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Abstract

Mapping of written input onto orthographic representations was examined in bilingual speakers whose two languages have partially overlapping orthographies. Russian-English bilinguals and English monolinguals were tested with a modified version of the picture-word interference paradigm, adapted for use with eye-tracking. Compared to English monolinguals, Russian-English bilinguals (tested in English) made more eye movements to written stimuli that, if mapped onto two orthographic systems simultaneously, constituted Russian words. Results suggest parallel activation of both languages during visual processing of written input, even when the orthography is associated with different phonological representations in the two languages. We suggest that decoding of written input in languages with partial orthographic overlap is not limited to one language only, but that the mapping of visual stimuli takes place onto the orthographic systems of both languages and that lexical representations in the non-target language become activated.

Introduction

Recent studies of bilingual language processing challenge earlier accounts of the language switch hypothesis (e.g., MacNamara & Kushnir, 1971), according to which bilinguals are able to selectively activate and deactivate their two languages. Instead, data support interactive parallel processing accounts, according to which linguistic input activates both languages simultaneously. For *spoken* word recognition, evidence supporting activation of both lexicons comes from research investigating spoken language processing in bilinguals using eye-tracking (Marian & Spivey, 2003a,b; Spivey & Marian, 1999). In the eye-tracking paradigm, participants are given spoken instructions to move objects on a table while their eye movements are recorded. Although participants rarely pick up incorrect objects, it is often observed that they fixate objects that have similar phonology to the spoken word (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). The eye-tracking technique, merging input from both the visual and auditory modalities, was adapted for use with bilinguals to index activation of a second language non-linguistically. For example, when Russian-English bilinguals were presented with a visual display containing four objects (actual objects or toy replicas, as applicable), such as a shark, a balloon (*sharik* in Russian), a horse, and a napkin, and were instructed in English to "pick up the shark," they frequently made eye movements to the cross-linguistic phonological competitor *sharik*. In this case, the Russian word *sharik* was a cross-linguistic cohort (cf. Marslen-Wilson, 1987; see also Cutler, 1995; Marslen-Wilson & Welsch, 1978) of the English target word *shark*, i.e., the beginning portion of the name of the target object carried phonetic similarity to the name of one of the other objects in the other language. Eye movements to the cross-linguistic cohort, even when the other language is not being used overtly, supports the hypothesis that phonemic input initially activates both languages during bilingual spoken language processing.

For *written* word recognition, studies examining whether or not both languages are activated in parallel used code switching (e.g., Doctor & Klein, 1992; Grainger, 1993; Grainger & Dijkstra, 1992; Li, 1996; Nas, 1983; Soares & Grosjean, 1984), phoneme monitoring (e.g., Colome, 2001), lexical decision (e.g., Brysbaert, Van Dyck, & Van de Poel, 1999; DeGroot, Delmaar, & Lupker, 2000; Dijkstra, Grainger, & van Heuven, 1999), and priming tasks (e.g., Beauvillain & Grainger, 1987). Results indicate that orthographic input simultaneously activates lexical items across the two lexicons in the very early stages of processing, that bilingual visual word recognition is based on a stimulus-driven analysis indifferent to language, and that lexical representation in bilingual visual word recognition is governed by orthography rather than by language. For example, Bijeljac-Babic, Biardeau, and Grainger (1997) investigated activation of orthographic representations in bilingual visual word recognition by using a masked priming paradigm. Orthographic priming was observed in both monolingual and bilingual conditions, suggesting that printed strings of letters can simultaneously activate lexical representations in both languages, insofar as these share the same alphabet.

In another study on visual word recognition, Van Heuven, Dijkstra, and Grainger (1998) used the interlingual neighbors paradigm (an orthographic neighbor is any word differing by a single letter from the target word). Cross-language interference on target word recognition was examined with a comprehensive corpus of Dutch and English words by varying the number of orthographic neighbors of the target word in the non-target language. The results showed that words in the non-target language with a greater number of orthographic neighbors in the target language had slower response times than words that had fewer orthographic neighbors in the target language. An increase in orthographic neighbors within the same language consistently produced inhibitory effects for the non-target language and facilitatory effects for the target language.

Because this work is based on bilinguals whose languages share orthography and where orthography-to-phonology mappings largely overlap across the two languages, the extent of parallel activation for languages that do not share orthography, or share it only partially, remains unclear. Studies with bilinguals that speak languages that do not overlap orthographically are limited (e.g., Tzelgov, Henik, Sneg, & Baruch, 1996). Languages that do not share visual representation make it possible to examine phonological and semantic activation of the non-target language during bilingual reading (Besner & Hildebrandt, 1987; Bowers, Mimouni, & Arguin, 2000; Brown, Sharma, & Kirsner, 1984; Chen & Tsoi, 1990; Smith & Kirsner, 1982), but not activation of the written form of both languages. Testing Russian-English bilinguals whose two languages share some, but not all, orthographic and phonological forms, provides precisely this advantage--it becomes possible to dissociate the activation of phonology and orthography during language processing by manipulating stimulus make-up.

