilinguals had longer reaction times when naming pictures accompanied by phonological Russian stimuli that constituted words semantically related to the picture names than monolingual speakers; reaction times to non-word control stimuli and English translations were comparable for the two groups. Because slower naming times on the PWI task result from the interference of the written stimulus with the picture name at the lexical-semantic level, this finding suggests that not only was phonology for the Russian language activated, as indicated by greater proportion of eye movements made to these by the bilingual than the monolingual speakers, but that this information was meaningful enough to get processed to the lexico-semantic level. This observation is further supported by the analysis of the error data: Although bilingual participants committed only 3 misnaming errors when the distractor word was a phonological Russian word, the mere fact that these errors exist support the idea that the phonological information for Russian was meaningful enough to activate the relevant lexico-semantic information.

In conclusion, we have successfully shown that phonology of the non-target language is activated for the target-language stimuli that bear little resemblance to the non-target language orthography. Furthermore, we have shown that activation of non-target language phonology is enough to produce interference effects during picture-naming in the target language. These findings extend the idea of parallel activation of languages in bilinguals to those languages in which shared orthographic symbols map onto distinct phonological representations, and inform models of bilingual reading on the role of phonology in the lexical access of written words. Finally, the idea that eye-movements during reading are under at least partial cognitive control offers an intriguing possibility that the bilinguals in this experiment exhibited a measure of cognitive control over interference from the non-target language during the modified PWI task. Future experiments might be able to explore the idea of cognitive control over language interference in bilinguals further by manipulating the amount of meaningful information present for the non-target language, and by testing different groups of bilingual speakers.

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