The two languages of a Russian-English bilingual include some graphemes that share both visual and auditory form (e.g., *K*), other graphemes that share visual, but not auditory form (e.g., *P*, which in Russian reads *R*), yet others that share auditory, but not visual form (letters specific to the Latin vs. Cyrillic alphabets). Of particular interest in designing the present study are the 12 letters that overlap orthographically across English and Russian. Of these, 6 share both orthography and phonology—A, E, K, M, O, T. The remaining six, although identical orthographically, carry no phonological overlap—B, C, H, P, Y, X (the corresponding phonological representations in Russian are, following the Library of Congress Transliteration Schemes for Non-Roman Scripts (1991): B-v, C-s, H-n, P-r, Y-u, X-h). Testing Russian-English bilinguals makes it possible to examine the mapping of the visual stimulus onto orthographic and phonological representations in the two languages during bilingual lexical access in circumstances where phonemic overlap across two languages is possible without orthographic overlap and where orthographic overlap between the two languages is possible without phonemic overlap. By manipulating orthographic form and the associated phonological representations, the present experiment tests activation of the other language when the written input shares orthographic, but does not share phonological, representation across languages. The stated relationship between Russian and English in terms of phonological and orthographic structure of the two languages can provide valuable insights into orthographic and phonological processing and contribute to understanding the extent to which constraints imposed by language structure modulate cross-language interactions.

The only other similar work exploring processing of Latin and Cyrillic alphabets comes from studies of monolingual speakers of Serbo-Croatian (e.g., Feldman & Turvey, 1983; Lukatela, Savic, Gligorijevic, Ognjenovic, & Turvey, 1978). Serbo-Croatian as a language is unique in that it uses two alphabets, Latin and Cyrillic. Serbo-Croatian speakers are slower in lexical decision tasks when two phonological interpretations could be assigned to the same letter string, an effect sensitive to the number and distribution of ambiguous characters. The major difference between studying Russian-English bilinguals and studying Serbo-Croatian speakers is that Serbo-Croatian speakers are monolingual and therefore, by definition, have an integrated lexicon.

In the present experiment, a modified version of the Picture-Word Interference (PWI) paradigm, adapted for use with an eye-tracker, was used. The PWI paradigm consists of presenting participants with a picture that also contains a written word. Participants have to name the picture while ignoring the word; reaction times are recorded. Multiple studies suggest that picture naming latencies vary as a function of the relation between a picture and a distracter word (e.g., Caramazza & Costa, 2000, 2001; Deschneiak & Schriefers, 2001; LaHeij & van den Hof, 1995; Rayner & Springer, 1986; Schriefers & Meyer, 1990). For example, semantically related words interfere more than semantically unrelated words (e.g., Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991; Starreveld & LaHeij, 1996, 1995). The surface form of the distractor word also influences picture naming (e.g., Meyer & Schriefers, 1991), with phonological similarities facilitating picture naming (e.g., Descheniak & Schriefers, 2001). Performance on the bilingual PWI task has been examined both for semantically and phonologically related items (e.g., Costa & Caramazza, 1999; Costa, Miozzo, & Caramazza, 1999) and was found to be vulnerable to semantic interference from a non-target language (e.g., Ehri & Buchard-Ryan, 1980; Hermans, Bongaerts, de Bot, & Schreuder, 1998), but the effect was mediated by degree of proficiency (e.g., Goodman, Haith, Guttentag, & Rao, 1985), by similarity of the two languages, and by response language (for a review, see Smith, 1997). The modification of the PWI task for use with eye-tracking consists of presenting the written word in a different quadrant of the visual display (as opposed to within the picture). The technique was piloted with monolingual English and bilingual Russian-English speakers and confirmed that interference effects persisted.

In sum, the present experiment examined parallel activation of both languages during bilingual written word recognition in monolingual settings and extended the study of parallel activation during bilingual written word recognition to languages with partial overlap in orthography and orthography-to-phonology mappings. We predicted that, compared to English monolinguals, Russian-English bilinguals naming pictures in English would make more eye movements to written stimuli that are semantically unrelated to the picture in English, but are related to it in Russian, thus suggesting that processing of written input is not limited to the target language, but that the visual stimulus is also mapped onto non-target language orthography, even when orthographic representations are associated with different phonological forms in the two languages.

Methods

Design

The study followed a 2 x 2 mixed factorial design, with group (bilingual vs. monolingual) as the between-subject factor and condition (control vs. Russian words) as the within-subject factor. All participants were tested in English only. In the first condition, the picture and the distracter word were semantically unrelated if the written stimulus was mapped onto either language (e.g., picture of a *palmtree*, written stimulus HOCTA). In the second condition, the picture and the distracter were unrelated if the written word was mapped onto English orthography only, but semantically related if it was also mapped onto Russian orthography (e.g., picture of a palmtree, word stimulus is COCHA. In English COCHA is a non-word, while in Russian it is the orthographic representation of the word *pinetree* and is pronounced *sasna*.) In the second condition, semantic interference is present if the written stimulus is mapped in parallel not only onto English orthography, but also onto Russian orthography, therefore activating the other language in a bottom-up manner. Proportion of eye movements to distracter words and reaction times for picture naming were measured.

Participants

Fifteen Russian-English bilinguals (mean age=25 years) and 15 English monolinguals (mean age=21 years) were tested. Russian-English bilinguals and monolingual English speakers were recruited among undergraduate and graduate students at Northwestern University and via personal contacts. All participants were paid for their participation.

In addition to picture naming, all participants were administered the Language Experience and Bilingual Status (LEABS) Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2003) for self–reported measures of language preference, proficiency, acquisition history, and current exposure. All bilinguals were fluent in both languages and were not enrolled in ESL classes. Measures of language experience collected via self-reports were included in analyses of covariance.

Stimuli

Twenty-four stimulus sets were generated for the two conditions. Across conditions, stimuli were controlled for length and bigram frequency. For English frequencies, the CELEX database was used (Baayen, Piepenbrock, & Van Rijn, 1993). For Russian frequencies, the new Frequency Dictionary at the Russian Research Institute of Artificial Intelligence (www.artint.ru/projects/frqlist/frqlist-en.asp; Sharoff, 2002) was used. Stimuli consisted of black line drawings and were generated using the IMSI Masterclips database and original artwork, and were altered in Adobe Photoshop. In order to meaningfully monitor eye movements, the locations of the target picture and the written word on the display were varied across four possible quadrants (top left, top right, bottom left, bottom right).

Procedure

All participants were tested in English. The bilingual speakers were tested in one language only so as to prevent overt activation of the other language during the experiment. Participants were asked to label pictures presented on a Mac computer display (G4 dual-processor computer) using Superlab software. Their verbal responses were recorded using a microphone. Eye movements during the experiment were recorded using an ISCAN head-mounted eye-tracker. The head-mounted eye-tracker consisted of a baseball-like cap, with two small cameras attached to the visor. One camera recorded the participant's field of view, and the other camera recorded the participant's eye movements; the outputs from the two cameras were superimposed and recorded using a digital recorder and were later analyzed using FinalCutPro software with frame-by-frame audio/video playback.

Results

The proportions of eye movements to distracter words during picture naming were analyzed with a 2 x 2 Analysis of Covariance, with group (monolingual or bilingual) and condition (control or Russian word) as the two independent variables and language preference when reading as covariate. Results revealed a main effect of group, $F(1, 27)=5.06$, $p<0.05$ and a significant interaction between condition and group, $F(1, 27)=4.78$, $p<0.05$. Overall, bilinguals made more eye movements to distracter words than monolinguals, 56% vs 34%. However, post-hoc analyses suggest that this difference was larger in the Russian words condition (61% for bilinguals vs 32% for monolinguals), where the two groups were significantly different from each other ($F(1,27)=7.77$, $p<0.01$), than in the control condition (50% for bilinguals vs 37% for monolinguals), where the two groups did not differ significantly ($F(1,27)=1.92$, $p>0.1$). A similar 2x2 Ancova on reaction time data did not reveal any significant effect of condition ($F=1.16$, $p>0.1$), group ($F=1.33$, $p>0.1$), or interaction between the two ($F=0.21$, $p>0.1$).

Based on self-reports collected with the LEABS Questionnaire, Russian-English bilinguals were grouped into 2 types, one consisting of bilinguals who preferred to read in English and one consisting of bilinguals who preferred to read in Russian. The proportion of looks made by the two types of bilinguals to Russian competitor words and to control stimuli were compared in two ways. First, we examined whether or not the two types of bilinguals looked at the written stimuli at all (individual trials were coded with a 0 if participants did not look at the written stimulus and with a 1 if they did). Next, we examined the number of times the participants looked at a written stimulus (individual trials were coded with a 0 if participants did not look at the written stimulus, with a 1 if they looked at it once, with a 2 if they looked at it twice, with a 3 if they looked at it three times, and so on). Results of the first comparison did not reveal any significant differences, suggesting that the two types of bilinguals were just as likely to fixate distracter Russian words. Results of the second comparison revealed a marginally significant interaction between condition and type of bilinguals, $F(1, 13)=4.43$, $p<0.06$. Bilinguals who preferred to read in English (N=9) looked at Russian words more often (60%) than at control stimuli (48%); this pattern was not observed for bilinguals (N=6) who preferred to read in Russian (47% to Russian words and 52% to control stimuli).

Discussion

The present experiment examined mapping of visual input onto orthographic representations and lexical forms in bilinguals whose two languages share partial orthographic overlap. Results suggest that Russian-English bilinguals, when presented with written language input in a monolingual English setting, map the visual stimulus onto orthographic representations in both languages. As a result, lexical representations in the non-target language become activated, as evidenced by more eye movements to Russian distracter words relative to bigram-matched control stimuli in bilinguals, but not in monolinguals. These findings contribute to the existing body of literature suggesting simultaneous activation of a bilingual's two languages during written language processing and extend them to speakers whose two languages overlap orthographically only partially.

Absence of differences in picture-naming reaction times suggests that the simultaneous activation of non-target language orthography and lexicon (as demonstrated by eye movement data) did not minimize the efficiency with which bilinguals accomplished a language production task in the target language. This finding is consistent with recent accounts of optimal speed/accuracy outcomes achieved by parallel interactive models of language processing.

The finding that preferred reading language influenced the degree of activation of a bilingual's other language (as indicated by number of times bilinguals looked at Russian words) points to the importance of carefully assessing bilinguals' experience and proficiency in the two languages. Proficiency understanding, speaking, reading, and writing in the two languages, as well as factors pertaining to acquisition and current use of the two languages are just some of the variables to be taken into account when testing language processing in bilinguals (Marian, to appear). In our study, bilinguals who preferred reading in their second language (English) were just as likely to fixate Russian words as their peers who preferred reading in Russian, but once a written stimulus drew their eye movements, bilinguals who preferred to read in English were more likely to look at the Russian word again, fixating it repeatedly. These results suggest that, while the non-target language was activated in both types of bilinguals, processing the written input and possibly accessing its lexical representation was more effortful for those bilinguals whose preferred reading language was English.

It is notable that activation of the non-target language occurred in spite of the differential orthography-to-phonology mappings associated with the two languages. Although these results suggest simultaneous mapping onto the orthography and lexicon of the non-target language, they do not provide information about activation of the non-target language phonology, since lexical activation of the non-target language during orthographic processing may or may not have included phonological activation (i.e., mapping to the lexicon may have been directly from orthographic representations, bypassing phonology). To examine activation of non-target language phonology during written language processing, a mirror image of the present experiment is required. Namely, while the present experiment tested activation of non-target language *orthography* by examining processing of input that overlapped *orthographically, but not phonologically*, a separate experiment tested activation of non-target language *phonology* by examining processing of input that overlapped *phonologically, but not orthographically* (Kaushanskaya & Marian, 2004).

Moreover, for a more comprehensive understanding of parallel activation of both languages in Russian-English bilinguals during written language processing, a closer look at semantic processing is necessary. In the present study, stimuli consisted of English non-words, so as to avoid word frequency confounds across languages. Future work needs to expand this paradigm to processing written stimuli that constitute words in both languages. Whether the written stimuli are English words or nonsense strings is likely to influence the strength of competition from Russian semantically-related words. Furthermore, when the written stimulus is a word in each language, word frequencies in the two languages are likely to influence the effect, with higher-frequency mappings resulting in faster activation. Finally, future efforts will also focus on examining input properties that are likely to influence the relative activation of the non-target language during written word recognition, such as amount of orthographic and phonemic overlap across the two languages.

The proposed project has implications for understanding language development and processing in bilinguals, and reading and acquisition of literacy in bilinguals, with potential implications for bilingual education and for assessment of bilinguals. For instance, understanding written word recognition in bilinguals who are in monolingual contexts may have implications for bilingual children entering mainstream (not ESOL) classrooms. The results of the 2000 Census indicate that 18% of American households speak a language other than English at home and that this proportion is increasing. Understanding how bilingual status influences cognitive and linguistic functioning may have direct implications for this linguistically diverse and severely under-served segment of the population. Beyond bilingual language processing, this research will contribute to advancing the understanding of language processing in general, including written word recognition and spoken word production.

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